Autonomous Targeting Sentry (ATS)

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Group 12

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1.0 Executive Summary

In the United States, defense has always been an important factor in the budget. In 2011, defense attributed for nearly 25% of the U.S. federal budget, more than any other individual factor.**[1]** With so much emphasis being placed on defense, it is evident that a constantly improving defense system is required. Autonomous sentry guns provide great protection to the area they surround, but do not rely on the use of people to do so. This aspect is what makes unmanned or autonomous defense systems such an important field of research. These defense systems can be deployed, not only in military settings, but in home defense, as well. The primary goal of this project is to simulate a realistic autonomous turret as a defense system to protect a high priority area.

The group's personal motivation when accepting this project was that it contains fields from both electrical and computer engineering, providing a complex task which challenges the skills obtained throughout our education. Since the autonomous target sentry gun has many components in which the group members had limited experience, throughout the process of the project, the designers learned these technologies in preparation for our future careers.

The key traits to an autonomous sentry gun that make it such a valuable defense system are reliability, accuracy, intelligence, and efficiency. Reliability is vital because an autonomous system does not have constant monitoring from a human, so it must be able to function on its own for long periods of time, without the risk of component failure. Accuracy and efficiency are major factors because any targets need to be taken down before they can pose any kind of threat to the turret itself. Lastly, the system needs to be intelligent so it cannot be bypassed by someone using a decoy or some sort of distraction.

The objective of the project was to research, design, and prototype an Autonomous Targeting Sentry (ATS). The turret utilizes knowledge of hardware components such as servo motors, microcontrollers, capacitive touch sensors, lasers, web cameras, and printed circuit board design. The system uses the openCV computer vision libraries to detect, track, and eliminate targets. The turret has the ability to be controlled manually from an application running on the on-board laptop. The user can take control of the turret at any time to operate the turret or shutdown the machine.

The turret utilizes two servo motors for pan and tilt of the paintball gun. High definition web cameras are used in conjecture with openCV to detect and track enemy targets. When a target enters the field of view of the web camera, the system begins tracking the target. The target is then warned that they are entering a restricted zone. The on-board computer continually updates the targets coordinates while the microcontroller translates coordinates to pulse widths for the servo motors to move the turret into place. After a second warning to the target, the system begins to fire upon the target until the target exits the field of view or the system determines the target is no longer a threat.

The team has organized this document to cover the research, design, and testing of ATS. The research aspect of the project covers several component comparisons and methods to reaching our objectives and specifications. The design section will discuss the group's component decisions and acquisition as well as detailed software design and implementation. The testing section will discuss how the team tested individual components, the overall system, and environmental variables. ATS is an intriguing, challenging and an instructional project, and the group is proud to show off the final product.

2.0 Project Description

2.1 Motivation and Goals

The motivation behind our project stems from the ever increasing budgets in both the government and private military sectors. The autonomous turret has many applications in security, military combat and un-manned vehicles. ATS features a perfect blend of software and hardware to complement the team's computer and software engineers. By incorporating hardware components such as microcontrollers, servo motors, and capacitive touch sensors ATS tests the group's electrical engineering skills; while motion tracking and the onboard control center allows the groups computer engineers to acquire the skills necessary for real world software design and development.

The goal of ATS was to incorporate our skills gained over the past four years to research and design a functional prototype of an automated turret. The prototype is lightweight and low cost and demonstrates the need and functionality of a real world automated turret. The system contains intuitive controls and interface so that anyone can operate and monitor the turret. In order to demonstrate the need for such a turret the system was designed to be accurate, reliable, and have quick response times; any lapse in functionality results in massive risk to the zone ATS is covering.

2.2 Objectives

To ensure the ATS systems meets a stringent quality factor, a system of specifications was ensured. For our weapon system, high and consistent accuracy was an objective. For the webcam to properly function with the object tracking software, a specified maximum resolution was specified. To keep up with a moving object, the servo motors were able to operate at a specified speed. In order to limit the amount of fire, the ATS system had specifications for the firing rate. In order for the tracking software to efficiently track a target, an ideal time to identify and track a target was specified. The following primary specifications along with secondary specifications were used in constructing a working prototype.

- System is cost efficient
- System has the ability to detect, track and target incoming objects
- ATS is light weight
- ATS is easily portable
- The ATS system is reliable
- The ATS system has the ability to prioritize targets with high threat levels
- The ATS system has easy set-up and usability
- Has the ability to track multiple targets
- Capable of following targets moving with high speeds
- The components are easily accessible with expectations of future upgrades
- All the components are interchangeable
- The weapon system has high levels of accuracy
- The ATS system is capable of demonstrating real world applications
- The system has two types of alarm systems, one continuous sounding alarm and an alarm to verbally warn incoming intruders
- The ATS has the option to be manually controlled via capacitive touch sensor, keyboard or an xbox conroller
- The base of the system is capable of housing all the electronic components above the turret system
- The printed circuit board is encased in a plexiglass box to protect the design
- System is able to determine when the target is no longer a threat when the target ceases to move
- Microcontrollers will control all the servo motors
- The manual control application has a video stream from the turret's web camera embedded
- A laser pointer aims down the barrel to indicate the target

2.3 Requirements and Specifications

In order to make a successful prototype to demonstrate real world applications, the ATS system must first be affordable. Since this was a self funded project, the members of the group wanted to reduce as much cost as possible so affordability was a major factor in our decision to build the ATS system. With a wide variety of potential targets, the ATS system is capable of tracking multiple moving targets either fast or slow. Since many industries push newer and more advanced components, the ATS system will components that are easily swappable in case of further improvements throughout its life cycle. The ATS system will also be well protected by a sturdy base construction. To meet these requirements the following objectives were created.

2.3.1 Hardware Requirements

Just like real world applications, specifications needed to be established prior to any prototyping. This is also the case for the design team; the designers needed to establish hardware specifications to ensure the ATS system is working properly. By doing so, the ATS system can prove to be a reliable system that will produce efficient results. Below is a list of requirements the designers established as hardware requirements.

- The weapon system has the ability to have a hit ratio greater than 50%
- Webcam has the ability provide a video stream with 1280 x 720resolution
- The entire turret system will weigh no more than 30 pounds
- The turret base will not exceed a height greater than three feet
- ATS has the ability to cover a lateral angle of tracking of 135 degrees
- ATS has the ability to cover a vertical angle of tracking of 90 degrees
- The turret is battery operated and has the ability operate for a minimum of 6 hours before a recharge is required
- The servo motors has the ability to move at least 4 radians per second with no load
- The paintball gun hopper has the ability to hold 200 paintballs for ammunition
- The alarm system has the ability to be heard from at least 100 feet away
- The high pressure aluminum alloy tank has the ability contain 20 oz of CO2 to pressurize the paintball gun
- The barrel of the gun is not be longer than 12 inches long
- The system shall has the ability to have a lag of no more than 0.25 seconds upon command via capacitive touch or the onboard laptop
- The battery system will not output more than 12 V at any given time
- The gun shall has the ability to fire more than 5 paintballs per second in automatic mode
- Turret has the ability to be able to detect and keep track of a minimum of 3 incoming targets
- Laser pointer has the ability to be visible on targets within 100 feet

2.3.2 Software Requirements

The ATS system is a compilation of both hardware and software components. A major component for the hardware to work properly is efficient working software. The software is the initial step for a working prototype. The requirements below are a list of software specifications the design team established for the ATS system.

- ATS plays an audio file to warn incoming intruders two seconds after entering the field of vision.

- ATS has a response time of less than 0.5 seconds from finding a target to aligning the gun
- A targetID must have 3 or more points to be a valid target.
- The object tracking class transmits the coordinates of the target to the microcontroller with an accuracy of one degree.
- A target is deemed no longer a threat when it has 0 velocity (not moving).
- The software stream resolution is 640 x 480
- ATS software is capable of handling at least 3 targets, simultaneously.
- The software determines a 0-target state and give the command to turn off firing.
- The software stores data over the 10 most recent frames

2.4 Responsibilities of Team Members

2.4.1 Ethan King

The roles and responsibilities that Ethan King, electrical engineer, will undertake are the selection of electrical components including resistors, capacitors, inductors, operational amplifiers, and voltage regulators. He was also responsible in choosing servo motors and implemented a embedded system to make sure each servo motor properly communicates with the microcontroller. Ethan king was also primarily responsible for the design and implementation of the printed circuit board with help from James Van'Gostein. Ethan King also worked with Stephen Rodriquez in programming, designing, implementing, and testing of a capacitive touch manual controller. Minor responsibilities include assisting Daniel O’Hara, Stephen Rodriguez, and James Van Gostein with getting the onboard computer to communicate with the microcontroller controlling each servo motor.

2.4.2 Daniel O’Hara

The roles and responsibilities that Daniel O'Hara, computer engineer, undertook were mostly on the software side of the project. He was responsible for the computer vision with the help of James Van Gostein. To be more specific, Daniel handled the motion tracking, target creation, and target selection. This means that he was be responsible for the computer vision from the point that the system receives the image from the camera to where it must make a decision based on if any objects are tracked. James Van Gostein took the lead on the software following that part. He is responsible for both the design and documentation of these algorithms, with the help of the OpenCV software that was used for this project. Other minor responsibilities included website creation and assistance with the project hardware as requested.

2.4.3 Stephen Rodriguez

The primary roles and responsibilities that Stephen Rodriguez, computer engineer, were mostly undertake charge of designing and implementing the power supply. From there, he assisted in servo motors and alarm systems. Together with Ethan King, he was be responsible for the majority of the hardware components, this included, the implementation and design of the power sources, microcontrollers, voltage regulators, alarms, web cameras, servo motors and architectural structures. Ethan King took the lead on the implementation and design of the printed circuit board layout and servo motors. Other smaller responsibilities were to assist both Daniel O'Hara and James Van Gostein in the software implementation since a large part of this project was software oriented.

2.4.4 James Van Gostein

James a CpE major worked with Daniel O'Hara on the software side of the project. He assisted in the vision tracking, creation of tracking points and grouping. James was in charge of the various methods of manual control. James tested and adjusted the various manual controls so they felt intuitive and easy to use. James was charged with the building of the base and gun mounting. James managed the budget and tracked the group's expenditures as well as logged meeting times and progress throughout the two semesters.

3.0 Research Related to Project Definition

3.1 Similar Existing Technologies

The ATS system as a whole is not a new technology. Different aspects of the entire system have previous been done for a variety of reasons, such as the motion tracking cameras and a gun system that intercepts incoming targets. These were the original unique technologies that when all integrated together can help build an autonomous targeting sentry. The influence of these similar existing technologies has broadened the range for the expansion of the different prototypes for future optimizations.

The web camera on board the system has had several similar functions in the past. The web camera for the ATS system is similar to those of any video surveillance cameras. For example, in banks, the surveillance camera is continually streaming a video. If the videos need to be replayed, the users can use facial recognition to identify particular people of interest.

Motion tracking is another similar existing technology. Motion tracking has been used for several different reasons such as monitoring areas at night and homeland security. Typically, these cameras have the ability to move on command. Even in the universities, the instructors have manual control of the cameras for those that record their classes. This is the same for homeland security, the user can move the directions of the camera to focus in different areas, and this increases the range of visibility which makes it practical instead of installing several other cameras.

The military actually has several technologies similar to the ATS system. The web cameras along with facial recognition and color detection make the ability for determining friend and foes targets. High tech security systems can include finger print and retinal scanners, these is to ensure the person of interest is who they're supposed to be. To demonstrate this same idea, the designers intend to have the ability to remotely enable or disable the system when the incoming target is a friendly. The intention is for only friendly targets have the remote with a specific password to power down the target, similar to a garage code where only those who are supposed know will know the correct sequence.

The military actually has a similar system called the Medium Extended Air Defense System (MEADS). **[2]** This system is a tri-nationally owned system, the United States of American, Italy and Germany, and the system is just like the ATS system. MEADS has the ability to detect and track an incoming missile and fire its missile to intercept the incoming target. The intent of MEADS is to provide safety for the city or military base that it is stationed in. Another military technology that is similar to ATS is the CROWS II gun mounting. The CROWS II is mounted on top of Humvees and controlled by an operator inside the vehicle. The system does not automatically track, but ATS's manual control functionality has been designed after the CROWS II.

By reflecting on all the similar existing technologies previous demonstrated successful in the past, the designers of the ATS system integrated several of them to make a specific design. The system has several functions, mainly as a defense turret to protect. This system can be further optimized depending on its use but initially can be used for homeland security and local security for businesses or home owners. It can even be used in military situations such as protect a military base from incoming armies and also has the ability to successfully intercept incoming planes, helicopters, and missiles. The ATS system's concept does have several uses, it can protect your possessions or it can save a life.

3.2 Similar Senior Design Projects

The creation of an autonomous turret system has been successfully completed in the past. Several other systems have been created, both on a production level, for sales, and a project level for varies opportunities such as senior design projects. These projects are related to the ATS system and can be found online for extensive research. The research of previous project's successes and failures aided in designing, prototyping, and testing the ATS system.

The idea of creating the ATS system was originally developed by the discovery of The Sentry Project. This prototype is an automatic targeting paintball gun intended for purchase for the curious buyers. This was the original inspiration for creating the ATS system that also consists of a laptop to autonomously control the servo motors that directs the paintball gun to incoming targets. The ATS system's concept is similar to The Sentry Project because it also uses web-cameras for of range targeting while continuously streaming video to the laptop so the user can have the perspective of what the gun see and targets. **[3]** From an overview, the ATS system has a lot of similarities to The Sentry Project however The Sentry Project is business owned and intended for profit. However, the ATS system's design varies significantly and the intent of the prototype is to demonstrate mastery of knowledge instead of profit.

After future investigation into the creating an autonomous gun, it was found that the University of Central Florida has had several groups create such a prototype recently for senior design projects. By reviewing previous completed projects, all the projects have similarities. Of course all the prototypes detect incoming targets autonomously however; each group used different approaches to reaching this goal. The group that graduated spring of 2008, created a prototype called the Paintball Targeting System. **[4]** This group used color recognition to trace incoming targets.

Another group that completed their senior design project in the spring of 2009 created the G8 Sentry Gun. **[5]** This project was unique from the others because it was able to distinguish between friendly or foe targets. This was done by implementing GPS positioning. The friendly would carry a mobile device that would alert the turret that a friendly is entering the targeting zone; those without this device would automatically be considered a foe.

The final group researched completed their project in the spring of 2011. The Autonomous Turret, like the others, main purpose systems was to detect, track and target an incoming intruder. **[6]** The main difference that separated this project from previous prototypes is that the designers used an off-board server to record the video history. This is a very useful implementation for video tracking for those whose intentions are to recognize the incoming targets. By using an off-board server, the video files are stored in a different location and this will better equip the owner of the Autonomous Turret to report the intruder to local officials who can further decide the plan of action to prevent such intrusions.

All of this research has been very helpful for the designers, however; the use of previous project's research alone is not sufficient enough to successfully construct the ATS system from the ground up. Although the ATS does incorporate some aspects of previous projects it is a very unique project implemented through the teams own methods. All research completed by previous projects was merely a spring board that propelled the ATS system to be the most advanced video tracking systems.

The ATS improves upon the color detection algorithm used by the Paintball Targeting System, and friend/foe detectors used by the G8 Sentry Gun, by going with an optical flow aglorithm. ATS chose not to incorporate an off-board server to record the video feed instead the designers intend to make the video tracking more efficient and not track only by color. Another unique aspect is the ATS has a capacitive touch remote, keyboard, and xbox360 controller that have the ability to control the turret remotely, which includes the ability to manually target, initiate and deactivate the system.

3.3 Possible Architectures and Related Diagrams

3.3.1 The Base

Possible options for the base included creating a tri-pod with a mounting for the gun at the top. The electronics would be housed in a plexiglass box and be hooked up to the on-board laptop. This architecture is very similar to a camera mounted on a tripod. The tri-pod must be sturdy enough to remain standing after the rapid firing of ATS, if the tri-pod rocks too much ATS's accuracy would suffer greatly. This design would raise the gun off of the ground level and allow for more vertical coverage. The group's second option was to create a rotating platform for the gun. This option would require a less complex gun mount but would be heavier requiring greater torque to get it to turn about. The base would be composed of the same plexiglass housing which would act as the base while a rotating plate hooked up to the horizontal servo. The top section would consist of the gun mount and ammunition. Another option was to create a fixed base with a pan and tilt system mounted on top to mount the gun. Pan and tilt servos are commonly used to mount cameras and other lightweight objects. Unfortunately the pan and tilt system used for cameras only support a maximum of two pounds, this is not enough to support the gun and ammunition and withstand the recoil of the gun when firing. The final option was to create a ceiling mounted turret where all of the components and ammunition could be housed in the ceiling and out of sight and reach.

3.3.2 The Gun Mount

Creating a lightweight durable gun mount was a major design challenge the group faces. The gun mount must be very strong to hold up to the vibration and stress of the automatic firing rate. If the gun mount is too heavy the servo motors would have a hard time rotating the gun, but if the mount is too light there is a chance it would break or severely decrease the accuracy of ATS. The group has a few different options for mounting the paintball gun. The first option is to create a frame for the gun to rest in. This can be done by creating a box made of lightweight metal rods. The rods support the barrel and the handle of the gun. Two more metal rods would be used to keep the gun straight and accurate. The second option the group is considering is a side mounting for the gun. The mount would be positioned on the left or right side of the gun and have the ability to swivel left, right, up and down. This is very similar to the system used by the paintballsentry project the group has researched online. **[3]** This mounting would be very lightweight and keep the sentry compact and offer a less cumbersome mounting. The pan and tilt option required that the group builds a platform to rest the gun on, unlike the camera pan and tilt option the groups platform must support more than two pounds.

3.4 Hardware Research

3.4.1 Microcontroller Research

A microcontroller is an integrated chip that has a wide variety of functions that enable them to provide unique control to a specific design. This is different from a microprocessor, which is a multifunctional chip that completes a variety of tasks. Therefore, a microcontroller is intended to be more self-contained and dedicated to specific tasks. Microcontrollers have the ability to execute a set of stored instructions capable of out tasks defined by the designer. Micro-controllers also have the ability to access external memory chips and read/write data to and from the memory. Microcontrollers consist of a processor core, memory and programmable input/output peripherals. In its entirety, a microcontroller is essentially a basic computer in a single integrated circuit.

There are a variety of the microcontroller designs available for completing the necessities for the ATS system; however, there are 3 main options that are sufficient for the design requirements. Each microcontroller has its advantages and disadvantages. The first option for a possible microcontroller is the PIC16F1503, Peripheral Interface Controller, from Microchip Technologies Inc. **[7]** These microcontrollers have the Harvard architecture – in which instructions and data come from separate sources. This simplifies the timing and design which helps optimize clock speed and power consumption. These microprocessors have RISC architecture, a built in oscillator with adjustable speeds and a wide range of interfaces with free Integrated Development Environment and several commercial compilers available for the designer. The disadvantages for these microcontrollers are that it is an older design but it is a simple and powerful architecture. These microcontrollers only have one accumulator and operations and registers are not orthogonal, meaning some instructions can only use the accumulator, while others can only address the RAM and/or immediate constraints. However, for the necessities of the system, these constraints should not be a problem for overall design of ATS.

Another main consideration for selecting the PIC family of microcontrollers is the programming language. These microcontrollers are provided with a free assembler package with Microchip MPLAB Integrated Development Environment. It can also be programmed at higher levels of programming such as C. Free C compilers are also available as well as low-cost development tools depending on the preference of the designer. Both are offered in design support from Microchip and have a technical support and training available twenty four hours a day, seven days a week.

The second option is the MSP430F5172 from Texas Instruments. **[8]** These microcontrollers are 16-bit and RISC based but the stand out advantage of the MSP430F5172 microcontroller is that is designed specifically for ultra-low-power consumption. This is a major advantage because the MSP430F5172's peripherals enable ultra-low-power optimization which could ultimately extend battery life. This feature validates TI's competition amongst the leading microcontroller distributors. TI's integrated communication peripherals and high-performance analog make this microcontroller a great option for controlling servo motors that is a key component in the system design. These 16 bit chips range from 1KB to 256KB of flash memory. Another advantage for this microprocessor is the TI Launchpad development board kit.

The MSP430F5172, like the PIC, can be programmed in a high level like C with Code Composer Studio. There is also an alternative C compiler which could have served as an efficient multi-platform compiler called mspgcc. This is a free and unlimited C compiler for TI's MSP430 series of microcontrollers. The MSP430 microcontrollers also have online training, tools and software to help support the designer.

The last option of microcontroller manufacturers to consider is Atmel Corporation. For the ATS system to be optimal with a minimum response time, simple calculations from the microcontroller need to be performed efficiently to reduce the lag time of targeting the incoming intruder. One of the perks of choosing an Atmel's SAM9 product line is this particular line is designed for high speed processing. With the line chip performing at approximately 240 MHz, this makes this microcontroller more than efficient for computing the simple calculations needed for the ATS system. **[9]** The major setback of choosing this microcontroller is it is much larger and consumes more power than smaller microcontrollers that are equally capable of completing the tasks needed for the ATS system. So this makes it a more expensive microcontroller needed for the application. So even though this microcontroller series is designed for high speed processing, it doesn't appear to be a necessity for the ATS system to perform sufficiently.

Table 1 contains the three different microcontrollers the designers intended to use. The key differences to note are the comparison in number of pins as well as the program memory. The designers of the ATS systems do not need an excessive amount of pins or a large memory, so the designers intend to implement Microchip's PIC16F1503.

Comparison of microcontrollers			
Product	**SAM3S1A**	**MSP430F5172**	**PIC16F1503**
Developer	Atmel Corporation	Texas Instruments	Microchip
Number of Pins	48	29	14
Memory Type	Flash	Flash	Flash
Program Memory (KB)	64	32	3.5
Operating Voltage (V)	1.62 to 3.6	1.8 to 3.6	1.8 to 5.5

Table 1 - Comparison of the different Microcontrollers

3.4.2 Printed Circuit Board Research

A printed circuit board (PCB) is typically a flat plate of insulating material that interconnects electronic components designed for a specific purpose. Connected by a conductive material, these electronic components have unique functions that control the device. And so, the PCB is a key component in controlling the ATS system as a whole for it contains the microcontrollers that control the servo motors for the mobility of the ATS system. There are several types of PCB manufacturers available but two options were looked into for implementation for the ATS system, ExpressPCB and 4PCB.

ExpressPCB provides a free, designer assisting, CAD software that includes two parts, ExpressSCH and ExpressPCB. **[10]** The ExpressSCH program is for drawing schematics. This is to begin the process of designing and to familiarize the designer of drawing schematics. The library provides common electrical components so when drawing the schematic; it can be as simple as placing the components on the page and wiring the pins together. ExpressPCB allows the user to develop a printed circuit board that corresponds to the schematic previously created. This is a possible because ExpressSCH can be linked with ExpressPCB to ensure continuity. This makes laying down traces for the printed circuit board easier. ExpressPCB has a package of three identical 3.8” x 2.5” PCB that can be purchased for $51.

A second option to use for the ATS system is 4PCB. **[11]** Like ExpressPCB, 4PBC offers free software called PCB Artist with tutorial videos to help the design the PCB. However, 4PCB offers a 60 square inches, approximately an 8” x 7” piece, of PCB for $33. This is much larger than the PCB manufactured by ExpressPCB but the benefits of a cheaper option makes it a definite consideration. 4PCB also allows student buyers to purchase a single board which ultimately benefitted the budget.

3.4.3 Servo Motors

3.4.3.1 Motor Control Options

To effectively control the autonomous turret, a system of motors was implemented to allow for full motion and firing. Since the turret is designed to be stationary, it is best to think of the turret as the origin of a spherical coordinate system. This allowed one motor to be dedicated to the yaw direction, a second motor dedicated to the pitch direction and a third motor could be dedicated to pulling the trigger

Since the turret remained stationary at the origin, rotational motors provided the easiest control. There are two types of motors that primarily stand out. These choices are a standard DC motor and a signal controlled servo motor, both of which have their own advantages and disadvantages.

Advantages to the DC motor include a full 360 degree range of motion, one input, and the availability of high torque. However there are large drawbacks when used in a controls environment. The largest of these drawbacks is the low precision. The motor is either on or off where speed can be adjusted based on the input. In order to accurately control the position a highly accurate microcontroller was most likely needed. Another large drawback is the significant cost of higher torque motors.

Advantages to the signal controlled servos include a lower cost when compared to DC motors, a signal controlled position, and multiple similarly previous projects to be the starting point of research. Like DC motors, the signal controlled servos has drawbacks. The largest drawback to servo motors is quickly increasing cost for the increase in torque. Another large drawback is that most stock servo motors only have a 90 degree range of motion. In order to gain a 180 degree range of motion additional charges may apply.

In order to keep the cost low and simplicity high, servo motors were chosen to control the yaw and pitch directions of the turret. For pulling the trigger, a low cost, low torque servo can be utilized.

3.4.3.2 Servo Control Method

Most standard servos have three leads, positive power, negative, and signal. The power lead not only acts as the power source for the servo, but can also be utilized to turn the servo either on or off. The typical input voltage for power is between 4.8 volts and 6.0 volts. The negative power lead should be common ground. The signal lead controlled the direction of the servo.

The primary method of controlling the servo is to send a pulse-width modulation signals along the signal lead. This pulse-width modulation signals is a fifty hertz square wave. The length of each pulse of the square wave controls how far the servo will rotate. For example a pulse of 600 microseconds will rotate the servo arm -90 degrees and a 2400 microsecond pulse will rotate the arm positive 90 degrees. **[12]**

3.4.3.3 Open Loop versus Closed Loop

For a servo motor, there is a significant difference in an open loop and closed loop control system. In an open loop control servo control system, the pulse widths control how far the servo rotates in a specified amount of time. In other words, the length of the pulse width modulation controls how fast the servo rotates, not the position. For example, a 600 microsecond pulse may rotate the servo 90 degrees counter-clockwise in 0.15 seconds while a 1000 microsecond pulse may rotate the servo 45 degrees counter-clockwise in the same 0.15 seconds.

In a close loop servo control system, the length of each pulse controls the position, instead of how fast the servo rotates. For example a 600 microsecond pulse may rotate the servo to the 90 degrees counter-clockwise position in 0.15 seconds while a 1000 microsecond pulse may rotate the servo to the 45 degree counter-clockwise position in 0.075 microseconds.

Most standard servo motors can only rotate 90 degrees and can be stretched to 180 degrees for an additional cost. These rotational limitations are placed by a potentiometer built into the servo motor. As the potentiometer rotates with the servo, the voltage across the potentiometer changes allowing this voltage change to be used for feedback to control the position. The potentiometer can be disconnected to achieve a full 360 degree continuous rotation, however the feedback to control the position is lost and an external circuit would have been required. Since it was specified that the turret rotates below 180 degrees, a continuous rotation is unneeded; this allows for the utilization of the built in closed loop system. **[13]**.

3.4.3.4 Servo Gear Material

There are four major gear materials used in servo motors. Nylon is in the lowest tier of gear material is generally the most common in stock servos. Karbonite is slightly above nylon in strength and durability and also runs quieter than Nylon. Metal gears are stronger than karbonite but have lower durability. Titanium gear is the highest tier of gear material. Titanium gears provide extremely high strength and durability, but at a significantly higher cost. These different gears can be purchased and swapped in as needed, however gear sets for each material do not exist for every servo combination.

3.4.3.5 Digital versus Analog Servos

Like many components in the electronics world, servo motors come in standard analog and digital varieties. Functionally speaking, a digital servo is a standard analog motor with a built in microprocessor that analyzes incoming signals to control the motor. Digital servos have two distinct advantages over their analog counter parts. With the built in microprocessor, the servo performance can be better optimized depending on servos function. Also because of the built in microprocessor, the pulse width modulation sent from the microprocessor operates at a higher frequency than the standard 50 Hz used for analog servos. This leads to higher accuracy, smoother acceleration, and the availability to hold higher torque. However, because of the addition of the microprocessor the servo comes with disadvantages. Since the digital servo operates at a higher frequency for higher accuracy, the power consumption also increases. The price of digital servos is also significantly higher than their analog counter parts. **[13]**

3.4.3.6 Torque Calculation

In order to calculate the required torque needed for the servo motors, the angular torque formula must be utilized.

$$T = (AngularAcceleration)(MomentofInertia)$$

The approximate weight of an unloaded paintball gun used as references was 2.25 pounds, or approximately 1.134 kilograms. The maximum allowed weight for one paintball gun is 3.5 grams, or 0.0035 kilograms. It assumed that 100 paintball guns will be loaded into the hopper for a weight of 0.350 kilograms. A lightweight paintball gun hopper, the component that holds, the paintball gun ammo, is advertised as approximately one pound. Since paintball gun hoppers vary largely, it was assumed the hopper weighed two pounds, or approximately 0.9072 kilograms. The total mass of the paintball gun, paintballs, and hopper, is approximately 2.392 kilograms. For simplicity, this mass of a loaded paintball gun is estimated to 2.500 kilograms. The length dimensions of the paintball gun are estimated to be 24 inches long by 3 inches wide by 8 inches high. For simplicity, the paintball gun was assumed to be a cuboid. The moment of inertia must be calculated across two axis, the pitch and the yaw. The calculations can be found in table 2.

It was assumed that the base platform would have been constructed of quarter-inch plywood. According to the APA plywood specifications, 0.842 inch thickness of unsanded plywood weighs approximately 3 pounds per square foot. **[14]** Quarter-inch plywood can be estimated to be .75 pounds per square foot, which is also a rule of thumb. Assuming the base platform is 24 inches by 24 inches, or 0.6 meters by 0.6 meters, of half inch-plywood, the approximate is estimated to be 3 pounds, or approximately 1.5 kilograms. Similar to the paintball gun, the base platform moments of inertia are calculated in table 2.

The base tower holding the paintball gun was assumed to be constructed of quarter-inch unsanded plywood. As previously used, quarter-inch plywood can be estimated to 0.75 pounds per square foot. It was assumed that the base tower compose of two quarter-inch plywood slabs that would have been approximately

8 inches long by 0.25 inches wide by 16 inches high for a total weight of approximately 1.5 pounds, or approximately. The two plywood slabs would have been placed parallel, 4 inches from the center to the outer of the plywood, or 3.75 inches from the center to the inner side of the plywood.

Table 2 consists of a summary of the dimensions, mass, and moments of inertia of the three major moving components of the autonomous turret. All units are provided in meters, kilograms, and newton-meters. “L” represents the length in meters, “W” represents the width in meters, “H” represents the height in meters, and M represents the mass in kilograms. Since the base platform would have not rotated along the pitch direction, the moment of inertia can be ignored in the pitch direction. The moment of inertia is given in Newton-meters. According to the above equation, the angular torque is calculated by multiplying the moment of inertia and angular acceleration, assumed to be 60 degrees per 0.15 seconds-squared or approximately 6.9 radians per seconds-squared. The total torque in either direction can be summed by the principle of superposition The torque listed in the table below is converted to oz-in by multiplication of 141.6.

Moment of inertia and torque calculations						
Part	**L**	**W**	**H**	**M**	**Moment of Inertia**	**Torque**
Paintball Gun	.61	.08	.20	2.5	$I_{yaw} = \frac{m}{12}(W^2 + L^2)$ $I_{pitch} = \frac{m}{12}(W^2 + L^2)$	$T_{yaw} = 77.2$ $T_{pitch} = 84.5$
Base Platform	.61	.61	.006	1.5	$I_{yaw} = \frac{m}{12}(W^2 + L^2)$	$T_{yaw} = 91.8$
Base Tower	.20	.006	.41	0.7	$I_{yaw} = \frac{m}{12}(W^2 + L^2)$ $I_{pitch} = \frac{m}{12}(W^2 + L^2)$	$T_{yaw} = 6.98$ $T_{pitch} = 6.98$
Total	NA	NA	NA	NA	NA	$T_{yaw} = 182$ $T_{pitch} = 91.5$

Table 2 - Dimensions, mass and moments of inertia of moving components

According to the calculations above, the amount of torque required to turn the autonomous turret in 182 oz-in in the yaw direction and 91.5 oz-in in the pitch direction. These numbers are calculated from heavy estimations due to large variations in paintball gun weight and unconfirmed base design. However, all these estimations were on the higher end in order to receive a higher required torque that should theoretically be needed.

3.4.4 Web Cameras

The web camera is a vital component in the system design. The sole purpose of the web camera is to provide optics for the ATS system, from there the software is implemented so the system has motion tracking, target creation, and target selection. For these implementations to occur, a high definition camera was needed. The system utilized a Logitech C310 HD Webcam. The webcam has a widescreen video at 720 pixels HD Resolution, a built-in mic and auto adjustment for poorly lit settings. The webcam was attached next to the turret on the base for maximum stability. The webcam was also connected to the laptop via USB and has real-time video capturing that displays on the laptop. **[15]**

3.4.5 Alarm Systems

The alarm system is strategic component to warn incoming intruders that they are entering a restricted area. The alarm system needs to be loud enough to ensure the incoming targets can hear the potential warning. Two alarm options have been chosen to be implemented onto the ATS system, a continuous audible alarm and a speakers of the laptop that can play an audio file stored on the onboard control system.

The first option that was considered is the Turbo series TMC-86-530-W, a panel mounted alarm by Floyd Bell Inc. **[16]** This option was a continuous sounding alarm that has a wide arrange of operating voltages ranging from 5Vdc to 30Vdc. The alarm was a non-descriptive alarm meaning it just outputs a continuous noise, much like a fire alarm. The typical operating current ranges from 2mA at 5Vdc to 10mA at 30Vdc. In table 3 below, the important working specifications are provided. The output sound and current consumption is linearly related, so the higher the input current, the louder the alarm is going to be. This option was a cheap viable option that only cost $9.64 per alarm component.

Turbo series TMC-86-530-W	
Mounting	Panel Mounted
Operating mode	Loud – Continuous
Operating current	2mA at 5 Vdc 10 mA at 30 Vdc
Termination	Wires
Surge Voltage	20% over the maximum rated voltage for five minutes

Table 3 - Specifications of Turbo series alarm

The second option considered was to just use a simple speaker that plays a unique audio file from the system. This gives the option to warn incoming intruders of specifically what the system's intentions are. For example, the system can verbally warn the intruders that they are entering a danger zone. This option gives a variety of audio files to instruct the intruder to exit the area and warn of an imminent attack. A basic set of computer speakers such as the Insignia 2.0 Stereo Computer Speaker System was to be a satisfactory option for the necessity of the system and these speakers are available for $19.99 from Best Buy. **[17]** However, the ATS designers decided to just use the speakers on board the laptop. These speakers were loud enough to warn off incoming intruders while playing custom audio file chosen by the designers.

There were advantages and disadvantages to using either option. The advantages of using the Turbo series TMC-86-530-W has the ability perform better outdoors because its casing is resistant to salt spray, humidity, dust and vibrations. However, the disadvantage is the alarm cannot inform incoming intruders of the system's intent to fire upon them. It more likely to startle the intruders but these intruders may not have a clear instructions of what the ATS system intends to do. The major advantage of using the speakers that read an audio file from the computer is the alarm can verbally alert intruder that they are in a potentially dangerous zone if they continue to proceed forward. The disadvantages are the alarm does not have the ability to be as loud and will not be as outdoor resistant. Therefore, the ATS design team decided to use both alarm components to serve the purpose of alerting incoming intruders.

3.4.6 Power Sources

There was a wide range of batteries available and each has certain advantages and disadvantages. The different types of batteries range from Alkaline batteries to lithium- ion batteries but for the purpose of the ATS system, the designers narrowed the choices of batteries to two viable options, lead - acid and nickel-metal-hydride batteries. Both of these types of batteries are matured and have proven quite reliable in the past. Therefore, there was a wide range of previous knowledge that the designers can turn too if problems arise during the implementation process of either power source.

First, the lead-acid batteries, typically known for being used as car batteries, are used for a lot of applications. CSB Battery technologies Inc. builds a 12V/1.3Ah Sealed Lead Acid battery available at RadioShack for 15.99.**[18]** This is a smaller version of a typical car battery so the size was not to be a problem for the ATS application. The lead acid battery has a an extremely high boiling point, temperatures far higher than the system was to ever experience and the battery was known to be very easy to work with. Under normal operating conditions, the internal material is not be hazardous, only if the battery is exposure or leakage of the internal material occurs, is the battery be hazardous but exposure is very unlikely.

One advantage of this is how small this battery is in relation to the ATS system. It has a length of 3.8 inches, a height of 2.05 inches and width of 1.89 inches and the battery only weighs 1.3 pounds so this didn't affect the weight or size dimensions of the ATS system. However, the major advantage is this battery is also rechargeable which makes an optimal battery for the ATS designers. Rechargeable batteries typically have a higher initial cost but can be recharged cheaply and used over and over. Therefore, the battery will have a lower total and also benefit from environmental damage compared to disposable batteries.

The second option, was the nickel metal hydride battery. These batteries work by using a hydrogen absorbing alloy for negative electrode This makes the capacity larger than other batteries. The energy density is similar to a lithium-ion battery, but the rate of self-discharge is much higher compared to a lithium-ion battery. This is one reason the lithium-ion batteries were not considered for the ATS system, because they tend to be every expensive.

Nickel-metal-hydride batteries come in all different shapes and sizes, so the next decision would be to determine how much power is needed. The designers determined that 12V would be more than sufficient to power the system. A suitable nickel-metal-hydride battery was the Tenergy 12V 1400mAh battery pack available through total power solutions on All-Bettery.com.**[19]** Like the lead-acid batteries, this battery pack is small, actually smaller with the dimension of 2.3 inches long, 1.3 inches wide, 1.1 inches tall and only weighs 8 ounces. A special feature of this battery pack is that it has a long life cycle and rapidly charges. However, the original intent for this battery pack is for RC aircrafts or mini Robots so the battery pack has 16 AWG Wires to connect to these usual platforms. This makes it a challenge to connect the nickel-metal-hydride battery pack directly to the printed circuit board where the microcontroller were. The designers will be able to splice the wires to connect directly to the printed circuit board but then has to determine how the battery pack will be capable of being recharged once connected directly to the PCB..

3.4.7 Range Detector

In order to accurately predict the location an object to be tracked, a range sensor would have been needed to be implemented. Naturally, there are various sensor types to determine the range of an object. One range sensor type is infrared range sensors. Typically infrared sensors cannot measure distance past thirty feet. The advantage to IR range sensors is the low price. However, IR sensors are not very accurate and tend to be limited to less than thirty feet. This is much less than the desired one-hundred feet making the IR sensor impractical.

Another type of range sensor is a laser range detector. The laser range detector is used in a variety of applications from recreational sports to military defense. Laser range detectors have a wide band of ranges well within the desired one-hundred feet and are highly accurate. Even though a laser rangefinder would work, it is difficult to find one with a reasonable price and the ability to work with the microcontroller. Typical laser range detector prices start around $100 and exceed the $1000 mark.

Another type of range sensor is an ultrasonic range detector. Like the laser range detector, the ultrasonic has a wide band of ranges within the desired one-hundred feet. Ultrasonic range detectors are typically cheaper than the typical laser range detector. However, unlike the laser range detector, the ultra-sonic range detector is typically inaccurate and could have had issues detecting the distance when multiple objects are moving.

Of these options, the best and only reliable range detection sensor typical would have been the laser range detection. However, for a starting price of approximately $100 and difficulty of incorporating said sensor with a microcontroller, the options of not having range detection was considered. Ideally the ATS system is in a relatively small confined space smaller than 100 feet by 100 feet. The average paintball gun should theoretically fire straight pass 100 feet. Although the turret is not able to predict the location of the tracked object, it should was still able to predict the direction of the tracked object. Although a range detector would have been a great advantage for the autonomous turret to have, the cost is not justified since the direction of an object and already be predicted. Thus, no range detector was implemented.

3.4.8 Manual Control Options

There are multiple methods of manual control for the autonomous turret. One method is to develop a website that offers a full control of the turret. This custom website would have options to control the pitch, yaw, and firing rate via a custom built GUI. The advantage to having a custom website is the easy expansion of various options. A video feed from the web cameras, preset firing rates, and accessibility to mobile devices are a few examples that could be implemented. The disadvantage to the having a custom built website is the need for a secondary computer to host a server and the need for additional networking hardware.

There are also multiple methods to control the servo motors with a physical “handheld’ controller. One method was to purchase a pre-built servo motor joystick controller from servocity.com. A two servo joystick controller from servocity.com currently cost $99.99. The advantage to this controller is no additional need for another circuit design. Power gets plugged directly into the controller and the controller outputs operating voltage power, ground, and signal. The disadvantage is the ridiculous cost for plastic and wiring, and the complete bypass of the microcontroller controlling the servo motor position and firing.

With the increase popularity of capacitive touch devices, an updated controller replacing the joysticks with a capacitive touch controller makes an interesting controller. One advantage to building a custom capacitive touch controller is the ability to design the controller to work cooperatively with the position and trigger microcontroller at a much lower cost. Another advantage is the possibility to incorporate custom modifications including predefined settings, custom firing rates, and a current position display. The main disadvantages are the huge step in difficulty and the need for an additional microcontroller.

A large deciding factor in choosing manual control method was cost. According to the Texas Instruments website, a capacitive touch booster pack with a MSP430 microcontroller Launchpad costs roughly $15.00. The MSP430 microcontroller and booster pack combination was chosen since the group is already somewhat familiar with the product. When compared to the prebuilt two servo joystick controller from servocity.com, the clear winner is a custom built capacitive touch controller. In addition to the capacitive touch controller, the turret has the ability to be controlled by the on-board keyboard and xbox360 wireless controller.

3.4.9 Manual Controller Communications

With the selection of a capacitive touch controller, a method of communication between the position and trigger microcontroller and the capacitive touch controller must be incorporated. There are three primary methods of are onboard, wired, and wireless.

The easiest method of communicating between the two microcontrollers is simply building the capacitive touch controller directly onto the turret. The capacitive touch controller would have simply be attached to the turret, translate the capacitive touch to pitch and yaw degrees, and then send this information to the microcontroller controller the servo motors. The servo microcontroller simply translates the pitch and yaw degrees to the correct pulse width modulation.

Although it is possible to transmit data over a wired or wireless connection, the difficulty of implementing a wired or wireless connection within a semester timeline may have been difficult since the difficulty of implementing a real world capacitive touch controller was largely unknown. The microcontroller implemented with the capacitive touch controller was programmed heavily with functions in order have the communication and calculations separate.

3.4.10 Laser Pointer

A laser pointer was another component the designers wished to implement to the ATS system so the users can visually see where the gun was pointing at. However, there is a wide range of laser pointers to choose from but the typical distinction between each other is the laser color. The color of the laser is based off of the wavelength intervals from the visible light spectrum. The designers narrowed the options down to three different options, a red, a green and a blue-violet laser pointer.

The first laser pointer was the red laser pointer, with a wavelength interval between 635 – 700 nm. **[20]** The red laser pointer pen from LasersMan.com actually outputs 5mW of power and has a wavelength of 650nm. But since the red laser point was one of the original laser pointer technologies and the growth of technology, the red laser pointers have no longer become a first choice option. The laser pointers lack the power and distance of new models but are still a cheap viable option, especially for simple uses likes pointing at a projector for presentations. Since the red laser pointer lacks the distance factor, the designers opted not to use this design. **[21]**

The next option was the blue-violet laser point. With a wavelength interval between 400 – 490 nm, the blue-violet color is on the opposite end of the visible light spectrum. **[20]** This laser is still a new cutting edge technology, and has only recently been available in the market, mainly known for the creation of the blu-ray, high definition video technology. LaserPointPro.com has a adjust focus blue-violet laser pointer pen that has a larger range than the red laser pointer, which would benefit the system for targeting the incoming targets further away. **[22]** Although the laser pointer is a new technology, it is also an expensive one, costing $73.99. So the designers of the system decided there is no need to impact their budget to meet the requirements that other laser pointers can achieve.

The final option was the green laser pointer. With a wavelength interval between 490 – 560 nm, the green color is right in the middle of the visible light spectrum. **[20]** Today, this laser pointer is far brighter than red lasers. Known for such long ranges, it has actually become a felony for individuals that would aim green lasers at planes flying for distracting the pilots. LaserPointPro.com has a mid-open green laser pointer available that has a wavelength of 532nm and operates at 3-4.2 volts. **[23]** So the designers decided the mid-open green laser pointer because it was more than sufficient enough to demonstrate compliance for the system.

In table 4 below, there is a comparison chart of the three different lasers the designers initially considered to use. The key things to note are the laser wavelength, laser range, and cost. The laser wavelength was what determines the color and range. As you can see by the range comparison, the green and blue-violet laser pointers are significantly larger than that of the red laser pointer. After that, the cost was the determining factor, and since the mid-open green laser pointer was significantly cheaper, the designers chose to use this model.

Laser Pointer Comparison			
Product	**Mid-open Green Laser Pointer**	**Red Laser Pointer Pen White**	**Adjust focus Laser Pointer**
Model number	HK-E03358	A0877000AV0107	HK-E03508
Laser Color	Green	Red	Blue-violet
Laser Wavelength	532nm	650nm	405nm
Laser output power	20mW	5mW	150mW
Power Supply	2 x LR03 AAA 1.5V batteries	2 x AAA batteries	1 x 18650 2200mAh 3.7V battery
Working Voltage	3.0 – 4.2 volts	3.0 volts	3.0 – 4.2 volts
Working Mode	Continuous Wave	Constant wave	Constant wave
Dimensions (Dia. x L) in centimeters	1.295 x 14.198	1.27 x 13.716	2.2 x 14.3
Laser Range (meters)	500 – 5000	Approx. 1600	500 – 5000
Cost	$14.99	$3.39	$73.99

Table 4 - Comparison of different laser pointers

3.5 Software Research

3.5.1 Computer Vision

Computer vision is an increasingly popular application and has a wide variety of uses. Computer vision has found its way into robotics, surveillance, defense systems, and other applications. The process of computer vision is generally the same for all applications with variances for each specific use. The usual steps of computer vision software follow the pattern of image processing, object detection, object tracking, and, lastly, decision making. The image has to be processed first so when the object detector receives the image, it is in the best condition for the detector to find what it is searching for (edges, corners, faces, etc...). Then once objects have been detected, the algorithm must keep track of those objects for various reasons. In surveillance, tracking objects is used to keep the camera focused on any movement so if there are intruders, they are caught on the camera and more easily identifiable. Then the last step is to make a decision. This part is very application specific, and for the ATS the decision to be made is whether to fire upon the object or not.

Image processing is the initial step in all computer vision applications, and is essential to be able to utilize computer vision algorithms. The processing that actually happens depends on the application, and what is needed. Image processing covers a broad range of features such as image filtering, image transforms, structural analysis, shape descriptors and feature detection. Once the image has been processed, the object detector must view the image and determine whether or not there are objects and, if so, where they are located. Object detection is most commonly executed by detecting specific features within the image, called haar-like features. These features represent the image that is sought after (for example a human face). Using this, the algorithm compares what it has learned through machine learning, and find where the objects are located.

Once objects have been found in the field of vision, each object must be tracked. The basic way of motion tracking is to just find out where pixels changed, because if a certain pixel changed colors over the course of just one image frame, then most likely movement occurred at that location. A more robust method is to track the objects calculating optical flow. Optical flow is the pattern of motion of the things you are trying to track. It is calculated through various methods such as the Lucas-Kanade method (two versions), the Horn-Schunck method, Farneback's method, or the block matching method. All of these methods find the optical flow, but utilize different approaches to complete the task at hand. The iterative Lucas-Kanade method with pyramids is probably the most popular and likely to be the choice for the ATS.

The last step in the computer vision application is to make a decision based on the information gathered from the image or stream. This is the vital step in computer vision and is the reason behind the need for computer vision. The ATS determines whether or not there are targets to shoot at. Then determine if any of them pose a threat (based on various factors which are discussed later on). Examples of other decisions in computer vision applications include a pass/fail on an inspection, or alerting the user of the system that something is out of the ordinary. The decision making process is based on a variety of factors that were determined within the processing, detection, and tracking done previously. **[24]**

3.5.1.1 Object Detection

Once the image has been acquired and pre-processed the first step to determine if there are targets or not is to check if there are any objects in the image. An object is used to represent a person, a face, or to be more general, a blob. Object detection is done in various ways and has varying levels of depth. Facial recognition is a specific type of object detection that is discussed in 3.5.1.5.

The first method to detect objects is to separate the background and foreground objects. A camera or defense system constantly monitors the same area so most likely there is some normal image with no objects of importance within the image. By knowing what the background is normally, the system then determines if the pixels of an area of the image has changed sufficiently enough to represent an object. Wherever this occurs the pixel is labeled as foreground. Then, the entire image is converted to a binary image, where the background and foreground are black and white, respectively. From this point, the process becomes relatively simple. Based on a threshold set for the minimum size of an object, the system determines if there are any objects or not. If so then it creates a target and record the position of the object in the image.

Another way to detect objects is to use machine learning. If the system already has an established knowledge of what type of objects it is looking for, and then finding them in images become easier. Machine learning uses a series of positive images of the object to be detected and negative images that are not the object sought after. To be more specific, the software learns based on haar-like features which consider adjacent rectangular areas in a specific area of the image. For example, the haar-like features to detect a face is the darker rectangles of the eyes, compared to the cheeks just below. These consistent features of the object being detected allow the system to understand what object it is sning the image for, so detection of the object becomes less complicated from that point. The reason haar-like features are so popular for object detection is the fast computation speed they allow. Using a two-dimensional look-up table, or integral image, the calculation of a rectangular area within the image only requires four look-ups. This speed is vital to the system, so it operates in real-time to make a decision based on the object it detects within the image. Since the ATS was placed in a singular position with the camera directed at a static background, images are taken of the scene and used for the machine learning process.

The previously discussed methods only take into account local features within the image. If global features are also taken into account, it provides a more accurate object detection algorithm. To find the global features of the image, the system takes a look at the image in its entirety and find major features within the image. However, this method requires a large amount of complex mathematics and this method is in early stages of research for computer vision. **[25]**

OpenCV's object detection method uses machine learning and haar-like features to detect a person's face and then creates an object based on that. It runs the image through a cascade of classifiers which eliminate non-objects through each stage. The first stage eliminates most non-objects, but it is essential that it does not miss real objects. Then the following stages continue to eliminate non-objects that may be closer representations of the object sought after. Once the classifiers are completed then the only remaining items should be objects of interest.

In figure 1, the process that the frame from the web camera is shown step by step. In the first picture the standard RGB image that was received from the web camera is shown. Next, in the second and third pictures, it was searched for objects (blobs, faces, etc...) and any objects found then have a rectangle drawn around them to denote where in the frame they are located. Using this process to detect objects allows the team to find all of the objects that are of importance without using an extremely robust algorithm that requires much more computational power. **[26]**

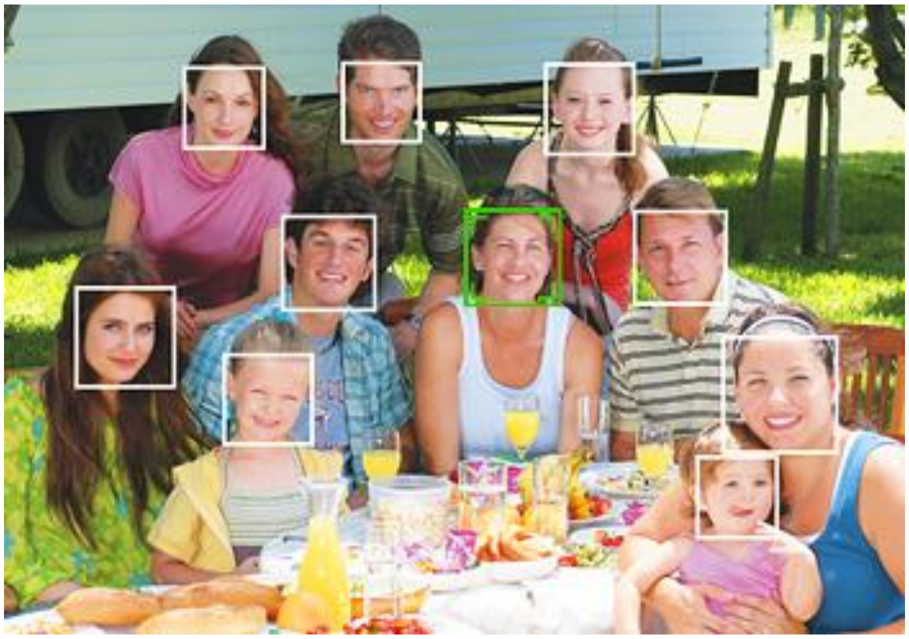


Figure 1 - Result of Object Detection algorithm

3.5.1.2 Object Tracking

Once the objects within the image have been detected, the next logical step is to track those objects. The basic concept of tracking the objects was to assign each object an x-position, a y-position, and a velocity. For every frame of the image, the system updates each object's position and velocity. Once a few frames have passed, data association is used to determine the future velocity and position of the object being targeted, allowing for an increase in accuracy since the ATS is leading its target. Object tracking and motion tracking complete the same step in the computer vision process; however there is a tradeoff for which one the system utilizes. Motion tracking is simply finding out which pixels changed from frame to frame, and wherever that occurs, motion has occurred. This method makes the process simpler because object detection is not be needed, but the tradeoff is that the algorithm is not as robust as object detection and tracking algorithms are. For the application of the ATS, a more robust algorithm is necessary to handle real world simulation scenarios because it is a matter of life and death.

By detecting and then tracking objects, rather than just tracking motion, the system is able to assign values to the objects, such as color, or target versus non-target. This allows the system to make more knowledgeable decisions based on each individual object, rather than just firing wherever enough motion to pass the threshold occurs. In section 3.5.1.4, color detection is discussed, so if it were implemented in the system, different values are assigned to objects so targets and non-targets are differentiated, making object detection a requirement.

There are actually a few different algorithms in which object tracking is done. The most basic of these methods is blob detection and tracking. In this method, the image is scanned and searched for regions in the image that differ from the pixels surrounding it. Once this has been found, the algorithm creates a “blob” based on the size of the region found on the image. OpenCV's blob tracking uses a method of finding foreground and background pixels, then searching for adjacent regions of foreground pixels to create the blobs. Then assigns ID's to each blob found in the image and then records the motion that occurs as each frame goes by. This algorithm loads most of the work in the first stage, blob detection, and then uses more simple algorithms for the tracking of each blob.

Features are also used to track and detect objects. Features, such as color, edges, texture, and optical flow, offer methods of keeping track of an object. For example, tracking humans by the color of their shirt is done because the shirt is generally a set distance below the face, so once the object detection has detected a face object, it then gets a set of pixels below it and find what color the shirt is. Then wherever that same segment of pixels is found, is where the object is. The OpenCV algorithm uses the most popular method of tracking by optical flow. The algorithm is known as the Lucas-kanade algorithm, which is a differential method. Another optical flow algorithm is the Horn-Schunck method which uses smoothness, but this method is more sensitive to noise than other methods because it is global rather than local. **[27]**

Optical flow is calculated using a wide variety of methods. The first, and most popular method, is the Lucas-Kanade method. In this method, it is assumed that the flow of nearby pixels is constant and then uses the least squares criterion to solve the basic optical flow equations. There is also a modified version of this method that uses iteration with pyramids to find the optical flow of the object. Another method that is used for finding the optical flow of an object is the Horn-Schunck method. In this method, a more global approach is taken to solve the problem, rather than the locality used in the Lucas-Kanade method. Also, a global constraint, smoothness, is introduced to solve the aperture problem, which is where it is impossible to tell what direction the object is moving because the ends of the object are unseen by local methods. To continue, the Farneback method uses polynomial expansion to do the approximation of nearby pixels. It provides a displacement between the two frames being considered. Pyramids also are used here to detect larger displacements within the image. The last method of optical flow to be considered is the block matching method. In this method, a series of overlapping blocks are made of the image and then run through a series of calculations to compare the overlapping blocks to one another. The function then calculates the optical flow of these overlapping blocks and then uses that to find the optical flow for the image.

Overall, object tracking proves to be quite a challenging task due to all of the variables that occur within the image. The major factors that make object tracking difficult are object occlusion, noise, complex object motion and shapes, changes in scene lighting, and the requirements of real-time processing. All of these factors make object tracking a very memory and CPU intensive process.

3.5.1.3 Motion Tracking

Motion tracking is the process of measuring an object's position and orientation in physical space. **[28]** The first step to tracking objects is to detect and distinguish objects from the background image. There are many methods to detect motion including mechanical, magnetic, optical and video. Video tracking is most relevant or our project as it is used in many security and surveillance systems. Video tracking is the process of comparing the position of an object in the current frame to the position in a reference frame. This is done by comparing individual pixels and identifying the number of different pixels. Since there are many variables such as lighting or outdoor conditions such as wind pre-processing are necessary. Once an object has been marked as moving the object is then tracked using a video tracking algorithm. Video tracking algorithms fall into two categories; target representation and localization or filtering and data association.

Target Representation and localization algorithms are generally less complex than filtering methods. To represent a target first a feature set must be chosen. This is chosen from the color or size of the target to be identified. Two of the most popular methods are blob tracking and kernel tracking. For ATS, blob detection proves to be more useful due to its ability to track the dynamic changes found in human motion. Blob detection attempts to identify regions in an image that differ in color or brightness.

Filtering and Data Association is a top down process that uses prior information of the object or surroundings. The most widely used methods are the Kalman Filter and particle filters. The Kalman filter is a set of recursive equations to estimate the state of a process. The filter supports estimation of past and future events meaning this filter is used to estimate where a moving object came from or where the object is heading. This is very useful when tracking objects that move behind obstacles or determining the path the object came from or is heading. The filter works by using time update equations and measurement equations; measurements are updated and used by the time equations to predict the future path of the object. **[29]** If the process is non-linear an extended Kalman filter is used instead to track and predict target paths. **[30]**

The best tracking algorithms often incorporate both Target Representation and localization with a filtering method for path prediction. For ATS's needs blob detection was the method of choice because of the ability to track humans effectively, but not used because optical flow seemed more effective at longer ranges. OpenCV contains the cvBlobsLib, a library to detect and filter blobs.

The optical flow of an object through a video sequence is shown in figure 2. In the figure, the optical flow vector is seen going up and to the right, following the path of movement of the object. As each frame of the video sequence goes by, the object has a new position. So the changes in the location of the object are recorded for use in calculating the optical flow. This is used to assist in finding out where the object was in the upcoming frames, thus allowing the program to predict the movement and become more accurate when firing upon any object.

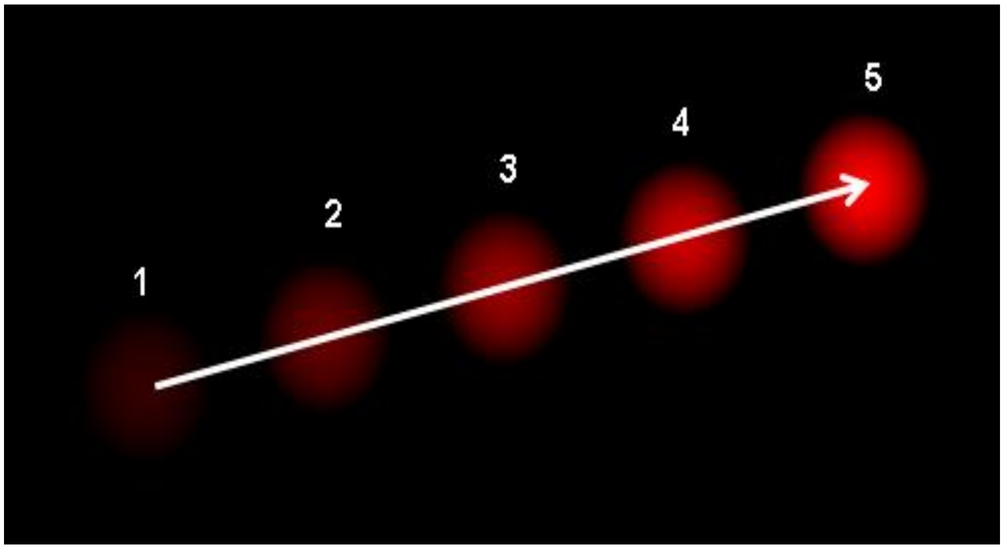


Figure 2 - Optical Flow of an object

3.5.1.4 Color Detection

Color detection was intended as another important aspect in ATS' computer vision. By detecting various colors, the system was supposed to be able to differentiate between allied targets and enemy targets. By specifying a certain range of color to represent an allied target, the system is able to calculate the average color of the target and determine if it is a threat or not, but this was not used due partially due to time and also due to its lack of impact on the actual prototype.

There are multiple ways in which an objects color is determined through computer vision. The first, and most straightforward, method of color detection is to take the pixels that represent the target, average their RGB values, and then check if it meets the requirements of the threshold. For example if allied targets were represented by green colors, comparisons are made with pure green (0, 255, 0) and depending on what the threshold is set to, it then determines if the target is an ally or an enemy. To make a more complex threshold, the Euclidean distance is calculated between the received pixels and the target color. A challenge in this method of color detection is that it makes it difficult to detect various shades of the same color without making a large threshold. Another possible solution for detecting colors is using HSV instead of RGB. The primary benefit of converting the RGB pixel into a pixel represented by HSV is that it is relatively easy to detect the various shades of a single color. A relatively small threshold is set for the hue, or the tint of the color, and then larger thresholds is set for saturation and value to detect all of the various shades of the color specified.

Once the color of the target has been found there are various ways to proceed with determining how to handle the target. One way, is to convert the image into a binary image based on where the color specified has been found. Then it is much easier to handle the image since, the various other colors of the image have been removed from the frame. This is effective and simple method, but is difficult to utilize for tracking more than one object of the specified color.

To fix the problem that multiple targets causes, the system finds targets first and then assigns them a color value based on what is found within each target. OpenCV's blob detection already locates multiple targets in a single frame so by taking that data and then assigning objects color, rather than finding out the color first makes handling multiple targets more simple. Then once the target has been assigned a color value, the sentry gun continues to track all targets, but it checks the color value of the target before determining to fire upon the target or leave them alone.

Overall, there are a couple of different approaches for determining the color of an object. The RGB method offers a more simple method, but comes with a couple weaknesses due to its simple nature. On the other hand, the HSV method handles those flaws, but is a more complex algorithm. Then, once the color of the object has been detected, there are various ways to approach the decision making. Once again, the tradeoff for having a simpler algorithm of converting the image to a binary image is that the system is not able to detect more than one target. The other approach of finding all targets and then assigning them a color seems to be the more practical approach for the application of a defense system because multiple targets is a probable occurrence in the real world.

In figure 3, the before and after of the color detection process is demonstrated. This particular color detection method uses the idea that there was a shirt a certain distance below the face that was detected. **[31]** So by checking those pixels, the color of the shirt is used as the color of the object. In the picture on the left, the standard RGB image taken from the web camera is shown. Once the object detector uses the frame to find all objects, the color detector looks a specific amount below those objects (which in this case are faces) to find the color of the objects (the shirt). Using hue, saturation, and value, the color was easily determined due to the fact that hue represents the "tint" of the color and gives the group information that is needed for color detection. So, the algorithm checks for a wide range of hues but only a small range for saturation and value so it returns any of the shades of the specified color, rather than just one very specific shade of a certain color. **[32]**

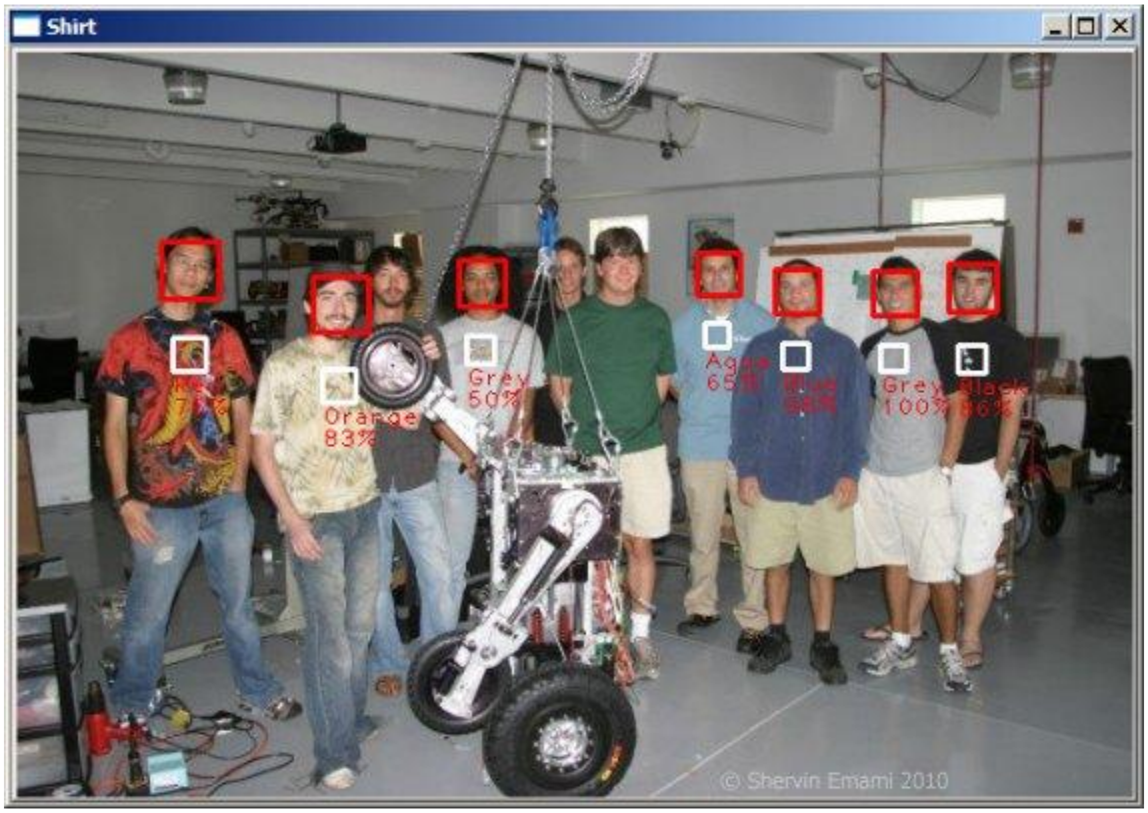


Figure 3 - Result of Color Detection

3.5.1.5 Facial Recognition

Facial detection and recognition has many real world applications from biometric identification to security systems, detecting criminals, and more recently in online photo albums to detect and tag recognized faces. The area that pertains to our project is biometric identification and security systems. Identifying particular users as friendly or dangerous allows the designers to restrict the turret from firing upon friendly targets. Facial detection is a specific class of object detection Facial detection software determines the presence, location, and sizes of human faces. **[33]** Once a face is detected in an image, the software then tries to find a matching face in a database, this is known as facial recognition. There are various methods to finding and detecting faces they involve the detection of one or more of the following variables: appearance of the face, shape of the face, and motions of the face. In most methods of facial detection a binary pattern-classification task transforms content in the image into features. Then one or more classifiers decide whether the region is a face. Face models are often used to train the classifiers and are contained in databases. Face models include a wide range of faces with different skin color, expressions, shape, and motions of the face. The most widely known method used today is the Viola Jones method.

Classifiers often look for features such as the eyes of the face since the region around the eyes is generally darker than other regions of the face. Classifiers may also try and detect movement of a face including blinking, raising eyebrows, flared nostrils, wrinkled forehead, and an open mouth. Skin color is not used as a classifier since there are so many variations on skin color to be a valid option. In the best facial recognition software multiple classifiers are used to search for and identify a single feature this is known as a weak classifier. **[34]** The classifiers are then layered together in an attempt to identify a face. Facial detection is not an exact science there are many variables and scenarios that results in false-positives and failures in detecting a face. If the viewing angle of the face is more than twenty-five degrees off from the front portrait of the face the classifiers may not be able to detect features. Other weaknesses include poor lighting, sunglasses, long hair, and facial expressions.

In 2001 Paul Viola and Michael Jones proposed a real time solution to the facial detection problem. In their report "Robust Real-time Object Detection" they document the steps and processes necessary to creating fast reliable facial detection software. **[35]** Unlike other facial recognition software at the time the Viola-Jones method does not use image intensities. The process involves finding the integral image representation for images, creating weak classifier using AdaBoost to locate and mark Haar-like features which are features that appear on the human face, and finally combining multiple classifiers in a cascading structure to increase speed of the detection by focusing on important regions of the image.

Finding the integral image representation requires a few operations per pixel but allows the group to detect facial features easier. The integral image at location (x, y) contains the sum of pixels above and to the left of (x, y) inclusive. The integral image is calculated in one pass over the original image. This allows the team to use the rectangles calculated in the integral image to compare rectangles by calculating the difference between two rectangular regions. These rectangles are compared to search for Haar-like features which derive its name from Haar wavelets. Since the number of rectangle features of each sub window is greater than forty five thousand computing each one is very inefficient and not feasible in a real time system. Therefore Viola and Jones use a variation of AdaBoost short for Adaptive Boosting which is an algorithm to train a machine to identify features of an object using weak classifiers. The idea is that multiple weak single characteristic classifiers are combined to form a strong classifier. The algorithm searches over the image and returns the perception with the lowest classification error. The biggest challenge comes from assigning weight to each of the classifier and determining the importance of each facial feature.

The last step of the Viola-Jones facial detection algorithm is to enhance performance and reduce processing time. This is done by setting up a cascade of weak classifiers. Each sub-window is analyzed by a classifier if the feature is detected then another classifier is used, if at any point the classifier fails to detect a feature the sub-window is rejected. The idea is that after several stages of classification the number of sub-windows is reduced greatly. From here more advanced recognition methods are performed on the remaining windows; this saves both time and processing power. Ideally the classifiers used are in increasing complexity that way if a window fails the first classifier test it is discarded reducing the need for further examination. As with most object detection methods there are tradeoffs; more classifiers means you achieve more accurate results with fewer false positives and fewer errors, but more classifiers means more processing power for the CPU, increasing time required to compute an image. Viola and Jones suggest a false positive rate is established and one classifier is used to start. Sample data is then used if the false positive rate is not met another classifier is added and so on until the thresholds are met.

An effective detection method involves using Haar-like features that are used to detect contrasts in the human face most notably the detection of the darkness around the eyes contrasted with the color of the person's cheeks. OpenCV uses an improved upon method of the Viola-Jones method in which a cascade of AdaBoosted classifiers are used to detect the Haar-like features of the human face. Classifiers output a "1" if the sub-window of the image is likely to contain a face and "0" otherwise. If a "1" is returned then the sub-window moves on to the next stage of processing continuing on until a face is detected or a classifier rejects the sub-window. **[36]** In order to check for images of different scales the image must be scanned several times with the classifiers must be resized to the scale. Facial recognition begins with the process of facial detection. Once a face is detected a database of faces are scanned to try and find a match.

In figure 4, a few examples of the haar-like features of a face are shown. The haar-like features are broken down into three sections including edge features, line features, and center-surround features. Haar-like features are used to minimize the amount of computation needed for object detection. When dealing with only image intensities, searching an image for haar-like features by summing up the pixels of adjacent rectangles within a specific window of the image is useful in finding the desired objects. By using a summed area table, the calculation of haar-like features becomes very fast and efficient, requiring only four lookups to the table. Viola and Jones detail haar-like features in their publication on "Rapid object detection using boosted cascade of simple features." **[37]**

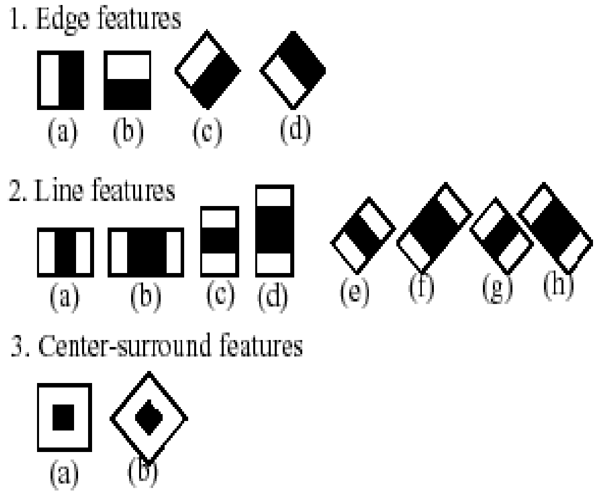


Figure 4 - Haar-like Features

3.5.1.6 FPGA or Computer Vision

The biggest decision the group was faced with was whether to use computer vision or an FPGA system to track targets. Each option has its advantages and disadvantages, a hardware FPGA system would have quicker processing times and would be more reliable for real time tracking, while computer vision has multiple other features the group can implement into the design such as facial recognition or path prediction tracking. Furthermore FPGA systems require specialized algorithms including Fourier transforms, Hough transforms, and stereo vision algorithms. These algorithms would take a great deal of time and research to implement whereas computer vision libraries have methods and functions to handle the calculations and algorithms.

FPGA systems are commonly implemented with a CMOS image detector to send the image to the FPGA board where the processing can take place. In Kazuhiro Shimizu and Shinichi Hira paper published by IEEE the implementation of an FPGA system with CMOS sensors is discussed. **[38]** The concept is that successive images or frames are captured by the CMOS imager and sent to the FPGA board where a vision algorithm is implemented. The FPGA then selects features of the image such as the hue or luminosity and from here can process the data since the feature data is much less than the full image data. According to the report the sampling must occur at 1000Hz in order to capture enough data for real-time tracking to be feasible. In order to reduce processing time and power filters are put into place along with a pipelining processing system.

Computer vision libraries are a popular way to implement motion tracking and image processing since computer vision libraries come with complete libraries and built in functions to handle the tedious processing and computation. The biggest flaw in computer vision systems is that they rely on a computer and operating system. Computer vision does not have the processing speed or reliability of a FPGA system. While computer vision is not without its flaws it is still a great way to implement motion tracking. Computer vision libraries and the built in methods and functions handle all of the processing and computation allowing the group to focus on other features to incorporate into the turret. Computer vision allowed the group to add features such as facial recognition for security, multiple target tracking, and target path prediction meaning targets can be tracked behind partial obstructions or even if they are hidden from the camera.

The group came to the decision to use OpenCV which is an open-source computer vision library. It was decided that even if software requires more processing and achieves lower response times than the hardware solution that the extra features and built in algorithms OpenCV is the best choice. The OpenCV libraries are available online along with instructions to install the libraries and tutorials that the group used to learn the functions and features. The second option was to use the aforget.net libraries, but in the end it was decided that OpenCV was more established featuring more tutorials and information. It was also decided that the group would prefer to use the C++ programming language used by OpenCv rather than C# used in the aforge libraries.

The following sections discuss the paintball gun components in further detail. The majority of the components including the paintball marker, hopper, and air tank were donated to the group by a mutual friend. Components such as the paintball ammunition, coil hose, and tubing system were acquired for the completion of the ATS system.

3.5.1 OpenCV

Open Source Computer Vision Library, or OpenCV, is a major component in the software part of the ATS. The system utilized a large variety of the computer vision methods to go from the web camera image to the decision of when and where to shoot. Object detection, Object tracking, motion tracking, color detection, and facial recognition are all featured within OpenCV. With these open source algorithms, the system was able to make well informed decisions based on all targets found in the range of the ATS. Using these algorithms also allowed the system to be more advanced because of the time saved from having to develop computer vision algorithms for the specific application. The OpenCV object detection algorithm, discussed in more detail in section 3.5.1.1, utilizes machine learning to be able to detect haar-like features of the object within the images it receives from the input, which, in our case, is the web camera. The OpenCV object tracking algorithm is more popularly known as the Lucas-kanade algorithm. It is the most popular object tracking algorithm, and does so by using optical flow. The color detection algorithm uses the HSV method as described in section 3.5.1.4. **[24]**

Aforge was another option for the open source computer vision software.**[39]** However, OpenCV was determined to better fit the needs of this project and team due to various reasons. OpenCV is coded in C++, while Aforge is in C#. The team only has experience in C, but it was decided that C++ was the better route. Also OpenCV has a wider variety of extra computer vision features such as color detection and facial recognition. Lastly, OpenCV is more established and therefore has more efficient algorithms.

4.0 Design

The ATS system contains both hardware and software components. The design team was split equally between hardware and software. Hardware design was primarily lead by Ethan King and Stephen Rodriguez. Software design was lead by Daniel O'Hara and James Van Gostein. The following sections will discuss in further detail the hardware component selection and software design layout.

4.1 Hardware Design

Overall, the ATS system is a project that has been demonstrated in the past, only the computer vision software is relatively new software. The hardware design on the other hand has similar components that have been completed for decades as engineers design new up and coming technologies. The hardware design is split into 4 different sections, physical layout, power systems, PCB integration and communications. Below in figure 5 is a hardware block diagram.

The ATS system is a common project and has been demonstrated by many senior design groups in previous semesters. After many considerations, a unanimous decision was reached to design a new hardware solution. The hardware contains many components such as the microcontrollers, voltage regulators, and LEDs. The implementation of these components is discussed in larger detail in the sections below.

In more detail, the hardware side of the ATS system consists of a laptop computer. This laptop computer performs the vision tracking algorithms and outputting data to a serial port. This serial port feeds data into a MAX232 voltage level changer. In turn, this allows the laptop computer to connect directly to four different MCUs. The four MCUs implemented each have their own tasks and are divided into UART to I2C conversion, a capacitive touch controller, a servo controller, and a secondary option controller. In addition to the microcontrollers, the hardware system includes the servo motors, trigger, and alarm. These components are summarized in the hardware block diagram below.

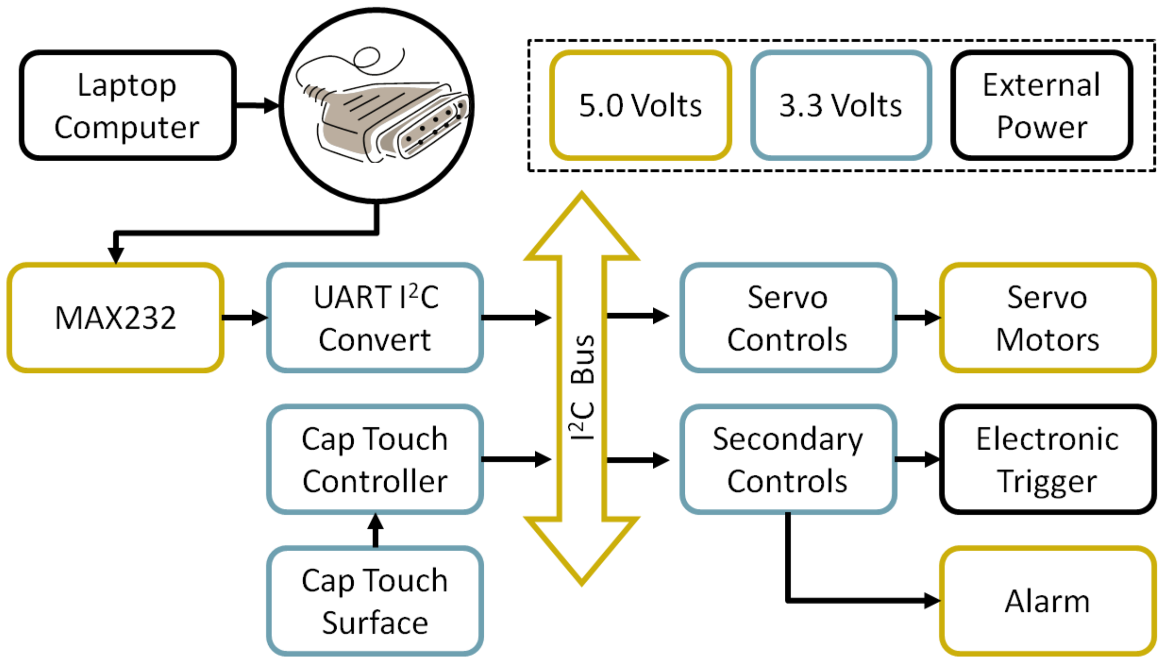


Figure 5 - Hardware block diagram

4.1.1 Embedded System

In order to control the servo motors in the ATS system, a microcontroller was implemented to control the PWM signals and various accessories. Multiple microcontrollers were implemented into one embedded system for both speed and reduced cost. The details of implementation are discussed in the sections below.

4.1.1.1 Microcontroller Selection

When the time to a chose a microcontroller for an embedded system solution to control the ATS system, a wide variety of choices were available. In truth, nearly any MCU with timer features was able to perform the job from Texas Instruments' MSP430 MCUs, to the Arduino based MCUs popularized by hobbyist. The decision of choosing a MCU was largely influenced by Texas Instruments' crash course seminar on the MSP430 microcontroller. Since TI donated actual MSP430 MCUs and programming boards a semester before the implementation process started, the choice to use the MSP430 came from familiarity of the product and low cost to implement the solution.

During the Texas Instrument seminar on the MSP430, two different products were donated. The first product was a MSP430 launchpad development kit which included the G2231 and G2211 microcontrollers, a programming development board, and a USB cable for flashing code. The second product was a capacitive touch booster pack which included the G2452 microcontroller and a LED surface used for capacitive touch applications.

In order to control the ATS system, or more specially the servo motors of the ATS system, the microcontrollers need some form of timing. Luckily the MSP430 microcontrollers have timer registers that can be used for a variety of purposes. The G2231 and G2211 microcontrollers contain one timer with two capture and compare registers. The G2452 microcontroller contains one timer with three capture and compare registers. The MSP430 capture and compare registers can be ran in different modes, but for the purpose of the ATS system, these registers were used to apply a PWM signal. The methodology of controlling the PWM is discussed further in the Servo Motor Microcontroller section.

In addition to needing timer functions, the microcontrollers also needed some form of communication protocol support. According to the datasheet the G2211 microcontroller does not support any communication protocols. However, the MSP430 G2231 and G2452 MCUs support, I2C, SPI, and UART communication protocols. Choosing MSP430s with communication support allowed for much easier multi MCU integration. Instead of having to create software support for an MCU, the built in support was used.

Furthermore, microcontrollers that had multiple available general purpose input output pins that are separate from communication pins were needed. The MSP430 value line microcontrollers chosen had multiple free GPIO pins that were not used in the final design. This allowed for future features to be added if need be.

After considering the requirements of the microcontrollers and comparing datasheets, it was chosen that a combination of four microcontrollers would be used. For converting UART to I2C and secondary controls MCUs, the MSP430G2231 was chosen. For controlling the servo motors and the capacitive touch controller, the MSP430G2452 was chosen. The functionality of each microcontroller is discussed in the appropriate section ahead.
A summary of the important features of the microcontrollers for consideration can be found in the below.

Microcontroller Comparison of Specs			
MSP430 Model	**G2231**	**G2452**	**G2211**
Operating Voltage	1.8 V – 3.6 V	1.8 V – 3.6 V	1.8 V – 3.6 V
Flash Memory	2kB	2kB	2kB
GPIO Pins	14	16	12
Capture & Compares	2	3	2
Communication	SPI, I2C, UART	SPI, I2C, UART	None
Dev Board Cost	$4.30	$4.30	$4.30

Table 5 – MSP430 Microcontroller Comparison

4.1.1.2 Communication

Before going into further detail about the embedded system, some form of communication between the laptop computer performing the vision tracking algorithms and the embedded system had to be implemented. The preferred choice, preferably for ease, was using the serial port IO classes available by Microsoft's .NET Framework. In addition a method of communication between multiple microcontrollers was needed. The preferred choice here was I2C.

Furthermore, a common data type had to be used when implementing two different communication methods. To keep things simple, the preferred choice was to constrain all data into eight bits, or one signed char. Signed chars are supported by both serial port classes and the MSP430 microcontrollers. To constrain all data into a single signed char the following scheme was created. Values between 0 and 64 can set the X angle. Values between 65 and 113 can set the Y Angle. Values 114 to 121 are used for calibration and allow access to changing duty width of the PWM and saving said duty widths. Values 122 and 123 are used for turning an external alarm on or off. Values 123 to 127 are used for controlling the electronic solenoid of the paintball gun. These values are summarized in the table below.

Command Codes	
0 to 64	Set X angle
65 to 113	Set Y angle
114 to 115	Decrease/Increase X pulse
116 to 117	Decrease/Increase Y Pulse
118 to 119	Save Min/Max X Pulse
120 to 121	Save Min/Max Y Pulse
122 to 123	Turn Alarm Off/On
124 to 127	Set trigger to Off, single, burst, or automatic

Table 6 – Command codes for communication

4.1.1.3 Cross Platform Communication: RS232 to UART

The Serial Port IO classes available by Microsoft's .NET Framework allowed the laptop to access the serial communication ports. During the time of implementation of the ATS system, serial ports were as rare as floppy drives. However, since the demand for serial communication is still relatively high, a prebuilt solution for converting USB protocol to RS232 protocol was used. A standard USB to DB9 cable from Amazon for approximately $10.00 was used to mimic a serial port.

The serial port IO classes allowed a user to easily change options such as stop bits, handshaking and baud rate. For the ATS system, the serial port was configured to communicate at 9600 baud. This baud rate was chosen because it is a common baud rate as well as the baud rate used in TI's MSP430 UART example code. Since there is a MCU specifically dedicated to converting UART to I2C signals, receiving data too fast was not a concern. This in turn allowed for handshaking to be disabled. In addition, the serial port was configured to use one stop bit, one start bit, and eight data bits. The following data is summarized in the table below

Even though the serial port was configured to output RS232 protocol similar to UART protocol, the logic levels and voltages of do not match. RS232 communication uses logic one as negative voltages and logic zero as positive voltages. In addition these voltages were typically in the ten volt range, much past the range of the MSP430 input voltages. On the other hand, UART uses logic level one as positive voltages and logic level zero as zero voltage. For UART the voltage level typically ranges between zeros to five volts.

The solution to converting the voltage levels from RS232 protocol to UART protocol was to use a common level changer called MAX232 by Maxim-IC. In summary, the MAX232 integrated circuit converts these RS232 signals to UART signals. The MAX232 IC chosen was semi random. In order to correctly integrate the MAX232 chip into the system, the only requirement for the IC was to have DIP packaging. From there the first MAX232 chip, the MAX232CPE, was chosen.

For integration of the MAX232CPE, the ATS system followed the diagram provided in the datasheet. Pin 13 and 14 of the MAX232 was tied to RXD and TXD of the DB9 cable respectively. Pin 11 and 12 of the MAX232 was tied to RxD and TxD of the UART to I2C microcontroller respectively. The MAX232 IC was powered with five volts and shares a common ground with all the MCUs. In addition one microfarad electrolytic capacitors were used in the final ATS design but the IC can work with ten microfarad capacitors if one microfarad capacitors are not available in the lab. The above data is summarized in the table below.

RS232 to UART Specification	
Baud	9600
Handshaking	Disabled
Parity	Disabled
Stop Bits	**1**
Data Bits	1
Port	Variable
MAX232 Specs	
Input Voltage	5 volts
Capacitors	1 µF

Table 7 – Specifications of cross platform communications

4.1.1.4 Intersystem Communication: I2C

In addition to the communication between the laptop computer and the embedded system, another communication method was needed for multiple MCU communication. According to various websites, the popular communication method for short on board communication is I2C. For the ATS system, the clock line is driven by the UART to I2C converter at approximately 100 kHz. The master is either the UART to I2C converter or the capacitive touch microcontroller. This depended on whichever was active. The slaves were the servo controls MCU and the secondary controls MCU. The I2C bus is be powered by five volts with a 1.8 kΩ pull down resistor.

For addressing, the I2C communication of the ATS system used an eight bit addressing system and a single byte transmission paradigm. With eight bit addressing, the ATS system is capable of supporting up to 127 different addresses—one bit is dedicated to read/write. With single byte data transmission, no additional conversion is needed to convert data types from the UART signal to the I2C data signal. Since there were only four MCUs implemented, the ATS system has the capability of adding more features if needed. For this system, UART to I2C is addressed to 60 hex, servo controls is addressed to 70 hex, secondary controls is addressed to 80 hex, and capacitive touch is addressed to 90 hex. The above data is summarized in the below table.

I2C Bus Specifications		
	Clock Line	**Data Line**
Voltage	5 volts	5 volts
Pull Down Resistor	1.8 kΩ	1.8 kΩ
Clock Frequency	100 kHz	NA
	Address (Hex)	**Master/Slave**
UART to I2C	60	Master
Servo Controls	70	Slave
Secondary Controls	80	Slave
Capacitive Touch	90	Master

Table 8 – I2C Bus specifications

4.1.1.5 Microcontroller Tasks

Since there are multiple microcontrollers in the embedded system to control the ATS system, the option to have semi-parallel control was plausible implementation. Although implementation was more complex than a single microcontroller implementation, the overall performance gained appeared to be significantly faster. With a multiple microcontroller implementation, the system was able to transmit commands to different MCUs without needing to fully interrupt any other process of another microcontroller. For example, the servo motor microcontroller was able process the state of updating while the angle without having to completely move through the I2C interrupt vector when a trigger command was transmitted to the secondary controls MCU. Although the servo motor MCU was briefly interrupted to process the address byte, it did not have to proceed to receive data, update the trigger, then continue to updating the ATS angles.

With four MCUs implemented, each MCU was able to have its own dedicated task. The UART to I2C converter MCU literally converts incoming UART signals from the laptop to I2C bus data for the embedded system. The servo motor controller is responsible for updating the PWM signals for the servo motors. The secondary controls MCU is responsible for changing the trigger timing and toggling the alarm. The capacitive touch controller MCU is responsible for waiting for user input and transmitting said input. The methodology is discussed in more detail in the sections below.

4.1.1.6 UART to I2C Conversion MCU

The UART to I2C converter is a MSP430G2231 microcontroller that was provided with the MSP430 launchpad development kit. This MCU has an operating voltage of 3.30 volts and a master clock frequency of 1 MHz. The primary responsibility of this MCU is converting incoming UART signals from MAX232 IC and transmitting said data to the I2C bus shared with the remaining three microcontrollers. Although there is code flashed onto the microcontroller for transmitting back to the laptop computer, the since the ATS system did not need to transmit back to the laptop computer, this feature is simply skipped.

When the UART to I2C converter initially receive power, the MCU initializes by configuring the master clock to 1 MHz and the sub master clock to 125 kHz. The 1 MHz master clock (MCLK) is responsible for executing the flashed code. The sub master clock (SMCLK) is used for synchronous timing of the I2C bus. Because of limitations of the MSP430 clock features, the SMCLK is only able to be equal to the MCLK divided by division of one, two, four, or eight. For future reference, implementing a I2C bus using the clocks of the MSP430 can be difficult without an external master provided a variable clock line.

After configuring the clocks, initialization continues by disabling the watchdog timer. The watchdog timer on the MSP430 is responsible for resetting the MCU in the case of a hang. This functionality was simply disabled for implementation purpose. The initialization continues by configuring pins P1.1 and P1.2 for UART TxD and RxD respectively. Pin 1.0 is configured four output for a transmission status LED. Pins P1.6 and P1.7 are used for the data and clock line for the I2C bus. During initialization, the MCU also clears the buffer used for transmission.

After initialization the MCU immediately hits the WaitForData where the microcontroller waits for incoming UART data. When UART data is received, the MCU enters an interrupt vector where it receives eight bits of data. This microcontroller then determines if the data it receives is greater than 121. If the incoming data is greater than 121, the I2C addresses changes to the secondary controls MCU, otherwise the address is set to the servo motor controller MCU. After determining address, the MCU immediately transmits the data to the I2C bus via a separate interrupt vector. During the UART interrupt vector, Pin P1.0 goes high to turn on the LED. After both interrupt vectors are completed, the MCU continues to wait for data. This software flow is summarized in the flowchart below.

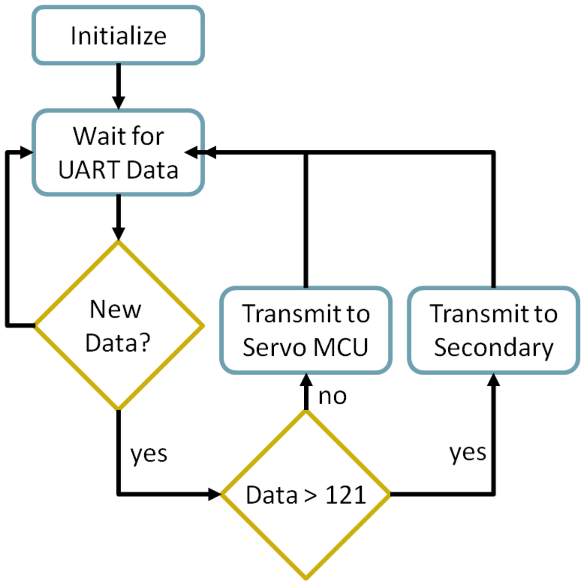


Figure 6 - UART to I2C Conversion MCU flow chart

4.1.1.7 Servo Motor Control MCU

The servo motor control MCU is a MSP430G2452 microcontroller that was provided with the MSP430 capacitive touch booster pack. This MCU has an operating voltage of 3.30 volts and a master clock frequency of 1 MHz. The SMCLK, although not used, is set equal to the MCLK. The primary responsibility of this MCU is updating the angles for the ATS system based on incoming data. In addition, this MCU has secondary responsibilities for saving calibration data.

The primary responsibility of this microcontroller is update the PWM lines for position the servo motors in 64 positions for the X angle, and 48 positions for the Y angle. The values 64 and 48 were obtained by dividing the incoming video stream of 640 by 480 pixels by a value of 10. There are two major components in creating these PWM signals, the frequency and the positive duty width.

To obtain a 50 Hz cycle, as specified by the servo motor manufacturer, timer A of the MSP430 was used. Timer A has various methodologies, but the method used to control PWM lines was the “Up To” mode. This mode counts clock cycles up to the value in the Timer A CCR0 register. The positive duty width is stored in either the Timer A CCR1 or Timer A CCR2 registers. The CCR1 and CCR2 registers can both be used at the same time and are configured to work as PWM lines on Pins P1.2 and P1.4 respectively. In order to select these pins at PWM lines, the MSP430G2x52 datasheet states that P1SEL = BIT2 + BIT4 and P1SEL2 = BIT4. To obtain a 50 Hz cycle, a value of 20,000 was stored into register CCR0. This value is obtained by dividing the master clock frequency by the specified frequency of 50 Hz.

The values stored in registers CCR1 and CCR2 are a little more involved in that obtains on both the calibration data and the desired angle provided by the laptop computer. When the MCU initializes, one of steps it takes is determine the maximum and minimum pulses in both the X and Y direction. The methodology of determining these pulses is discussed further ahead. With the known maximum and minimum pulses, the difference can be divided by the desired resolution, 64 for the X angle and 48 for the pitch angle. This value is then multiplied by the current angle and the minimum pulse is added. This follows a basic linear slope formula and can be seen in the equations below

$$CCR1 = \frac{YMaxPulse - YMinPulse}{48} * YAngle + YMinPulse$$

$$CCR2 = \frac{XMaxPulse - XMinPulse}{64} * XAngle + XMinPulse$$

Observing the above equations, the only unknowns are the YAngle and XAngle. These angles are easily processed by the incoming data on the I2C bus.

As mentioned previously, the secondary responsibility of the servo motor controls MCU is to calibrate the pulses. Calibration is handled by storing the maximum and minimum pulses into the MSP430 built in flash memory. Conveniently the values stored in the Timer A registers are all milliseconds. This causes the pulses to range between approximately 900 milliseconds to 2400 milliseconds. This led to the requirement of saving four, 16 bit integers into flash memory. However, the MSP430 flash configurations only allowed writing a single byte at a time. The workaround for this was to create a separate C function that took in two integers passed in by value. One integer corresponded to the actual pulse value while the second integer corresponded to the address in flash memory. These pulses were stored in the range of memory between 0x1040 and 0x1047.

In order to calibrate the pulses correctly, additional commands were needed to control the pulse width directly since angle commands never exceed the maximum and minimum pulse due to the equations defined above. These commands not only allow a user to move the turret via direct pulse changes, but also allow the user to save these pulses externally without having to flash the microcontroller. Controlling the PWM lines via direct pulses are controlled by commands 114 to 117 and saving said pulses are controlled by commands 118 to 121. Furthermore when writing these pulse values to flash, the microcontroller automatically updates these maximum and minimum pulses, so there is no need for a hard reset.

The actual programming flow of this microcontroller resembles a finite state machine commonly used in FPGA implementations. When the microcontroller starts, it immediately initialize by configuring the MCLK and SMCLK to 1 MHz. The MCU then disable the watch dog timer (WDT). The choice to disable the watchdog timer was more of a safety concern since the designers wished to avoid having the ATS system point to original position and immediately fire in case of any hangs. After disabling the WDT, the MCU immediately pulls the maximum and minimum pulses for both the X and Y angles from flash memory. Similar to writing the memory to flash, the same restriction applies in which only one byte is able to be read at a time. The workaround implemented was to simply logically OR one byte of memory with another byte of memory shifted left eight times. After this, the MCU sets the angle to half the resolution in either the X or Y angle in order to point the ATS system straight ahead. The final step of initialization is to configure pins. Pin P1.0 is configured to output for a status LED. Pin 1.2 and P1.4 are configured to outputs with the pin one select lines configured for PWM signals. Pin 1.6 and 1.7 are configured for I2C clock and data lines.

After initialization, the MCU immediately enters a wait for data loop assuming no reset occurs. The wait for data loop is a simple while loop that checks if the current state of the MCU is to wait for data. The popular alternative entering a low power mode while waiting for a I2C interrupt was ignored due to a bug that would cause the MSP430 to become stuck in a low power mode when jumping to an interrupt vector in a separate source file. If a I2C interrupt occurs, the MCU immediately enters a interrupt vector to receive the data and the MCU state changes to decoding data.

The decoding data state is largely based on how the data is encoded by the command codes. Since all data was constrained to a single byte of data, some form of extracting information was developed. The decode data state calls a function which determines the value of the newly received data. If the data falls between zero and sixty-four, the MCU recognizes an X angle change. If the data falls between a 65 and a 113 the MCU recognizes a Y angle change. The X angle is determined by simply setting the variable XAngle equal to the received data. The Y angle is determined by simply setting the variable YAngle equal to the difference between the received data and 65. The decode function also allows functionally for calibration. During decoding, no actual data is changed besides the angles. Instead, decoding data actually changes the MCU state. Decoding data was determined by using a simple if else control statement where angle changes, commands 0 to 113, were processed first to reduce latency effects.

After decoding the data, a new MCU state was called that is dependent on the data received. The MCU then enter one of the following states: update x angle, update y angle, decrease x pulse, increase x pulse, decrease y pulse, increase y pulse, save min x pulse, save max x pulse, save y min pulse, or save y max pulse. Each state is fairly literal and calls similar functions but with different pass by value integers. After one of these states is completed, the MCU begins to immediately wait for data once again. This entire process is summarized in the simplified flow chart below.

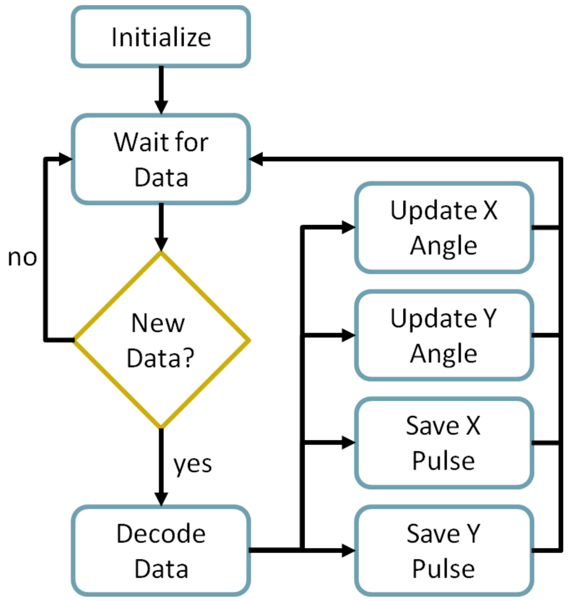


Figure 7 - Servo Motor Control MCU flow chart

4.1.1.8 Secondary Controls MCU

The secondary controls microcontroller is a MSP430G2231 microcontroller that was conveniently included as a spare microcontroller in the launchpad development kit. The operating voltage of this MCU is 3.30 volts and the master clock is set to 1 MHz while the sub master clock is set to 125 kHz. The MCLK is responsible for clocking the microcontrollers flashed code while the SMCLK is used to simulate automatic trigger functionality for the electronic solenoid of the paintball gun.

The secondary controls microcontroller is responsible for controlling the electronic solenoid and turning the hardware alarm off or on. The electronic solenoid timing function uses the Timer A registers built into the MSP430. The MSP430G2231 only has two captures and compare registers which allow for one PWM line to be controlled. This PWM line is located on pin P1.2. The electronic alarm is controlled by turning a single pin low or high, similar to turning on a LED off or on. However due to the voltage requirements of the solenoid and trigger, the devices do not directly interact with the MCU pins.

The hardware alarm implemented into the embedded system has an operating voltage between five volts and fifteen volts. The electronic solenoid implemented has an operating voltage of approximately nine volts—this was determined by an oscilloscope. According to the MSP430 datasheet, the MCU is not able to output such voltages. Instead, the pins used to implement these devices are connected to the base of a BJT. For the trigger, the positive lead of the trigger is tied to the collector of the BJT and ground is tied to the emitter and ground of the microcontroller of the BJT. With this implementation in place, the BJT simulates the mechanical switch found on the trigger. For the alarm, positive and negative leads of the alarm are placed on the collector. The collector is also powered with a positive five volt Vcc provided by a switching regulator. The emitter of the BJT is tied to ground. This set up allows the alarm to simulate a load whenever the base goes high. In both configurations, a 3.6kΩ resistor is implemented for an approximate 1 mA biasing current.

As previously mentioned, the electronic trigger is simulated using the timer functions of the MSP430. For this MCU, the timer A is configured for the count up to mode similar to the servo motor microcontroller. However, instead of using the MCLK as source clock, the SMCLK is used as the source clock. The SMCLK is used for two reasons. The first is that the extra resolution provided by the MCLK was not needed. The second reason was a personal preference to have lower numbers stored into the capture and compare registers. The value stored into the CCR0 register was hardcoded to be 5000. The value stored into the CCR1 register was recorded to be 1000. This allowed the paintball gun to fire at a maximum rate of 125,000 / 5000 or 25 shots per seconds. This rate can be adjusted using the dip switches located on the electronic trigger if a slower fire rate is preferred. Using this configuration allows the trigger to be turned off, fire a single shot, fire a burst of approximately five shots, or fire at a simulated automatic fire rate. These modes are controlled by sending a 124, 125, 126, or 127 to the ATS system via a laptop computer.

The alarm can be turned either on or off. Functionality for a pulse alarm is not available since the two captures and compare registers were already implemented for the trigger functionality. However this was not a concern since a pulsing alarm provided a larger nuisance than having it fully on or off. The alarm can be turned off by sending a 122 and turned on by sending a 123 from the laptop computer.

Similar to the servo motor MCU, the secondary controls microcontroller resembles a finite state machine. When the microcontroller is powered, it first initializes by configuring the MCLK and SMCLK. During initialization the values along port one are cleared. This is to make sure the alarm or trigger do not accidently proc during start up. Additionally the watchdog timer is disabled and the pins are configured. Pin P1.0 is used for a status LED. Pins P1.2 and P1.4 are used for the trigger and alarm BJTs respectively. Pins P1.6 and P1.7 are reserved for I2C communication.

After initialization, the MCU enters a wait for data state where it enters a while loop constantly checking the MCU state. If data is received on the I2C bus, the MCU enters the decode data state. The decode data state has the same functionality found in the servo motor control MCU but with command codes that correspond to secondary controls. After decoding the data, the MCU enters one of the following states: turn alarm off, fire a single shot, fire a burst shot, turn on automatic fire, turn alarm off, and turn alarm on. The MCU then returns to the waiting for data state. Due to low power bugs, the secondary controls MCU should never enter a low power mode while waiting for data. This flow is summarized in the flowchart below.

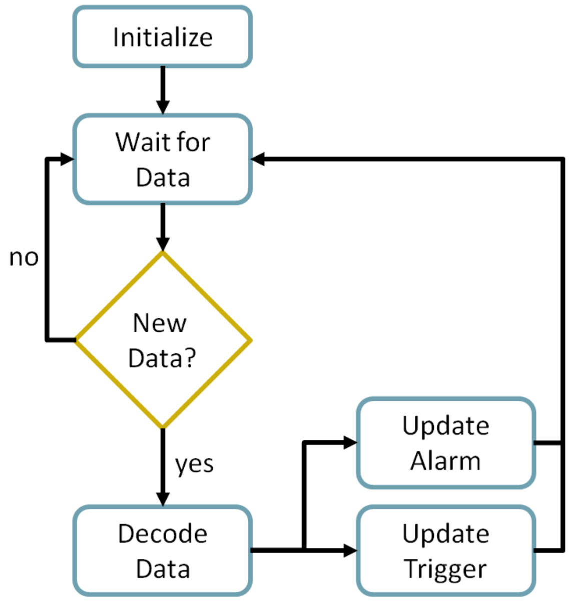


Figure 8 - Secondary Controls MCU flow chart

4.1.1.9 Capacitive Touch MCU

The capacitive touch microcontroller is a MSP430G2452 that was included in the capacitive touch booster cap. This MCU has an operating voltage of 3.30 volts. The MCLK operates at 1 MHz and the SMCLK operates at 125 kHz. The MCLK is used to process the code flashed to the MSP430. The SMCLK is used to provide a clock when transmitting along the I2C bus. The primary responsibility of the capacitive touch microcontroller is to wait for user input on the capacitive touch surface and transmit the updates to the either the servo motor controls MCU or the secondary MCU.

The capacitive touch features uses a combination of Texas Instruments built in API from the capacitive touch library and self generated functions. The cap touch API is used to return the raw capacitance and provide data structures supporting the capacitive touch surface.

Controlling the ATS system via the capacitive touch surface is fairly straightforward. If a user taps the surface in either the up, down, left, or right direction, the sentry moves in the corresponding direction. Instead of changing the angles, however, the cap touch MCU transmits direct pulse changes similar to calibration. This allows a user to have the freedom to push the servo motors beyond the calibrated width based off the webcam. If the user taps the surface in the middle, paintball gun toggles between turning off and on automatic fire. This is accomplished by transmitting commands between 114 to 117 to the servo motor controls MCU and either 124 or 126 to the secondary controls MCU.

Similar to the servo controls MCU, the cap touch MCU follows a finite state structure. When the MCU initially receives power, it immediately enters an initialization state. During this initialization, the microcontroller configures the clocks, disables the watchdog timer, and configures the pins. In addition to configuration, the capacitive touch takes an initial raw capacitance and stores those values to an array. At this time, it is best to avoid touching the capacitive touch surface.

After initialization the microcontroller enters a wait for user input state. During this state, the MCU constantly cycles through the various buttons on the capacitive surface and taking measurements. If a measurement exceeds a hardcoded threshold, the MCU assumes a touch occurred and immediately switches states to transmit the corresponding data. After transmission the microcontroller continues waiting for user input. This process summarized in the flowchart below.

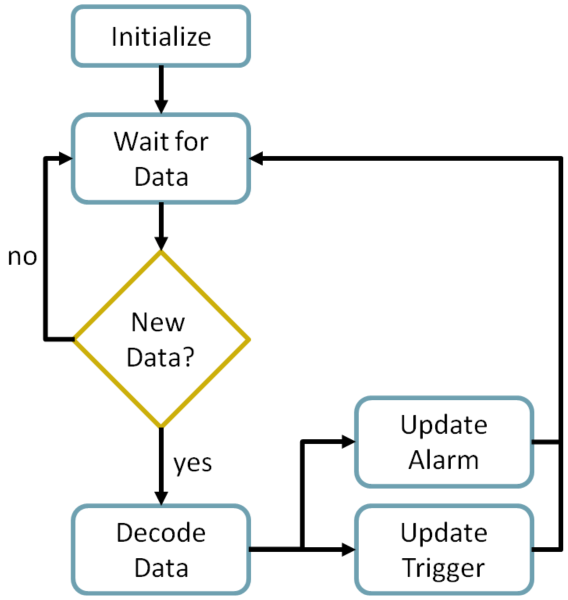


Figure 9 - 8 Capacitive Touch MCU flow chart

4.1.1.10 Laptop and Embedded System Interfacing

In order to for the vision tracking software to communicate the hardware components of the ATS system, a software solution was implemented in addition to the RS232 to UART to I2C conversion hardware. The solution implemented was to create two separate software programs. One program created reads commands from the vision tracking software and outputs said commands to the serial port. The second program created is used for calibrating the ATS system.

4.1.1.11 ATSCOM

ATSCOM is a program developed in Microsoft Visual Studio 2010 and written in the C++ programming language. ATSCOM is separate from the vision tracking software partly in due to OpenCV conflicts. ATSCOM uses .NET Framework 4.0 and has the option common mode language runtime support enabled. The program uses Microsoft's system dynamic link library to provide access to the System IO classes.

After starting the ATSCOM program, a command line immediately opens and asks the user to select a COM port. If the serial port is plugged into the computer and all appropriate drivers are installed, the software recognizes all connected ports. If the user has multiple USB devices connected, multiple COM ports may be listed. If this case is true, which is highly likely, a user has the ability to check the COM ports in the computer management section for a Windows based operating system. If the COM port needed is 5, the user enters COM5 and presses enter.

Due to conflicts, the communication software is a separate program. Due to the complexity of shared memory and threading in a Windows environment, the preferred method to pass data was via text files. Although simple, the text file method proved to be quick and reliable during testing. ATSCOM reads in values such as angles and trigger settings as integers. If there is a change in angle, trigger, etc, then the program converts the integer to a single byte, encode the data based on the commands codes, and write the data to the serial port. Due to limitation found during testing, only signed chars are allowed to be written to the serial port. A slight delay is introduced between each transmission to prevent writing to the UART to I2C converter too quickly. Due to conflicts of two programs attempting to open a serial port, ATSCAL and ATSCOM cannot use the same serial port at the same time.

4.1.1.12 ATSCAL

ATSCAL is a separate standalone program also written in Microsoft Visual Studio 2010 and written in C#. ATSCAL was primarily designed by using the windows form application setting. This allowed for easy programming in that no additional Windows programming was needed to create a GUI. The GUI features a combination of buttons and text boxes. In addition, the application uses a public serial port so that all buttons and text boxes have access to transmitting to the embedded system.

The primary purpose of ATSCAL is to calibrate the ATS system. Calibrations are needed for a variety of reasons including a new webcam, a change webcam position, or the rare event when the base "slips." The GUI features buttons for directly changing the pulse width of the servo controls MCU, saving the pulses, and changing the angle. Additional buttons were added for turn the alarm off or on and changing the trigger function. These additional buttons were mostly created for testing purposes. The user also has the ability to change the COM port if multiple devices or ATS systems are connected. However, if no device is connected, the program will close and display a message stating the case. Due to conflicts of two programs attempting to open a serial port, ATSCAL and ATSCOM cannot use the same serial port at the same time. The GUI can be seen in the figure below

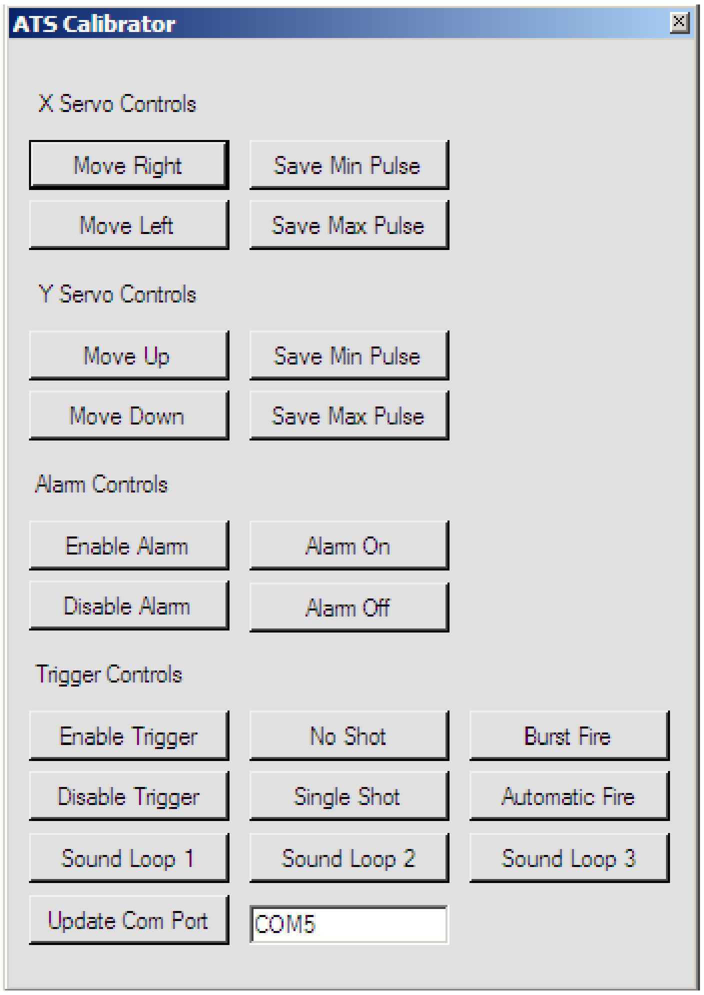


Figure 10 - ATSCAL GUI

4.1.2 Servo Motor Selection and Acquisition

In order to effectively control the autonomous turrets, a system of two servo motors was incorporated. One servo motor is dedicated to controlling the pitch of the turret, and the second servo motor is dedicated to controlling the yaw of the turret. For the below, all prices were estimated using servocity.com. Servo motor acquisition is discussed at the end of this section.

When choosing the appropriate servo motor, there are multiple parameters to keep in mind. The primary servo motor parameters include torque, speed, dimensions, stock angle of rotation, power input voltage, input signal voltage, and gear type. Concerning torque, there are multiple servos ranging from 11 oz-in up to a monstrous 611 oz-in. The torque must not only be high enough to hold the paintball gun, but the base of the turret and the ammo for the paintball gun as well. In general, servo speed is measured in seconds per 60 degrees of rotation. The dimensions each servo was an important factor to consider since the base was designed around the dimensions of each servo. Most stock servo motors only rotate 90 degrees in one rotation with the option to rotate 180 degrees at an increased cost. For the yaw, the servo motor rotation must be greater than 90 degrees but less than 180 degrees in order to maximize field of view while still being able to utilize the built in closed-loop system of the servo. The input power voltage was noted in order to know which voltage regulator to implement for powering the servo motors. The input signal voltage must be noted in order to know what voltage the microprocessor must output and if the need for an amplifier is needed. For the prototype, standard nylon gears were more than adequate. This offered a wider range of servo selection at a reduced cost.

For the pitch, a moderate speed servo with high torque within a reasonable price was sufficient. The angle of rotation should be 90 degrees in order to provide a reasonable firing angle while still keeping a minimum cost. The first option was a Hitec HS-8055BB Mega power servo motor. **[41]** The HS-8055BB is an analog servo with 274.96 oz-in torque, a moderate speed of 0.19 seconds per 60 degrees and a cost of $39.99. Another option was a HS-5805MG servo. The HS-5805MG is a digital servo with a torque of 274.96 oz-in torque, a moderate speed of 0.19 seconds per 60 degrees, and a cost of $79.99. The third option was a Futuba S3306 servo. The S3306 is an analog servo with a torque 266.5 oz-in, a moderate speed of 0.20 seconds pre 60 degrees, and a cost of $39.99. The two Hitec servo motors offer a slightly higher torque and slightly higher speed than its Futuba counter parts. Between the HS-8055BB analog servo and the HS-5805MG digital servo, the only difference is the increase in cost. Although the HS-8505MG digital servo may be more accurate, the double in price was discerning. For this reason, the Hitec HS-8055BB analog servo is incorporated to control the pitch. The HS-8055BB has an operating voltage of 4.8 to 6.0 volts and a required pulse of 3.0 to 5.0 volt peak square wave.

For the yaw, a moderate speed servo with high torque within a reasonable price proved to be sufficient. The angle of rotation should be greater than 90 degrees, but less than or equal to 180 degrees. The first option is the Hitec HS-8155BB Mega Sail Arm. The HS-8155BB is an analog servo with a torque of 274.96 oz/in, a moderate speed of 0.19 seconds per 60 degrees, and a cost of $44.99. The HS-8155BB has a stock rotation of 140 degrees, but no option to rotate 180 degrees. **[42]** The second option is once again the Hitec HS-805BB Mega power servo. The HS-805BB servo rotates 90 degrees at stock but can be stretched to 180 degrees for a total cost of $49.99. Since most webcams do not have a 180 degree field of view, a servo rotating a full 180 degrees was not needed. In order to slightly reduce cost, the HS-8155BB Mega Sail Arm is incorporated to control the yaw. This servo has an operating voltage 4.8 to 6.0 and a required pulse of 3.0 volt peak square wave.

As previously mentioned, all servo motor prices were estimated using servocity.com. When actually purchasing the servos, there were multiple websites offering the chosen servos at different prices and shipping cost. Popular websites include ServoCity, Amazon, and HobbyHorse. Table 9 has a summary of the cost of each servo and shipping cost per order.

According to the frequently asked questions at the ServoCity website, all orders under $200.00 are shipped by the United States Postal Service and may take up two eight days. **[43]** If expedited shipping is needed, the customer must contact ServoCity by phone which may be a bit cumbersome during a time crunch. All orders under $200.00 have a shipping cost of $6.99. According to the ServoCity website, a Hitec HS-805BB servo motor cost $39.99 and a HS-815BB servo motor for $44.99.

At the Amazon website a Hitec HS-805BB servo motor cost $36.52, and a HS-815BB servo motor for $44.33. There are multiple shipping methods offered by Amazon including standard three to five business days and next day shipping. According to the help section at the Amazon website, standard shipping cost $4.99 per shipment.

At the HobbyHorse website a Hitec HS-805BB servo motor cost $39.99 and a HS-815BB servo motor for $44.99. Similar to ServoCity, the HobbyHorse website only has standard shipping readily available with no mention of the possibility of next day delivery. According to the shipping section at the HobbyHorse website, standard shipping cost $7.00 per order on all order under $125.00. **[44]**

Table 9 is a summary of the servo motor cost and shipping cost per order at three popular websites: servocity.com, amazon.com, and hobbyhorse.com. Amazon currently has the best deal on the HS-8055BB and HS-815BB servo motors. Hobbyhorse has the best deal on the Hitec HS-81 servo motor. However, since hobbyhorse has an additional $7.00 charge for shipping to purchase the HS-81 servo motor, the cost surpasses the $14.09 cost of the HS-81 servo motor from amazon.com. The cheapest method is to purchase the servo motors from amazon.com

Summary of Servo Motor Cost			
Servo motor	**servocity.com**	**amazon.com**	**hobbyhorse.com**
Hitec HS-805BB	$39.99	$36.52	$39.99
Hitec HS-815BB	$44.99	$44.33	$44.99
shipping per order	$6.99	$4.99	$7.00

Table 9 - Cost summary of servo motors

In summary, the pitch is controlled by a Hitec HS-805BB servo motor for $36.52, and the yaw is controlled by the Hitec HS-815BB servo motor for $44.33. Shipping cost $6.99 since servo motors were packed and shipped together. The total cost of the servos is estimated to be $99.93. All servo motors were originally purchased from servo city due to personal preference

4.1.2.1 Servo Motor Specifications

The Hitec HS-805BB servo motor has an operating voltage between 4.8 and 6.0 volts. With an operating voltage of 4.8 volts, the servo has a stall torque of 274.96.10 oz-in, a speed of 0.19 seconds per 60 degrees, and a 700 mA current drain. At an operating voltage of 6.0 volts, the servo has a torque of 343.01 oz-in, a speed of 0.14 seconds per 60 degrees, and an 830 mA current drain. Assuming the servo had a one inch arm, running the servo motor at 5.0 volts should theoretically meet the requirement for 91.5 oz-in. This servo requires a 3 to 5 volt peak to peak square wave pulse. The HS-805BB servo motor uses the standard pulse duration ranging from 900 microseconds to 2100 microseconds. A 900 microsecond pulse will set the servo motor to 0 degrees. A 1500 microsecond motor will set the servo motor to 45 degrees. A 2100 microsecond servo motor will set the servo motor to 90 degrees clockwise. Assuming the rotation in degrees is linear with the pulse width, the position can be estimated by pulse width = 900+40/3*A where A is the desired angle in degrees. The connector wire length is 11.81 inches, which was not long enough to reach the PCB. The remedy was to simply purchase a low cost servo extension. The HS-805BB servo motor is 2.26 inches high, 2.59 inches long, and 1.18 inches wide and weighs 5.36 ounces. The mounting hole diameter is unlisted but was assumed to be four 0.176 inch diameter holes.

The Hitec HS-8155BB servo motor has an operating voltage between 4.8 and 6.0 volts. With an operating voltage of 4.8 volts, the servo has a stall torque of 274.96.10 oz-in, a speed of 0.19 seconds per 60 degrees, and a 700 mA current drain. At an operating voltage of 6.0 volts, the servo has a torque of 343.01 oz-in, a speed of 0.14 seconds per 60 degrees, and an 830 mA current drain. It was assumed the servo had a one inch arm, running the servo motor at 5.0 volts should theoretically meet the requirement for 91.5 oz-in. This servo requires a 3 to 5 volt peak to peak square wave pulse. The pulse width duration is not specified which may cause an issue since this servo does not operate a standard ninety degrees. It is assumed that the servo motor operates similar to a standard ninety degree servo motor stretched to a length of 140 degrees. The HS-815BB servo motor is assumed to use the standard pulse duration ranging from 900 microseconds to 2100 microseconds. A 900 microsecond pulse will set the servo motor to 0 degrees. A 1500 microsecond motor will set the servo motor to neutral 70 degrees. A 2100 microsecond servo motor will set the servo motor to 140 degrees clockwise. Assuming the rotation in degrees is linear with the pulse width, the position can be estimated by pulse width = 900+60/7*A where A is the desired angle in degrees. The HS-815BB servo motor is 2.28 inches high, 2.59 inches long, and 1.18 inches wide and weighs 5.36 ounces. The mounting hole diameter is unlisted but was assumed to be four 0.176 inch diameter holes. These comparisons are below in table 10.

Summary of Servo Motor Specifications					
	HS-805BB		**HS-815BB**		
Oper. Voltage	**4.80**	**6.00**	**4.80**	**6.00**	**V**
Torque	275.0	343.0	275.0	343.0	**oz-in**
Speed	0.19	0.14	0.19	0.14	**S/60°**
Current	700	830	700	830	**mA**
Required Pulse	3.00	5.00	3.00	5.00	**V_{pk-pk}**
Pulse Equation	$900+\frac{40}{3}A$		$900+\frac{60}{7}A$		**μS**
Wire Length	11.81		11.81		**in**
Height	2.26		2.26		**in**
Width	1.18		1.18		**in**
Length	2.59		2.59		**in**
Hole Diameter	0.176		0.176		**in**

Table 10 - Servo Motor Specifications

4.1.2.2 Servo Motor Implementation

The connector wire for each servo has three pins. One pin is dedicated to the operating voltage which ranges from 4.8 to 6.0 volts. The operating voltage is discussed in detail further ahead. The second pin is dedicated to ground. This pin share common ground for all analog devices that require ground. The third pin is dedicated to the pulse width signal. This pin is discussed further ahead.

In order to function to the specifications provided online, the servo motors had to receive the appropriate operating voltage. A linear voltage regulator is capable of producing an output of a voltage between 4.8 and 6.0 volts. Assuming an operating voltage of 5.0 volts, a commonly used linear voltage regulator would be the LM7805 from National Semiconductor. According to the national semiconductor datasheet, the minimum input voltage to maintain regulation for the LM7805 is 7.5 volts. Assuming the operating voltage for the servo motors is at 5 volts, the minimum voltage drop across the LM7805 would be 2.5 volts. While operating at 5 volts, the servo motor required approximately 750 milliamps. The current going into a linear voltage regulator can be estimated to the current going out of the linear voltage regulator, or approximately 750 milliamps for the pitch and yaw servo motors. The power dissipated across the LM7805 is approximately 1.875 watts.

Power dissipation in the watts range is somewhat problematic for a linear voltage regulator. According to the LM7805 datasheet, the maximum power dissipation can be calculated from the formula below. Since the LM7805 could have been in a somewhat enclosed box possibly outside, the ambient temperature, TA, can be approximated to 35 degrees Celsius. From the datasheet, the maximum junction temperature, TJMAX, is equal to 125 degrees Celsius, and the junction-to-ambient temperature is equal to 39 degrees Celsius per watt assuming no heat sink. From the equations below the maximum power dissipation is 2.308 watts. This would theoretically work, however it was assumed that the input voltage was only 7.5 watts. The maximum input voltage before passing the maximum power dissipation is calculated to be 10.5 watts. If the entire PCB would be ran on a 12 volts power supply, the LM7805 linear voltage regulator would burn the instant the servo motors were required to turn. This is only assumed for the pitch and yaw servo motors. For the trigger servo motor, the maximum current drain is theoretically 280 milliamps. Assuming a voltage drop of 7 volts and current drain of 280 milliamps, the power dissipation is calculated to be approximately 1.96 watts, still within the max power dissipation of the LM7805. **[46]**

$$PDMAX = (TJMAX - TA)/\theta JA.$$

$$PDMAX = (125 - 35)/39$$

$$PDMAX = 2.308$$

The alternative to a linear voltage regulator is a switching voltage regulator. A switching regulator rapidly switches elements on and off so that the each element is neither fully conduction or fully switched off. This leads to extremely low power dissipation and the reason to why switching regulators was more suited for the high power dissipation environment caused by the servo motors. The main advantage to using the switching voltage regulator is its low power dissipation allowing the servo motors to be properly powered. Theoretically, all three servo motors were to be connected to the same switching voltage regulator. However, a large drawback is that the output caused a ripple voltage that needed to be properly filtered to prevent a constantly changing operating voltage and to prevent any possible electromagnetic interference.

Like linear voltage regulators, there is a wide variety of options to choose from. However, the switching regulator most familiar to the group is the LM2576 simple switcher voltage regulator from National Semiconductor. The LM2576 is a switching regulator frequently used in the electronics II laboratory at the University of Central Florida. According to the datasheet, the LM2576 has 3.3V, 5V, 12V, 15V, and adjustable output versions ranging from 1.23V to 37V. The LM2576 has a guaranteed three amp output current, which is much higher than the linear regulator counterparts. For this reason, the LM2576 was adjusted to 5 volts output to power the pitch and yaw servo motors. **[47]**

4.1.3 Base

Before designing the base, a large factor had to be decided before continuing. Similar to how a longer wrench is easier to turn that a shorter wrench because of the principle of torque, turning the base towards the outside of the base should be easier to turn. This will result into relieving some of the torque off the servo motors. The advantage to designing the base with reducing torque in mind is the possibility to increase the weight from the paintball gun ammo, compressed air tank, and the base itself. This will allow for a larger choice of sturdier and heavier base materials. However, the main disadvantage is the slower speed. In other words the tradeoff for reduced torque on the servo motor is the reduced speed in turning the base.

Alternatively the base can be designed with no plans to reduce the torque applied to the servo motors. The main advantage is the ease of designing the base is substantially easier while its disadvantage is the possibility of running into a torque issue once the base, ammo, and compressed air are attached to the paintball gun. The workaround for this is to offset the weight of the paintball gun is to have the compressed air tank attached to the stationary part of the base. The compressed air tank can be attached to the paintball gun by a simple hose. The weight of the paintball gun can be further reduced by simply reducing the amount of ammo loaded into the paintball gun at any time.

Considering the two options, the preferred method was to reduce the amount of torque on the servo motors by reducing the weight of the paint ball gun and base. Once again, the compressed air tank will be attached to a stationary part of the base and the amount of ammo will be limited. Considering the servo motors have a significantly higher torque than the estimated torque found in the research section, this method should be safe. Also, the torque can be increased or decrease by changing the operating voltage.

ATS is a hanging turret built from the front fork of a children’s bicycle. The bicycle fork provides the two axes required for implementing the pitch and yaw servo motors. The yaw is implemented by fitting a servo arm between the L-bracket that normally connects the steering of the bicycle to the front fork the motion is aided by the existing ball bearing located in the head stock. The pitch axis comes from the hub of the bicycle which is used normally to attach the spokes to the wheel of the bike. The servo was mounted on a plate welded to the fork and the servo arm was fitted between two screws on the gun mount. Just like the yaw the pitch motion is assisted by the ball bearings located in the hub. The gun mount is made out of a single piece of extruded aluminum attached to the hub with the use of two screws through the spoke holes. Grooves were cut in the aluminum to extend the solenoid valve wires to the gun's PCB at the top of the base. Finally the metal was powder coated flat black to match the gun and give the appearance that the turret and gun are one piece.

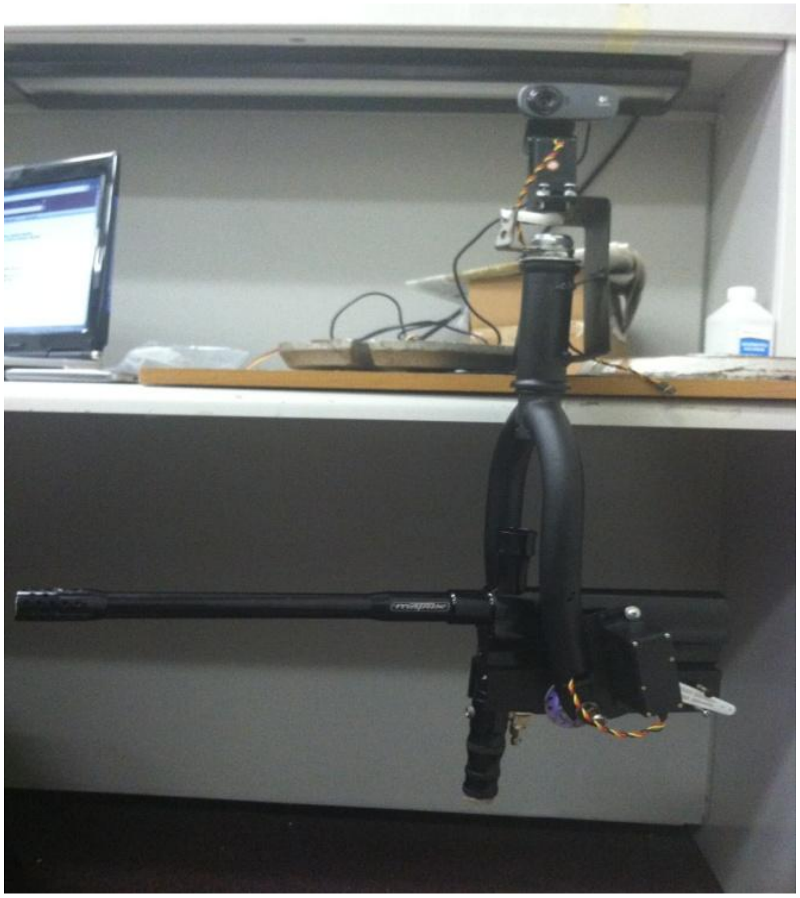


Figure 11 - Gun and Mount System

4.1.4 Power Source

The power source was an essential component for powering the ATS system. It was needed since the system was portable and self-sufficient. The battery chosen to power was the 12V sealed lead acid battery. Similar to a car battery, just significantly smaller, this battery had the ability provide enough voltage to ensure reliable energy to the ATS system.

Before designing and implementing the battery unit, the designers had to first determine where to place the battery. The top of the ATS system was to be a sufficient location for storage. This was an optimal position because in ideal situations the ATS system is to be hung from the ceiling. So the designers thought it would be optimal to store the battery, along with all other external components, up above the ceiling tiles. This has the functionality so intruders cannot access the essentials of the ATS system easily and cosmetically gives the ATS system a cleaner look since only the weapon system will be shown. By storing the battery and extra components above, in an isolated compartment, these components are protected from environmental issues that could potentially affect the performance of the electrical components. Also, the weight wasn't an issue, it actually aided the ATS system in the fact that it added extra weight to keep the system from toppling over the edge during demonstration. So this was an effective layout for several reasons, especially since the PCB was stored with the battery.

The implementation of the battery was be a simple connection to the PCB. The main components on the PCB that will need the energy provided were the microcontrollers and servo motors. The designers were able to just connect the battery via alligator clip connections to the PCB to provide power, and solder connections from the ground pin to ground the power. Once the power was implemented onto the PCB, the ATS system was essentially powered to perform as designed. Since the battery is 12 volts however, the use of regulators had to be implemented. The operating voltage for the servo motors was 5 volts and the microcontrollers operated on 3.3 volts. So the designers implemented a 5 volt and a 3 volt regulator respectively to ensure the battery didn't fry any electrical components.

The battery has the capability to recharge, so the direct connections to battery made it easy for the designers to disconnect and remove from the system. This was also if the owners decide to exchange the battery. To charge the battery, the designers purchased a charger that connected directly into the wall with both a positive and negative terminals for the battery. It was a simple charge, much like plugging in a phone charger. All of these connections had an isolative material, rubber, so the designers could easily remove by hand.

4.1.5 Alarm system

While designing the alarm system, a decision was made regarding the importance of sound volume. Since the ATS system needed to successfully warn the incoming targets, it was crucial that alarms were heard before being fired upon. To do this, the designers chose to implement two types of alarm systems, a continuous alarm as well as use the set of speakers from the lap top to play an audio file that can verbally warn incoming targets.

The first alarm was the continuous alarm. This alarm system’s loudness was based on the input current voltage, the higher the input current voltage resulted in a higher decibel level, making it louder and easier to hear from further distances. This alarm was directly connected to the microcontroller so when the software detects the incoming target, a signal was be sent from the microcontroller triggering the alarm. The connection was be soldered to one of the I/O pins directly. Like all electrical devices, a ground wire was be connected to a shared ground for all other devices. The designers also implemented a transistor to send the signal that would trigger the alarm.

The second alarm was the custom audio files that was to be played from the lap top speakers. The decision to implement this type of alarm system was because it has adjustable volume settings but mainly has the ability to verbally warn incoming targets that they are within firing distance. So when an object was being tracked by the system, the software triggered this alarm by playing a recorded audio file. This warning was intended for incoming humans so that they would properly understand the system's intent. The designers had the ability to play any desired audio file and would play the warning "I see you" when the software started tracking the incoming target. This was a more playful warning to entertain the designers but any audio file could be played to warn the intruders they are in a restricted area.

The designers choose to use both of these alarms systems to replicate real life alarm systems. Generally, when a continuous sounding alarm goes off, it is loud and high pitched, which usually initially grabs the attention of the audience. At the same time, verbal commands are to be announced warning of the imminent danger or providing specific instructions. For this reason, the designers of the system chose to implement both alarm systems.

4.1.6 Web camera

The web camera is typical camera but a vital component in the ATS system. It is the initial component in that kick starts the targeting. So the web camera needed to be properly implemented into the system to ensure the vision is provided to the laptop so the software detects incoming targets. The web camera was connected directly to the laptop via a universal serial bus (USB) cable, just like the mouse or a thumb drive is connected to a laptop.

On the other end of the cable, the camera itself was placed on the base to the side of the turret. It was looking in the direction of the barrel (when centered) but does not rotate with the gun. By doing this, the live video feed was streamed directly to the laptop giving the user a view of what the turret sees. This greatly increases accuracy because this method is the best way to keep the camera stable. So calculating the trajectory of the projectiles wasn't too complex so we saw an increase in accuracy due to stability.

4.1.7 Laser Pointer

The laser pointer was initially going to be connected through the microcontroller. This was to have its own dedicated to the operating voltage. Like every electrical component, the laser pointer was also going to tie to the ground pin, which was be shared for all devices that need to be grounded.

So, the laser pointer has an operating voltage between 3 and 4.2 volts. So in order for the design to meet this range, a linear voltage regulator was be used to manage the necessary voltages needed. The designers were going to adjust as necessary to ensure the laser pointer was performing to its abilities. Once satisfied, the laser pointer was then be tied onto the barrel of the gun. By doing this, laser pointer would aim down range towards incoming targets. **[51]**

However, the designers decided against this method because their rationale was to just demonstrate accuracy with the use of the laser pointer. So the designers just wedged the laser pointer down the barrel of the gun and had it continuously running off of its own battery power. When the laser pointer was on the target, the designers deemed that as a successful hit. This was sufficient enough to please the designers needs so just opted for this option.

Ideally, the shot should hit the exact location of the later pointer; however, just because the laser pointer was aiming down field doesn't mean the gun was to hit exactly where the laser was pointing to. This was caused mainly by the trajectory of the paintball. There are other factors that could affect the accuracy of the paintball such as distance and weather elements. The main objective was determining the prime location to attach the laser pointer onto the system. So the designers decided to place the laser pointer within the barrel to demonstrate where the projectile would impact the target. This concept was derived from the similar technologies used for tactical weapons used in the armed forces.

The major difficulty to determining this location was based off of two main reasons, distance from the barrel and angle. The slightest angle tilt would largely affect where the laser pointed further way from the gun system. Ideally, the laser pointer should be parallel to the barrel, the distance between the barrel and laser point would have affected the overall sights of the gun. So the combination of the two was what provided the greatest results. To achieve the most optimal positioning of the laser pointer, the designers went with the option of placing the laser pointer in the barrel to mimic the impact of where the shots would land. By doing so, the most targeting would be more efficient for demonstration purposes. This was discussed furthermore in the testing sections.

4.1.8 Paintball Gun Components

The following sections discuss the paintball gun components in further detail. A majority of the components are currently possessed such as the AirTech E-Matrix Paintball Gun, Co2 tank and hopper. Components such as the paintball ammunition, coil hose and Co2 gas will need to be acquired for the completion of the ATS system.

4.1.8.1 AirTech E-Matrix Paintball Gun

For the gun of the sentry an AirTech E-Matrix paintball marker was fitted to the base. The gun was a good choice because one was donated to the group. The marker is lightweight and capable of firing eighteen balls a second; the gun has very few moving parts so there is very little recoil. The trigger of the marker was removed and the circuit board of the gun was removed and triggered using a transistor to short two pins. The gun uses compressed air due to the problems Co2 can cause when firing at a high rate. To keep the base lightweight a hose was fitted from the tank to the gun. The gun also has a place to feed the paintballs through flexible tubing from a hopper fitted up top. It was imperative that the gun was maintained during testing; if the gun is not cleaned regularly to prevent jams and paint build up the paintballs could break in the barrel which would render the sentry useless. The gun is by not top of the line, but improvements can be made in the future by adding a longer barrel or mounting a new gun entirely. The gun is a great choice because it is lightweight, donated, and was used in the build to show functionality of ATS. Paintball marker being used is displayed in figure below.

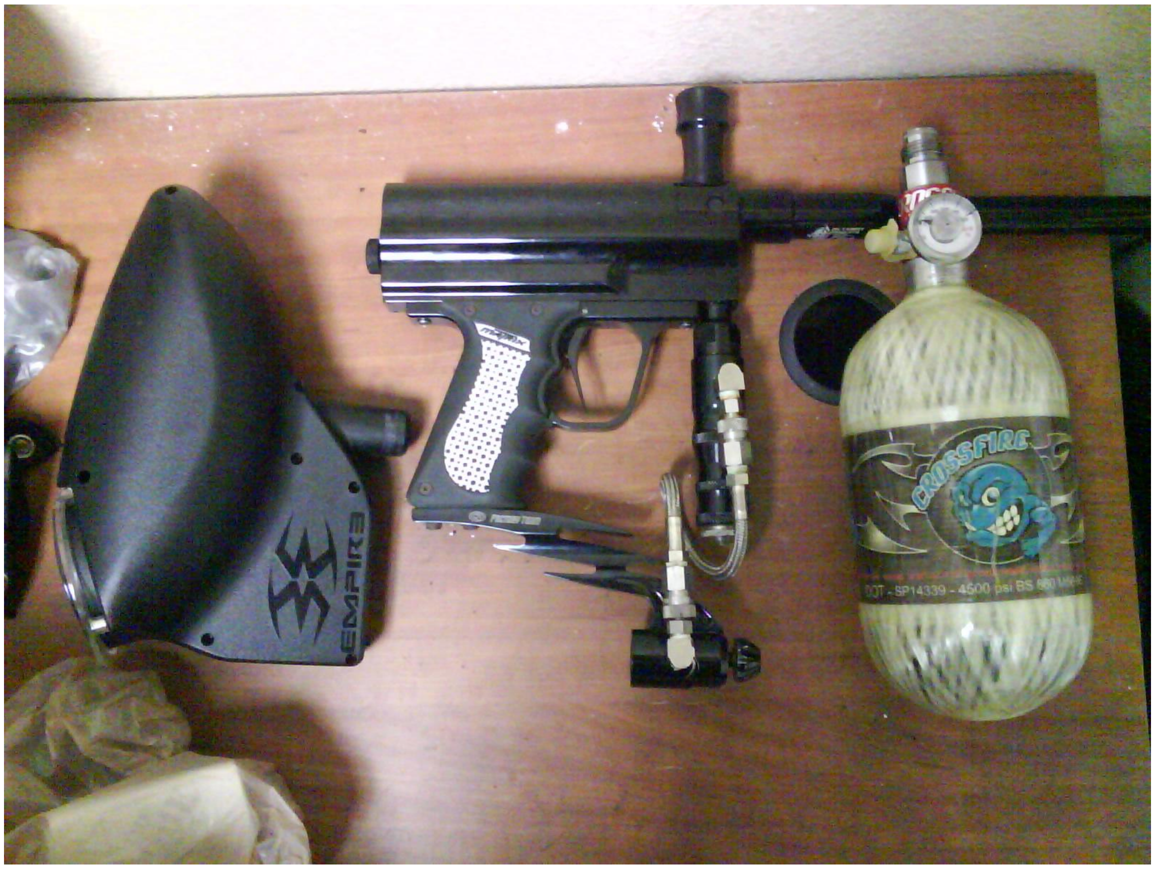


Figure 12 - Paintball marker, hopper, and high pressure air tank

4.1.8.2 High Pressure Air Tank

The nitrogen tank that used by ATS is a carbon fiber wrapped Aluminum Alloy tank. The tank is 68 cubic inches and filled to 4500psi. The tank provides enough air for about one thousand shots, this is highly dependent on how clean the gun is and the velocity the gun is set to. The tank is composed of an aluminum alloy cylinder and a valve. The tank can be refilled at any paintball place or scuba shop for fewer than ten dollars. A picture of the air tank is within figure 7, above.

4.1.8.3 Macrro Line Kit

In order to keep the base lightweight a coil hose was attached the air tank to the gun. The hose used for this project is sold in a macro line kit for about five dollars. **[52]** The hose was purchased from on Amazon and features many positive reviews giving an overall rating of four out of five stars.

4.1.8.4 Paintball Hopper system

The paintballs are fed to the gun by a tubing system. The halo hopper sits on top of a Warp Feed. The hopper stores balls that are fed to the Warp Feed which essentially pushes the paintballs down the tube to the gun. The hopper can hold 200 paintballs the team will initialize the ammo count to 200 and keep track of it as the gun is fired. Above, in figure 7, there is a picture of the paintball marker, hopper, and HPA tank can be seen.

4.1.8.5 Paintballs

Paintballs are the ammunition used by ATS. They are small gelatin capsules filled with non-toxic paint. Paintballs vary very much in size and quality. The paintballs needed for ATS must be .68 caliber balls. The quality of the paintballs is dependent on the hardness of the shell and the spherical shape. High quality paintballs are very thin so they break on contact and almost perfectly spherical. For the purpose of ATS the quality of the paintballs is not a high priority since the function of the turret is to show functionality. For testing purposes the group purchased a cheap case of RPS 05630 Stinger Paintballs, a 2000 ct. case sells for $24 on Amazon and other online retailers. **[53]** For demonstration purposes the group chose to shoot only air when presenting to the committee due to safety and an indoor demonstration.

The color of paintball the team has chosen also plays an important role in the project. Since ATS defines targets that are non-green as the enemy, green colored paintballs are used. Once the target is covered in a sufficient amount of green paint ATS determines that the target is no longer a threat and ceases fire. This is vital in saving ammunition and to avoid over firing on targets unnecessarily.

4.1.9 Printed Circuit Board

Before designing the printed circuit board, there was a fair amount of communication of which software and which board house to use. The CAD software of choice was the sixth revision of Eagle. The decision to use Eagle was largely in part of the simplicity to use, multiple online tutorials on generating

Gerber files for board houses, and the auto-route feature. The board house chosen was Colorado division Advanced Circuits provided on the 4pcb website. The primary reason for using 4pcb was primarily the low cost. For a student a standard two layer PCB cost $33.00 with an additional cost for shipping.

The PCB designed is a five inch by five inch two-layer board. In order to reduce the PCB size, the alarm and trigger are mounted separately but have terminal block connectors for connecting said devices. The board features a common ground plane for the microcontrollers, servo motors, MAX232 chip, trigger connections, and alarm connections. The trace width of signal lines, such as the I2C bus, PWM lines, etc, are set to ten mils with ten mils of clearance. The five volt power line is 35 mils to allow for high current draw from the servo motor. One microfarad filter capacitors are implemented for each microcontroller's Vcc.

The two switching voltage regulators along with the required inductors and capacitors are located at the top of the board. This allowed for adequate room for heat sinks and kept the hottest parts away from the microcontroller and capacitive touch surface. Power connection to the battery is located on the left side of the board. The four microcontrollers along with the I2C bus are located at the bottom left of the board. Two sets of three header pins are located at the bottom of the board for connecting the servo motors. The bottom right of the board is reserved for the capacitive touch surface, MAX232 IC, and the DB9 subd connector. In the four corners of the PCB, holes are drilled for motherboard mounting stand offs. Instead of directly connecting the MCUs, four IC dip sockets were soldered onto the board. This allowed for a user to easily flash the MCUs on the launchpad development board. The layout can be seen in the figure below.

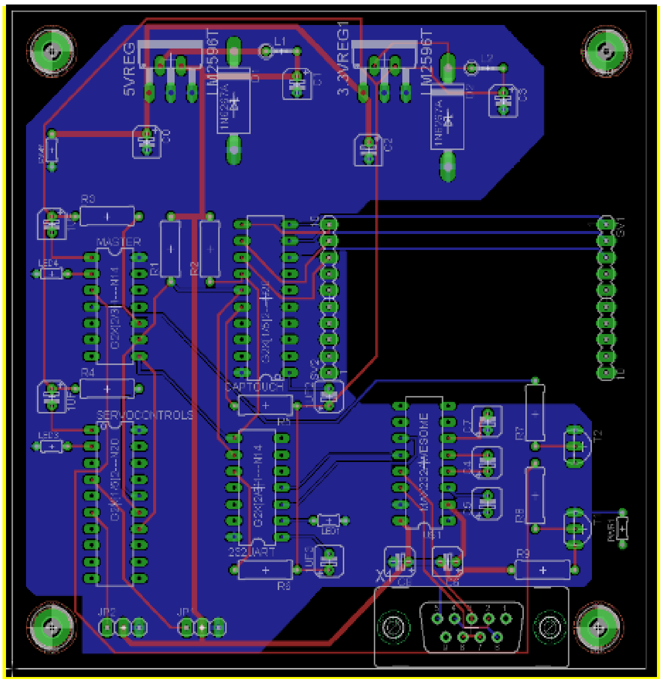


Figure 13 – Printed Circuit Board Layout

4.2 Software Design

Overall, computer vision is a new and constantly growing software field. In recent years, the popularity has grown dramatically. Also, with the help of open source software like OpenCV or Aforge.net, knowledge of computer vision and how it works has become easily accessible. The ATS' software consists of a computer vision application that makes decisions on whether or not to engage targets found within the field of vision based on the targets threat level.

In figure 9, the software activity diagram, the process that the ATS goes through to determine whether or not to fire is demonstrated. First, the web camera captures the video stream from the field of vision. This stream was brought into the program from the videoCapture class. The VideoCapture class then sets up the device with the program so grabbing frames from the stream was simple. Then that frame was taken into the cvtColor function. A traditional RGB image was transformed into an grayscale image, which made calculating optical flow easier.

Once the frame has been converted, it must then be searched for good features to track. This was done using an OpenCV algorithm. This function then passes the image and an array of corners to cornerSubPix. CornerSubPix then improves upon what was found in the previous function and return with it a corner count. At this point, objects have been detected and now need to be tracked once there have been two frames sent from the web camera. The algorithm chosen for ATS' computer vision application is the iterative Lucas-Kanade with pyramids. It calculates the optical flow for the sparse feature set that was sent to it from the previously described functions.

At this point, createTrackPoints is called to create all of the data from the optical flow algorithm. Then we generate targets from those by creating a bunch of TargetIDs. Next, we find which one has the most points and select it as the most important and primary target. Lastly, we sent out the data on a frame-by-frame basis in output files to be read by the communication program.

In the end, the videoWriter class writes what has happened to a file that is viewed later by the user of the ATS. The rest of the functions detailed in the software design are auxiliary functions used to complete various tasks to support the main functions of the computer vision application. For example, the rectangle and line drawing functions are used to demonstrate what the object being tracked actually looks like to the program when displayed on the user interface. Another extra feature was an alarm system. Once an object has been detected on the screen, an alarm plays, alerting the target that it is in range of the system. After a short period, the target was attacked until it left the field of vision of the ATS. **[24]**

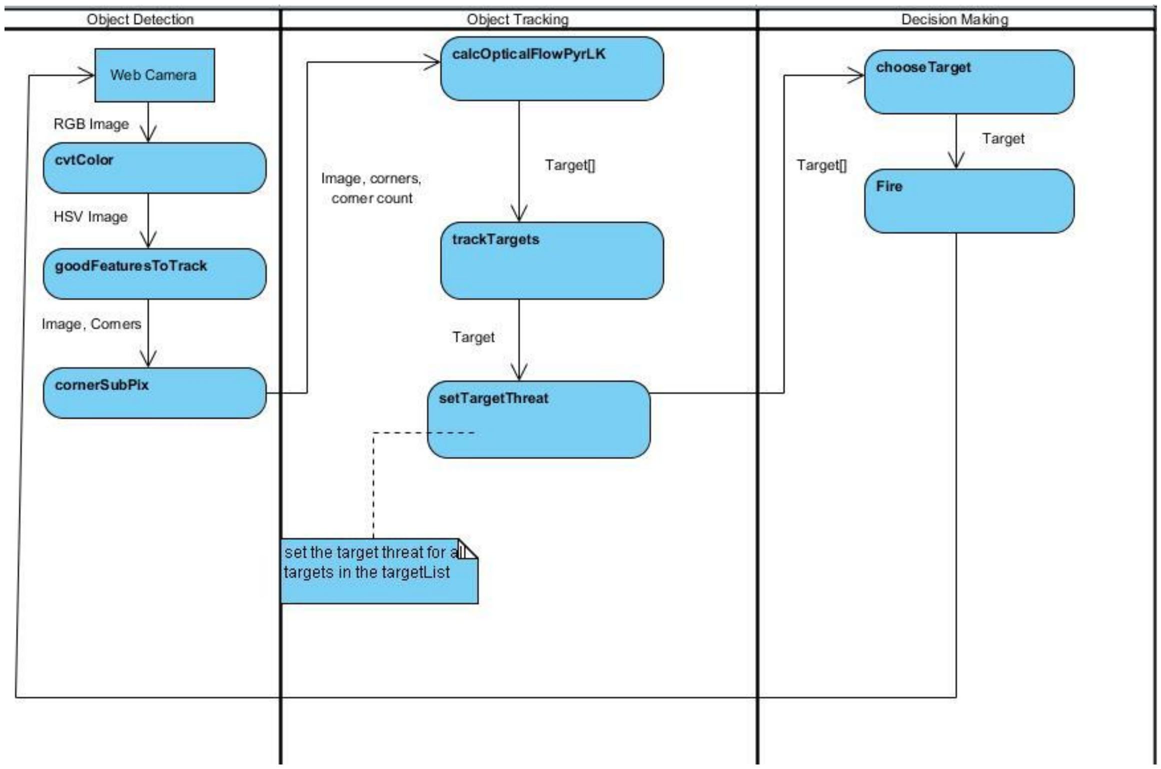


Figure 14 - Software activity diagram

The following figure 10 diagrams the process of the software development for the ATS. In each step of the process, the software developer returns to a previous section for further enhancement as needed. The system has already been analyzed and designed so the next step was to write code for what has been designed. Once the code was written, initial testing begins. Depending on how the testing went, the next iteration goes back to analysis, design, or coding. If all of the tests that were run were successful, then coding was continued. However, if something went wrong during the testing, and the system needed redesigning or the analysis of the system needed to be altered, then it is done. The process was iterative and constantly developed over time. Many of the phases were occurring simultaneously. To explain, someone was coding part of the program, while another member was testing a portion of the system. This modularity allowed for faster development and improved the ability for the system to be upgraded and maintained in the future. Once all test cases were been passed, the system still needed to be maintained so the process never really reaches an end. Other software development processes were considered, such as the agile method or the waterfall method, but neither of them fit well with the application of the ATS. Overall, it has been decided that this software development process provides the best solution to the specific application of the ATS.

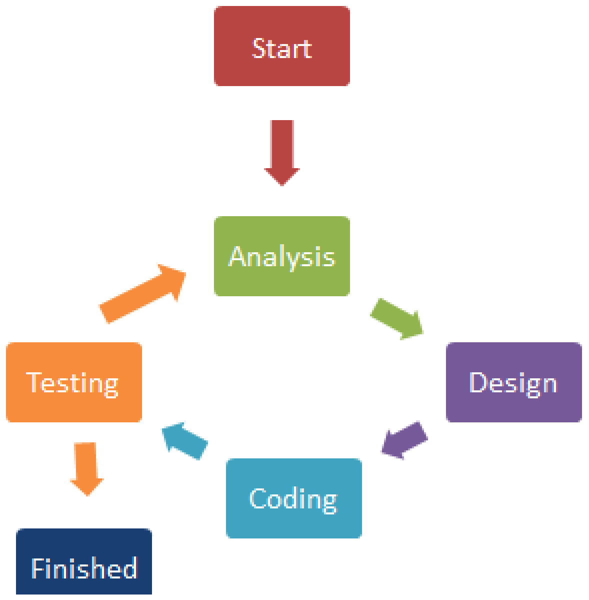


Figure 15 - Software development process

4.2.1 Object Detection Class

The Object Detection class directly followed the video Capture class in the code, but was the first class to be coded. This class relied heavily on OpenCV algorithms to detect objects and various features of those objects. It was also responsible for determining the color of each object so each target is be deemed as a threat or non-threat. To detect objects, in this specific case people are the objects, the goodFeaturestoTrack and cornerSubPix methods were used. The first of these two methods takes an image and finds all of the vital features of the image that stand out as objects (i.e. foreground objects). Then the cornerSubPix continues this process and refines the locations of each output from the previous method. Then the line or rectangle methods was used to draw those features on the image so the user sees what is happening during the object detection process on the user interface. As for the color detection part of the object detection, first a cvtColor function was used to convert the image from the standard RGB image format into a grayscale image. This is helpful because it is quite simple to track optical flow in a grayscale image.

voidcvtColor(InputArray**src**, OutputArray**dst**, int**code**, int**dstCn**=0)

Converts an image from one color space to another.

Parameter Name	Parameter Description
Src	Source image: 8-bit unsigned, 16-bit unsigned (CV_16UC...), or single-precision floating-point.
Dst	Destination image of the same size and depth as src
Code	Color space conversion code. See the description below.
dstCn	Number of channels in the destination image. If the parameter is 0, the number of the channels is derived automatically from src and code.

Target[ ] createTargets(frame **currImage**)

searches an image for targets.

Return value - a dynamic array of all targets found. If no target was found, null will be returned.

Parameter Name	Parameter Description
Points	The list of points that are being tracked for motion.

voidgoodFeaturesToTrack(InputArray**image**, OutputArray**corners**, int**maxCorners**, double **qualityLevel**, double **minDistance**, InputArray**mask**=noArray(), int**blockSize**=3, bool**useHarrisDetector**=false, double **k**=0.04)

Determines strong corners on an image.

Parameter Name	Parameter Description
Image	Input 8-bit or floating-point 32-bit, single-channel image.
corners	Output vector of detected corners.
maxCorners	Maximum number of corners to return. If there are more corners than are found, the strongest of them is returned.
qualityLevel	Parameter characterizing the minimal accepted quality of image corners. The parameter value is multiplied by the best corner quality measure, which is the minimal eigenvalue or the Harris function response. The corners with the quality measure less than the product are rejected. For example, if the best corner has the quality measure = 1500, and the qualityLevel=0.01, then all the corners with the quality measure less than 15 are rejected.
minDistance	Minimum possible Euclidean distance between the returned corners.
Mask	Optional region of interest. If the image is not empty (it needs to have the type CV_8UC1 and the same size as image), it specifies the region in which the corners are detected.
blockSize	Size of an average block for computing a derivative covariation matrix over each pixel neighborhood.
useHarrisDetector	Parameter indicating whether to use a Harris detector
K	Free parameter of the Harris detector.

voidcornerSubPix(InputArray**image**, InputOutputArray**corners**, Size **winSize**, Size **zeroZone**, TermCriteria**criteria**)

Refines the corner locations.

Parameter Name	Parameter Description
Image	Input image.
corners	Initial coordinates of the input corners and refined coordinates provided for output.
winSize	Half of the side length of the search window
zeroZone	Half of the size of the dead region in the middle of the search zone over which the summation in the formula below is not done. It is used sometimes to avoid possible singularities of the autocorrelation matrix. The value of (-1,-1) indicates that there is no such a size.
Criteria	Criteria for termination of the iterative process of corner refinement. That is, the process of corner position refinement stops either after criteria.maxCount iterations or when the corner position moves by less than criteria.epsilon on some iteration.

voidline(Mat&**img**, Point **pt1**, Point **pt2**, constScalar&**color**, int**thickness**=1, int**lineType**=8, int**shift**=0)

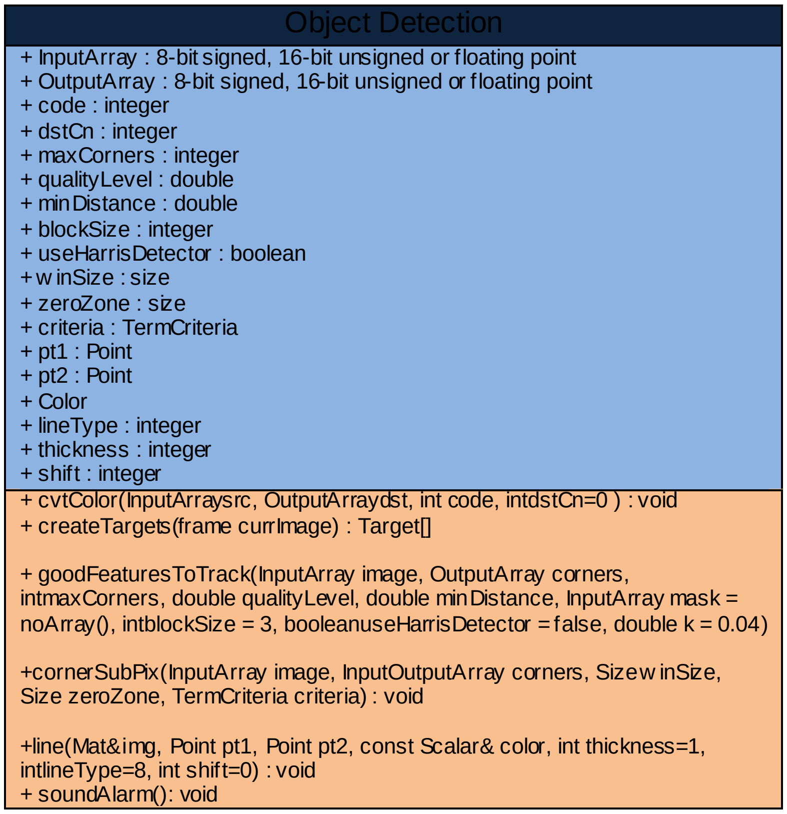
Draws a line segment connecting two points.

Parameter Name	Parameter Description
Img	Image
pt1	Vertex of the rectangle
pt2	Vertex of the rectangle opposite to pt1 .
Color	Rectangle color or brightness (grayscale image).
thickness	Line thickness
lineType	**8** (or omitted) - 8-connected line. **4** - 4-connected line. **CV_AA** – anti-aliased line.
Shift	Number of fractional bits in the point coordinates.

voidrectangle(Mat&**img**, Point **pt1**, Point **pt2**, constScalar&**color**, intthickness=1, int**lineType**=8, int**shift**=0)

Draws a simple, thick, or filled up-right rectangle.

Parameter Name	**Parameter Description**
Img	Image
pt1	Vertex of the rectangle
pt2	Vertex of the rectangle opposite to pt1 .
Color	Rectangle color or brightness (grayscale image).
thickness	Thickness of lines that make up the rectangle. Negative values, like CV_FILLED, mean that the function has to draw a filled rectangle.
lineType	Type of the line
Shift	Number of fractional bits in the point coordinates.



```
Object Detection
+ InputArray : 8-bit signed, 16-bit unsigned or floating point
+ OutputArray : 8-bit signed, 16-bit unsigned or floating point
+ code : integer
+ dstCn : integer
+ maxCorners : integer
+ qualityLevel : double
+ minDistance : double
+ blockSize : integer
+ useHarrisDetector : boolean
+ winSize : size
+ zeroZone : size
+ criteria : TermCriteria
+ pt1 : Point
+ pt2 : Point
+ Color
+ lineType : integer
+ thickness : integer
+ shift : integer
+ cvtColor(InputArraysrc, OutputArraydst, int code, intdstCn=0 ) : void
+ createTargets(frame currImage) : Target[]

+ goodFeaturesToTrack(InputArray image, OutputArray corners,
intmaxCorners, double qualityLevel, double minDistance, InputArray mask =
noArray(), intblockSize = 3, booleanuseHarrisDetector = false, double k = 0.04)

+cornerSubPix(InputArray image, InputOutputArray corners, Size winSize,
Size zeroZone, TermCriteria criteria) : void

+line(Mat&img, Point pt1, Point pt2, const Scalar& color, int thickness=1,
intlineType=8, int shift=0) : void
+ soundAlarm(): void
```

Figure 16 - Object detection class diagram

4.2.2 Motion/Object Tracking Class

The Motion/Object Tracking class was the next class after object detection to handle the image frames. The responsibility of this class was to take all objects detected from the object detection class and update their positions, velocities, ranges, and threat levels based on the differences found between the previous and current frames from the web camera. This task was completed by calculating optical flow using the iterative Lucas-Kanade method with pyramids which is detailed in the object and motion tracking research sections. The other major method of the motion/object tracking class is to track the targets once they have been created. This method was called later in the program once the targets have actually been created so it was implemented later than the other part of the class. OpenCV functions were used in this class to assist with the tracking. The trackTargets class was responsible for the physical updating of all of the variables for each target in the targetID[]. If the targetID[] is null, then it just returns immediately.

Void trackTargets(TargetID[] **targetList**, frame **prevImage**, frame **currImage**)

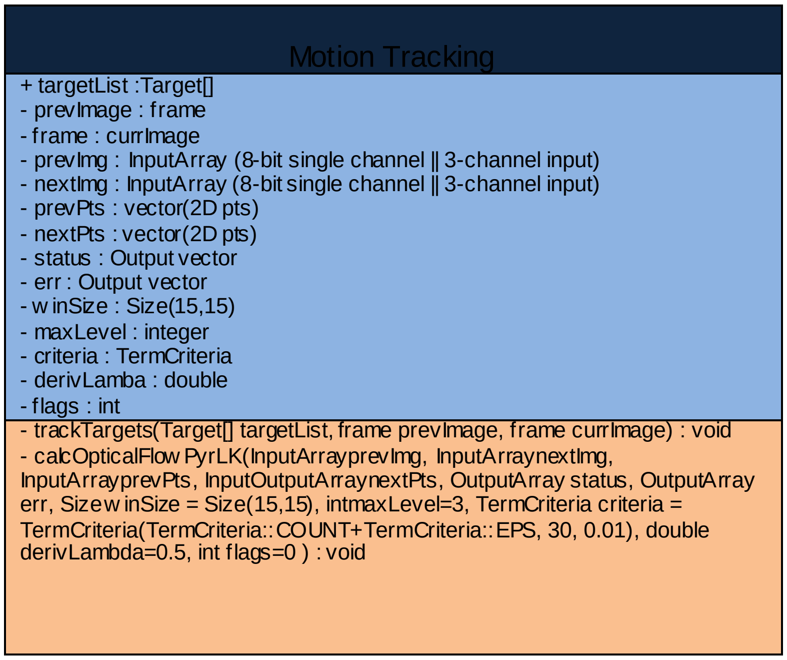
updates the positions and velocities of each target in the array.

Parameter Name	**Parameter Description**
targetList	the list of targets received from findTargets. If null, return.
prevImage	the last image from the video stream.
currImage	the current image from the video stream.

void calcOpticalFlowPyrLK(InputArray**prevImg**, InputArray**nextImg**, InputArray**prevPts**, InputOutputArray**nextPts**, OutputArray**status**, OutputArray**err**, Size **winSize**=Size(15,15), int**maxLevel**=3, TermCriteria**criteria**=TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, 0.01), double **derivLambda**=0.5, int**flags**=0)

Calculates an optical flow for a sparse feature set using the iterative Lucas-Kanade method with pyramids.

Parameter Name	**Parameter Description**
prevImg	First 8-bit single-channel or 3-channel input image.
nextImg	Second input image of the same size and the same type as prevImg.
prevPts	Vector of 2D points for which the flow needs to be found. The point coordinates must be single-precision floating-point numbers.
nextPts	Output vector of 2D points (with single-precision floating-point coordinates) containing the calculated new positions of input features in the second image. When OPTFLOW_USE_INITIAL_FLOW flag is passed, the vector must have the same size as in the input.
status	Output status vector. Each element of the vector is set to 1 if the flow for the corresponding features has been found. Otherwise, it is set to 0.
err	Output vector that contains the difference between patches around the original and moved points.
winSize	Size of the search window at each pyramid level.
maxLevel	0-based maximal pyramid level number. If set to 0, pyramids are not used (single level). If set to 1, two levels are used, and so on.
criteria	Parameter specifying the termination criteria of the iterative search algorithm (after the specified maximum number of iterations criteria.maxCount or when the search window moves by less than criteria.epsilon.
derivLambda	Not used.
flags	Operation flags: **OPTFLOW_USE_INITIAL_FLOW** Use initial estimations stored in nextPts . If the flag is not set, then prevPts is copied to nextPts and is considered as the initial estimate.


Motion Tracking

+ targetList :Target[]
- prevImage : frame
- frame : currImage
- prevImg : InputArray (8-bit single channel || 3-channel input)
- nextImg : InputArray (8-bit single channel || 3-channel input)
- prevPts : vector(2D pts)
- nextPts : vector(2D pts)
- status : Output vector
- err : Output vector
- winSize : Size(15,15)
- maxLevel : integer
- criteria : TermCriteria
- derivLamba : double
- flags : int

- trackTargets(Target[] targetList, frame prevImage, frame currImage) : void
- calcOpticalFlowPyrLK(InputArrayprevImg, InputArraynextImg, InputArrayprevPts, InputOutputArraynextPts, OutputArray status, OutputArray err, Sizew inSize = Size(15,15), intmaxLevel=3, TermCriteria criteria = TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, 0.01), double derivLambda=0.5, int flags=0) : void

Figure 17 - Motion Tracking class diagram

4.2.3 TargetID Class

The TargetID class creates targets with all of the necessary information that a target must possess to be tracked. Each target has a numPoints, topLeft, bottomRight, and an ID. The ID is a simple counting variable to differentiate all of the targets in the system and is incremented each time a new target is encountered. The position and velocity fields are just stored in the trackpoints that it consists of. They kept track of past values of their respective variables so an average is determined from the multiple values. The numPoints are used to calculate averages. The topLeft and BottomRight Point2fs are used to determine the size of the target. The only methods that the target class has are access methods that get and set all of the variables that a target possesses. This was coded after the trackpoint class but after the basic object detection and tracking classes are in place due to the need for the information of the target before one is created.

Variable Type	**Variable Name**	**Variable Description**
numPoints	Int	The number of points the targetID consists of.
topLeft	Point2f	The point that is the furthest upper-left of the targetID
bottomRight	Point2f	The point that is the furthest bottom-right of the targetID
int	targetID	an Identification number to keep track of all of the targets.

Position getnumPoints();

gets the number of points.

void incNumPoints();

increments the number of points.

Point2f gettopleft();

gets the top-left point of the targetID.

Void settopleft(Point2f **newpt**);

updates the topleft of the specified target.

Parameter Name	**Parameter Description**
Newpt	the new topleft of the target.

Point2f getbottomright();

gets the top-left point of the targetID.

Void setbottomright(Point2f **newpt**);

updates the bottomright of the specified target.

Parameter Name	Parameter Description
Newpt	the new bottomright of the target.

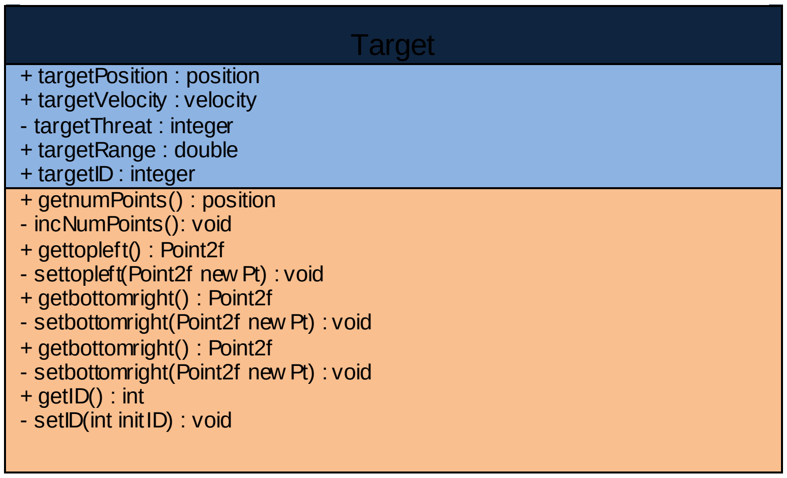
Int getID();

gets the ID of the specified target.

Void setID(int **initID**);

sets the initial ID of the target.

Parameter Name	Parameter Description
initID	the value of the ID for the target. 1 greater than the last target.


Target
+ targetPosition : position
+ targetVelocity : velocity
- targetThreat : integer
+ targetRange : double
+ targetID : integer
+ getnumPoints() : position
- incNumPoints(): void
+ gettopleft() : Point2f
- settopleft(Point2f new Pt) : void
+ getbottomright() : Point2f
- setbottomright(Point2f new Pt) : void
+ getbottomright() : Point2f
- setbottomright(Point2f new Pt) : void
+ getID() : int
- setID(int initID) : void
Figure 18 - Target class diagram

4.2.4 Trackpoint Class

The trackpoint class consists of a wide variety of data of a single point. It consists of a Point2f[11] which contains the initial position of the point, used for resetting the point once it goes off screen, and the 10 most recent positions of that point. It contains a boolean moving which is used as a flag to check if it is moving or not. It has x and y velocity variables. Lastly, it has a groupID which is used to associate it with a given targetID.

The only functions this class has are standard get and set functions for each variable.

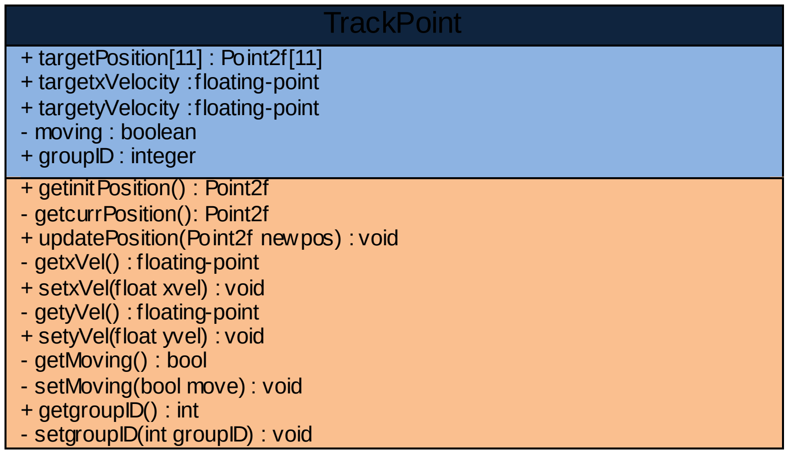

TrackPoint
+ targetPosition[11] : Point2f[11]
+ targetxVelocity : floating-point
+ targetyVelocity : floating-point
- moving : boolean
+ groupID : integer
+ getinitPosition() : Point2f
- getcurrPosition(): Point2f
+ updatePosition(Point2f newpos) : void
- getxVel() : floating-point
+ setxVel(float xvel) : void
- getyVel() : floating-point
+ setyVel(float yvel) : void
- getMoving() : bool
- setMoving(bool move) : void
+ getgroupID() : int
- setgroupID(int groupID) : void

Figure 19 – TrackPoint class diagram

4.2.5 Turret Class

The turret class will be the main class of the software. It will instantiate the turret and initializes it with the given data upon the first execution of the program. It will then continue to keep track and update all of the vital information of the system. It will also control the firing, target selection, determine the angles needed for the servo motors, send audible alerts, and keep track of all of the targets in the field of vision. The fire function will take the given target and fire rate and attack that target, firing at the specified rate. The choose target method will make a comparison of all existing targets, and determine which one has the highest priority, returning that target. The alertWarning and alertEngaged functions will set the physical alarm and play an audio file to alert the target of its current status before attacking it. The rest of the functions are used to get and set the various variables such as the angles, ammoRemaining, fire rate, and if any targets exist at the current time. This is one of the most important classes and will be a high priority in the software of the ATS.

Variable Type	Variable Name	Variable Description
boolean	engaged	true if currently attacking a target.
boolean	targetsExist	true if there are any targets of any threat level in the field of vision.
Int	ammoRemaining	an estimate of how much ammunition is left in the weapon. Initialized to a set amount upon program start and decremented based on the fire rate selected.
Int	fireRate	the rate at which the gun should fire. 0 = automatic, 1 = burst, 2 = single shot

Void fire(Target **currTarget**, int**firerate**);

Assigns the turret to fire at the target with the highest threat.

Parameter Name	Parameter Description
currTarget	the target in the field of vision with the highest threat level
Firerate	the rate at which the gun should fire

Target chooseTarget(boolean**targetsExist**, Target[] **TargetList**)

Selects the target which has the highest threat level of the TargetList.

Return Value - the target with the highest threat level in the field of vision. Null if targetsExist == false.

Parameter Name	Parameter Description
targetsExist	true if there are any targets of any threat level in the field of vision.
TargetList	a dynamic array of all targets found. If no target was found null will be returned.

voidalertWarning();

plays the warning audio file if a target becomes in the tracking range of the sentry gun.

voidalertEngaging();

plays the firing audio file to alert the target it is about to be engaged.

IntgetHAngle();

returns the current angle of the horizontal servo motor.

voidsetHAngle(int**angle**)

sets the angle of the horizontal servo motor.

Parameter Name	Parameter Description
angle	the value of the horizontal angle that the servo motor needs to be set at to shoot the target.

IntgetVAngle();

returns the current angle of the vertical servo motor.

voidsetVAngle(int angle)

sets the angle of the vertical servo motor.

Parameter Name	Parameter Description
angle	the value of the vertical angle that the servo motor needs to be set at to shoot the target.

Boolean getEngaged();

returns whether or not the turret is engaging a target.

Void setEngaged(boolean**engaged**);

sets the engaged flag for the turret.

Parameter Name	Parameter Description
engaged	true if the turret is engaged in combat, false otherwise.

Boolean getTargetsExist()returns whether or not targets are in the field of vision.

Void setTargetsExist(booleantargetsExist);

sets the turretsExist flag for the turret.

Parameter Name	Parameter Description
targetsExist	true if there are targets in the field of vision. False otherwise.

Int getAmmoRemaining();

returns the estimated amount of ammunition left in the weapon.

Int getFireRate();

returns the rate of fire in which the weapon is set to.

Void setFireRate(intfirerate);

sets the fireRate of the turret to the specified value.

Parameter Name	Parameter Description
Firerate	the rate at which the user wants the turret to fire at.

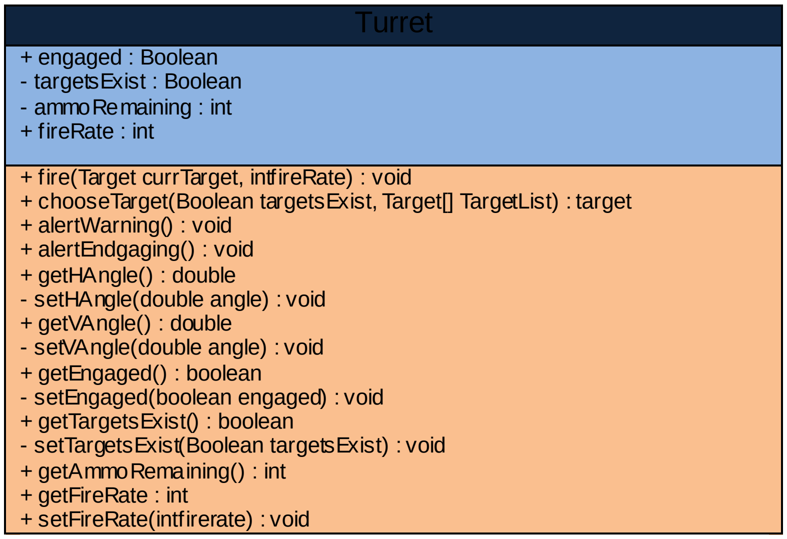

Turret
+ engaged : Boolean
- targetsExist : Boolean
- ammoRemaining : int
+ fireRate : int
+ fire(Target currTarget, intfireRate) : void
+ chooseTarget(Boolean targetsExist, Target[] TargetList) : target
+ alertWarning() : void
+ alertEndgaging() : void
+ getHAngle() : double
- setHAngle(double angle) : void
+ getVAngle() : double
- setVAngle(double angle) : void
+ getEngaged() : boolean
- setEngaged(boolean engaged) : void
+ getTargetsExist() : boolean
- setTargetsExist(Boolean targetsExist) : void
+ getAmmoRemaining() : int
+ getFireRate : int
+ setFireRate(intfirerate) : void

Figure 20 - Turret class diagram

4.2.6 Video Capture Class

The Video Capture class is the first class that was accessed by the ATS software program. Its objective was to take the video stream from the web camera and interface it with the program. This step was vital in the process so the frames are operated upon to find the targets within the field of vision. The video Capture class completes this task by connecting to the device that is the web camera either with the constructor or with the open method. The frames are then taken from the stream by using the grab method or the retrieve method. The retrieve method decodes the frame as well as grabbing it. Also, the get and set functions for the property ID allow the access to a wide variety of variables of the video stream such as hue, saturation, brightness, frame rate, and other useful variables. Lastly, the release method detaches the device from the program so it is safely disconnected. This was only used when the program has been terminated (either by error or intentionally).

VideoCapture::VideoCapture(int**device**)

VideoCapture::VideoCapture(conststring&**filename**)

VideoCapture::VideoCapture()

VideoCapture constructors.

Parameter Name	Parameter Description
Filename	name of the opened video file
Device	id of the opened video capturing device (i.e. a camera index). If there is a single camera connected, just pass 0.

boolVideoCapture::open(int**device**)

Open video file or a capturing device for video capturing

boolVideoCapture::isOpened()

Returns true if video capturing has been initialized already.

voidVideoCapture::release()

Closes video file or capturing device.

boolVideoCapture::grab()

Grabs the next frame from video file or capturing device. Returns true if grab was success.

boolVideoCapture::retrieve(Mat&**image**, int**channel**=0)

Decodes and returns the grabbed video frame. Returns true if success, or false and a null pointer if unsuccessful.

Parameter Name	Parameter Description
Image	The image being captured.
channel	The channel of the stream that the image is coming from. (set it to zero if only one channel).

boolVideoCapture::read(Mat&**image**)

Grabs, decodes and returns the next video frame. Returns true if success, false otherwise.

doubleVideoCapture::get(int**propId**)

Returns the specified VideoCapture property

Property Identifier	Description
CV_CAP_PROP_POS_MSEC	Current position of the video file in milliseconds or video capture timestamp.
CV_CAP_PROP_POS_FRAMES	0-based index of the frame to be decoded/captured next.
CV_CAP_PROP_POS_AVI_RATIO	Relative position of the video file: 0 - start of the film, 1 - end of the film.
CV_CAP_PROP_FRAME_WIDTH	Width of the frames in the video stream.
CV_CAP_PROP_FRAME_HEIGHT	Height of the frames in the video stream.
CV_CAP_PROP_FPS	Frame rate.
CV_CAP_PROP_FOURCC	4-character code of codec.
CV_CAP_PROP_FRAME_COUNT	Number of frames in the video file.
CV_CAP_PROP_FORMAT	Format of the Mat objects returned by retrieve() .
CV_CAP_PROP_MODE	Backend-specific value indicating the current capture mode.
CV_CAP_PROP_BRIGHTNESS	Brightness of the image (camera only)
CV_CAP_PROP_CONTRAST	Contrast of the image (camera only).
CV_CAP_PROP_SATURATION	Saturation of the image (camera only).
CV_CAP_PROP_HUE	Hue of the image (camera only).
CV_CAP_PROP_GAIN	Gain of the image (camera only).
CV_CAP_PROP_EXPOSURE	Exposure (camera only).
CV_CAP_PROP_CONVERT_RGB	Boolean flags indicating whether images should be converted to RGB.

CV_CAP_PROP_WHITE_BALANCE	Currently not supported
CV_CAP_PROP_RECTIFICATION	Rectification flag for stereo cameras (note: only supported by DC1394 v 2.x backend currently)

VideoCapture::set(int**propertyId**, double **value**)

Parameter Name	Parameter Description
propertyId	see Table
Value	The value that the property id should be set to based on the specified values for each property.

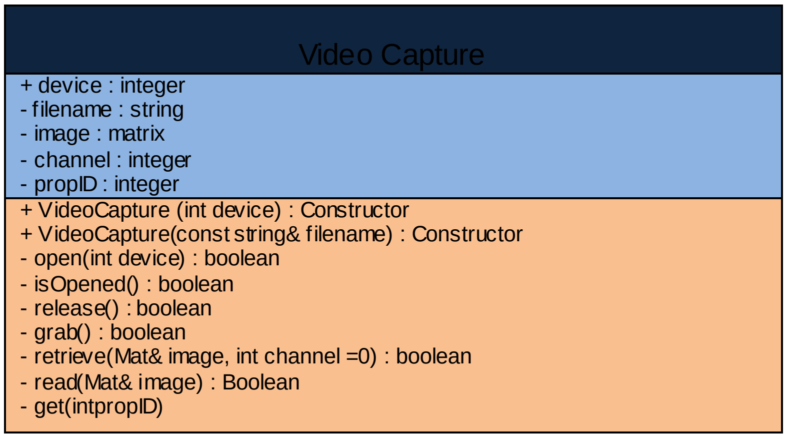

Video Capture
+ device : integer
- filename : string
- image : matrix
- channel : integer
- propID : integer
+ VideoCapture (int device) : Constructor
+ VideoCapture(const string& filename) : Constructor
- open(int device) : boolean
- isOpened() : boolean
- release() : boolean
- grab() : boolean
- retrieve(Mat& image, int channel =0) : boolean
- read(Mat& image) : Boolean
- get(intpropID)

Figure 21 - Video Capture class diagram

4.2.7 Video Write Class

The Video Writer class is similar to the Video Capture class in multiple ways. It operates the same way opening and closing the device or file and writes/receives frames in the same ways. The Video Writer class writes frames to a file so it was viewed later by the system user to see what occurred in the ATS' field of vision. This class was used when the turret is engaged to a target so the user views all engagements on a file by file basis. The file was opened upon the initial firing of the target and then closed once the weapon ceases its fire. The file is created either by the constructor or the open method and the isOpenedmethod is to check if already has been opened. The write method writes a single frame to the video file and was called on each loop through the program. This was one of the last classes to be implemented in the software.

VideoWriter::VideoWriter()

VideoWriter::VideoWriter(conststring&**filename**, int**fourcc**, double **fps**, Size **frameSize**, bool**isColor**=true)

VideoWriter constructors (first is an empty constructor and the second is when it is known what type of video is going to be written)

boolVideoWriter::open(conststring&**filename**, int**fourcc**, double **fps**, Size **frameSize**, bool**isColor**=true)

Initializes or reinitializes video writer.

Parameter Name	Parameter Description
filename	Name of the output video file
fourcc	4-character code of codec used to compress the frames. For example, CV_FOURCC('P','I','M','1') is a MPEG-1 codec, CV_FOURCC('M','J','P','G') is a motion-jpeg codec etc.
fps	Framerate of the created video stream.
frameSize	Size of the video frames.
isColor	If it is not zero, the encoder will expect and encode color frames, otherwise it will work with grayscale frames (the flag is currently supported on Windows only).

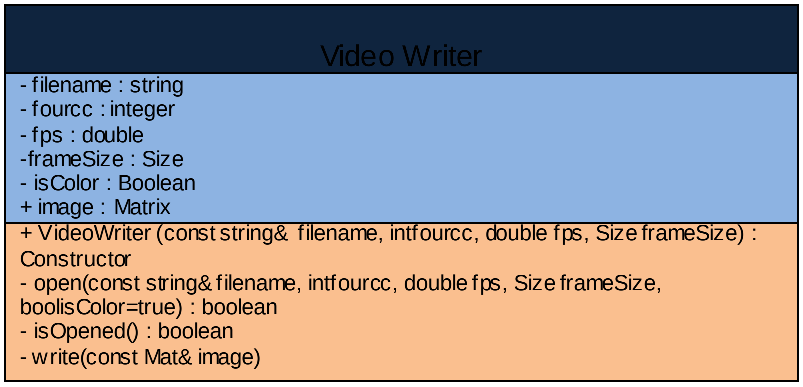
boolVideoWriter::isOpened()

Returns true if video writer has been successfully initialized.

voidVideoWriter::write(constMat&**image**)

Writes the next video frame

Parameter Name	Parameter Description
writer	Video writer structure (OpenCV 1.x API)
image	The written frame


Video Writer
- filename : string
- fourcc : integer
- fps : double
-frameSize : Size
- isColor : Boolean
+ image : Matrix
+ VideoWriter (const string& filename, intfourcc, double fps, Size frameSize) : Constructor
- open(const string& filename, intfourcc, double fps, Size frameSize, boolisColor=true) : boolean
- isOpened() : boolean
- write(const Mat& image)
Figure 22 - Video Writer class diagram

4.2.8 Manual Control Class

The manual control class will function as a built in user interface on the turret controls computer. The Manual Control Class will be implemented using a Windows Form Application designed in Microsoft Visual Studios 2010. The application will provide a friendly user interface with buttons to rotate the gun, fire the gun, and sound the alarm. The application will also include the video feed from the web camera, along with an emergency stop button and list to select the rate of fire for ATS.

Several methods will be implemented in the Manual Control class, there are methods to rotate the turret right or left as well as up or down this will be achieved by adding buttons to the application as well as mapping the controls to the arrow keys. The Fire() method will be used to fire the gun, this will be implemented by another button on the application as well as the spacebar key on the computers keyboard. Buttons for playing audible files will be added to the alertWarning() and alertEngaged() methods and lastly a kill switch button will be implemented to bring the turret offline if need be.

Return Type	Method Name	Method Description
Double	getXpositon()	Returns the x coordinate the servo is currently set to.
Double	getYPosition()	Returns the y coordinate the vertical servo is set to.
Void	rotateRight()	Rotates the turret right by a set degree.
Void	rotateLeft()	Rotates the turret left by a set degree.
Void	panUP()	Tilts the turret upwards.
Void	panDown()	Tilts the turret downwards.
Void	Fire()	Fires the turret.
Void	alertWarning()	Plays an audio file to warn intruders that they are entering a dangerous zone and that they should proceed to leave.
Void	alertEngaged()	Plays an audio file to warn intruders that they are about to be fired upon by ATS.
Void	setFireRate(intfirerate)	sets the firing rate of the turret 0 = automatic, 1 = burst, 2 = single shot.
Double	xPosition	The x coordinate the horizontal servo is currently set to.
Double	yPosition	The y coordinate the vertical servo is currently set to.
Integer	fireRate	Controls the rate of fire of ATS.

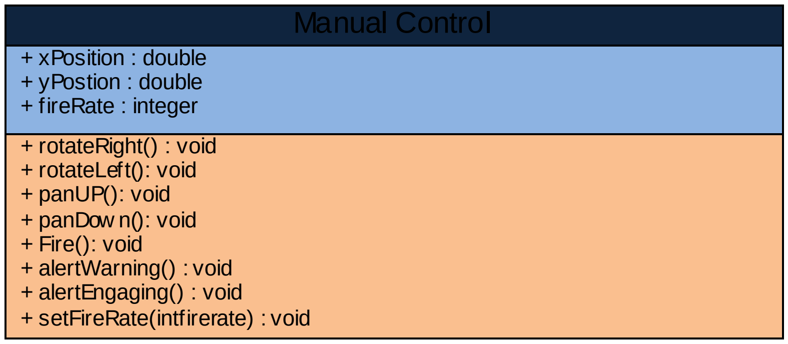


Figure 23 - Manual control class diagram

Figure 18 shows an early prototype for the manual control class. The Windows Application form was made in Visual Studios 2010 and contains buttons and controls to fire and move the gun, alert and warn intruders, an emergency stop and a rate of fire selection window. The blank area on the top of the application is reserved for the video feed; this feature is to be implemented still. This application is designed with future improvements in mind including visual improvements and detailed readouts including the coordinates the gun is currently aiming at, number of targets in the field of view, weather and wind conditions, threat list, and target highlighter which would illuminate targets in the embedded video.

4.2.9 Facial Detection and Recognition class

The facial detection and recognition class was be used as a security system to access manual control. This was a luxury step to securing the system from any threats that manage to reach the base of the turret. To ensure the turret remained under the proper operators control the system was to require that the user undergoes a facial recognition scan and confirmation.

When accessing the manual control the user was to first be asked to position his or her face in front of the on board computers web camera. The system was then supposed to scan the image in an attempt to detect a face using various Haar-like features. Once the class acknowledges the face is a valid user, the system was to run the image in the attempt to find a matching face in the face database the team creates. The face database was supposed to be nothing more than a collection of images of the teams faces. To grant additional users access to the manual control class an image of the person must be entered into the facial database. This class was an precautionary security feature that safeguards the turret from malicious users.

Void **detect_and_draw(**IplImage* image) – draws an object from an image.

cvMemStorage – Creates memory for calculations. Memory is automatically released when there are no objects referring to it.

cvHaarClassifierCascade – Create a new Haar Classifier. Haar classifiers are used to detect human facial features such as the dark area under the eyes.

HaarClassifierCascade**cvLoad**(cascade_name, 0, 0, 0) – Load the HaarClassifier Cascade. The cascade works by using a sequence of haar-classifiers to eliminate entries that are not faces quickly and to ensure accuracy. The cascade starts with simple classifiers in order to eliminate false entries quickly but then images must pass tougher tests to be considered a face. This saves processing time and power.

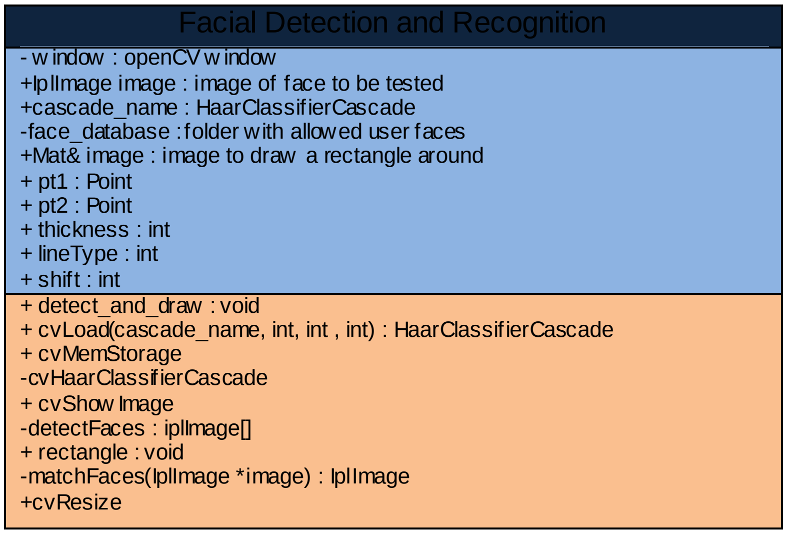
cvShowImage(window, image) – shows the specified image in the window.

IplImage[] **detectFaces** (IplImage *image) – detects faces using Haar Features. Returns an array of images that are considered to be faces.

Void rectangle(Mat&image, Point pt1, Point pt2, constScalar&color, int thickness=1, intlineType=8, intshift=0) – draws a rectangle, the rectangle will be drawn around objects considered to be faces.

IplImage**matchFaces**(IplImage *image) – returns a matching face from our face database.

cvResize -used to resize the input image


Facial Detection and Recognition

- window : openCV window
+IplImage image : image of face to be tested
+cascade_name : HaarClassifierCascade
-face_database :folder with allowed user faces
+Mat& image : image to draw a rectangle around
+ pt1 : Point
+ pt2 : Point
+ thickness : int
+ lineType : int
+ shift : int

+ detect_and_draw : void
+ cvLoad(cascade_name, int, int , int) : HaarClassifierCascade
+ cvMemStorage
-cvHaarClassifierCascade
+ cvShow Image
-detectFaces : iplImage[]
+ rectangle : void
-matchFaces(IplImage *image) : IplImage
+cvResize

Figure 24 - Facial detection and recognition class diagram

4.2.10 Data Structures

Position – A position object consists of 5 integer values. These 4 values represent the 4 corners of the rectangle that enclose the target. These values are used in keeping track of where targets are, as well as, informing the sentry gun on where to shoot if the target is in the firing zone. The 5th integer value represents the center of rectangle, which is the specific spot where the turret was aiming for. This center value was updated every frame from the other 4 values. Every frame that goes through the system checked for the targets, then updated the position if the target is found to still be in the frame and if not the position's were all set to -1.

Velocity – A velocity object contained 2 components, speed and direction. The first component was a floating-point value that represents the speed in which the target is moving. This was calculated from the change in position over the course of 2 frames where the target has been spotted. The 2nd component represents the direction in which the target is moving. The direction was represented by an integer, from 1 to 360, which represent what direction the image is moving. [Example: If the direction was equal to 180 the target was moving from right to left within the field of vision.

TargetID – A target is any object in the camera's field of vision that is foreign to the view and passes a certain threshold. For example, trees that have been in the field of vision the entire time weren't considered targets and neither were very small moving objects. Since there are multiple targets, each target needs its own identification number. The ID was continually incremented, starting from zero, for each target that gets detected. Target's also consist of two Point2f objects representing the corners of the size of the target (topleft and bottomright). Lastly, the number of points that make up a targetID are stored to calculate average position.

TrackPoint – A trackpoint is a standard point with much more data. It consists of an array containing its initial position, and its 10 most recent positions. It has a boolean flag to check if the point is moving in the past 10 frames. Also it has x and y velocities which are calculated every frame. Lastly, it contains a groupID used to associate the points with a targetID.

4.2.11 Constants

The following list are constants that were defined and used throughout the ATS software program.

- **UP** – This represents a 0 and when passed from the manual control class to the turret class, the turret moves up a set amount.
- **DOWN** - This represents a 1 and when passed from the manual control class to the turret class, the turret moves up a set amount.
- **LEFT** - This represents a 2 and when passed from the manual control class to the turret class, the turret moves up a set amount.
- **RIGHT** - This represents a 3 and when passed from the manual control class to the turret class, the turret moves up a set amount.
- **AUTO** – This represents a 0 and when passed to the setFireRate function, it sets the fire rate to automatic.
- **BURST** - This represents a 1 and when passed to the setFireRate function, it sets the fire rate to automatic.
- **SINGLE** - This represents a 2 and when passed to the setFireRate function, it sets the fire rate to automatic.
- **MANUAL** – This value represents a 0, and, when passed to the turret, it sets the manual control on.
- **AUTONOMOUS** - This value represents a 1 and, when passed to the

turret, it sets the manual control off.

- **xThresh** – This value represents the x threshold for velocity.
- **ythresh** – This value represents the y threshold for velocity.
- **diagThresh** – This value represents the diagonal threshold for velocity.

4.2.12 Software Components

Since the system software is a majority of the prototype, the system required a variety of programming languages and software environments. The openCV classes were developed in visual studio 2010 using C++. The PCB was designed using EagleCAD. The microcontroller IDE that the designers used Code Composer and C#.

4.2.12.1 C++

The developers used the C++ language. OpenCV is written in C++ therefore it was the language of choice for our project. The language is object oriented, and since most of the group is familiar with object oriented concepts and the C language, C++ is a good fit.

4.2.12.2 Visual Studios 2010

Visual Studios is the most complete IDE available to developers working with the C++ language. It supports multiple languages and makes creating the Windows application for our on board computer a simplified task. There are extensive tutorials on adding the OpenCV libraries to a project and through our research it is the preferred IDE when working with OpenCV. The IDE contains IntelliSense which is an excellent syntax highlighting tool, and a debugging tool which debugs your code as you write. Visual Studios was provided via Microsoft's DreamSpark which provides software to students.**[55]**

4.2.12.3 EagleCAD

EagleCAD will be used to design our printed circuit board. EagleCAD's website provides training with tutorials, videos, detailed manuals, and forums. EagleCAD will provide everything needed for designing and setting up our board and laying the traces. **[56]**

4.2.12.4 Code Composer Studio Version 5

In order to program and fully test the microcontrollers, some form of programming IDE with a debugging interface was needed. The fifth version of Code Composer Studio is an eclipse based IDE similar to many other programming IDEs such as Microsoft Visual Studio. Code Composer has the ability to flash the program onto a MSP430 MCU as well as being able to view the values inside registers and global variables. Code composer is also both supported for Windows and Linux based operating systems. For these reasons, Code Composer was a great IDE for both programming and MCU flashing.

Code Composer allowed the designers to code in assembly, C, or C++. The preferred method was to use a combination of C and assembly, which is supported by the IDE. For testing purposes, the debugger allowed the designers to add multiple breakpoints, add graphs for variables, or update a window display desired variables whenever there was a change. Code composer also has various options for optimizations where a designer can opt for code using a lower memory for the cost of performance or code with higher performance and a higher memory footprint.

One drawback to using Code Composer is that, even though assembly code can be mixed into C source files, a project could not contain a combination of C and C++ source files. The compiler would allow the designers to add C and C++ source files; however, the project would no longer be able to access header files. Without access to header files, accessing the various registers and functions built into the MSP430 were inaccessible. This is theoretically a bug since the issue randomly arrived and disappeared.

5.0 Design Summary

The hardware design summary below contains the selection and specifications of servo motors, microcontrollers, web camera, laser pointer and alarm systems. The purpose of the software design summary was to discuss the various classes including methods and parameters used throughout the system.

5.1 Hardware Design Summary

ATS' hardware design consisted of only a few components that work in unison together to construct a successfully working turret. The main components were the turret itself, which was a paintball gun firing paintballs at incoming targets. The targets were to be located through a web camera attached to the base of the ATS system gun and linked directly to an onboard laptop. This is to be a real time video feed and display on the monitor, from there the software is able to detect the incoming targets.

Once the software successfully detects the incoming targets, the paintball gun has the ability aim at their present location and track their movement. To do so, the system that consists of two servo motors, one for lateral movement and one for vertical movement. The software has the ability to track the incoming target and relay the positioning to the microcontroller on the printed circuit board. The microcontroller does the simple calculations for determining where the gun itself needs to point and passes the signal to its respective servo motor.

The turret was start tracking at when the target came into view via the web camera. When a the ATS system acknowledges that target is coming; the alarms are triggered, sounding warning to the target that they are entering a dangerous area. There are two types of alarms on the system, an on board, continuous sounding alarm and also a speaker system that has the ability to play an audio file that will verbally warn the incoming target of their increasing risks. The continuous sounding alarm is going to be connected directly to the printed circuit board, so when the software identifies the target's movement, the signal is sent from the microcontroller triggering the alarm. Also when this happens, the speaker system, which are the speakers of the laptop, is going to start its verbal warnings in case the incoming targets are human and can understand instructions.

Like most other electrical components, the ATS system has a battery powering the turret. The power source is be directly connected to the printed circuit board. From this connection, the main concerns are to power the microcontroller and the servo motors specifically. A 12 volt battery was more than sufficient enough to power these components and the designers used voltage regulators to step down the voltages to the proper operating voltages for the microcontrollers and servo motors, 3 volts and 5 volts respectively. All these components were kept above the base of the structure. The only other component that needed a power source will be the laptop. However; the laptop did not need to be tied to this battery instead the designers relied on its own battery pack to run all the software. The only remaining hardware of the ATS system was the base in which it is be a light weight and easily portable.

The architecture of the stand was to be a hanging mount. This was to be optimal to be hung from a ceiling. By doing so, the designers intended to store all vital components within the ceiling tiles so they are out of reach from intruders. This also give the ATS system a clean cosmetic look since none of the extra components will be exposed. Only the operating turret is visible and on that turret is the pitch and yaw servo motors. All wiring can be run through the bike frame used to build the base and mount for the system. This keeps the clean look mentioned earlier.

5.2 Software Design Summary

ATS' software design consisted of a computer vision application with some extra features to enhance the quality. The process of computer vision has the ability to be completed by making a series of operations upon each frame received from the input, the web camera. First the web camera has to be interfaced to the application by the Video Capture Class. Then the frame received from that class was sent to the object detection class. It then searched the frame for any and all targets, and returned an array of the targets (which will be null if no targets are found). Then each target got assigned a threat level based on its range from the turret. The color was to be used to determine allied targets from unknown targets, where any target wearing a certain green color would be deemed no threat; however, this feature wasn’t implemented due to the compressed timeline the designers had to complete their work.

Once the targets were detected by the system, the application would need to keep track of their locations. It would accomplish this by comparing two frames and calculating the optical flow of the video stream using the iterative Lucas-Kanade method with pyramids. After the motion was detected, each target would then have their position and velocity updated, accordingly. To make sure the program knew which target was which, they would be assigned ID numbers to differentiate them from one another in the system. The targets range would also be recorded in order to determine its importance as a target. This value would be used to choose which individual target should be fired upon, amongst a group of targets.

At this point, the turret now knew where all targets were and now had to select what target, if any, to shoot at. It searched the target list for the highest threat level, and if it passed the threshold for a dangerous enemy, then it would set the location the turret needs to aim at and give the command to fire. The program would continuously check all threat levels, and update targets, as the turret was engaged to a target so if the priority changes, the turret would disengage its current target for the more threatening one in the field of vision.

An additional feature of an alarm would be added to the software. There are two distances in which a target will be alerted by a sound file played, asynchronously, by the program. The first was when a target started to be tracked, in which targets would be tracked, and the second was the distance in which the target will be engaged, this was time based after the initial warning. This delay was adjustable depending of the situation the ATS system was in.

OpenCV's computer vision methods and classes were used throughout the software application to enhance the feature set and quality of the ATS' software. OpenCV has a wide variety of ways to complete the process of computer vision, and the algorithms that would be implemented within this system are some of the most efficient and effective in the aspects of object detection, motion tracking, and machine learning.

6.0 Prototyping

The prototyping process the designers followed is represented graphically by figure 20**,** show below. The program was already researched and designed so the next step was to begin building the prototype. An evolutionary approach was used to make the ATS' software component. The first iteration consisted of a program that can detect objects. Once that was complete, the object tracking was to be implemented, but for manual control first. After another iteration, the autonomous tracking needed be added. In the last iteration, the extra features, sounding audio files and automatic firing, was than added to the software. Once each iteration of building/refining finishes, the system was be tested to see how well it functions. If successful, the next step in the evolutionary process began. However, if the current iteration did not work properly, then it was fixed before moving on to the next iteration in the process.

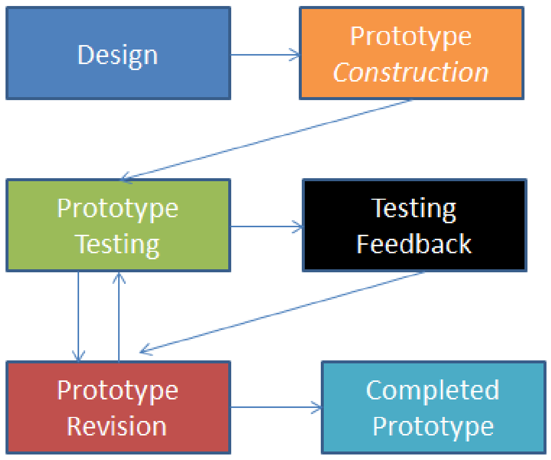


Figure 25 - Prototyping process

The prototyping process was organized into modules for both hardware and software. Each module was built to run individually and then was integrated into the overall system once completed. The hardware modules consisted of the capacitive touch controller, the base and weapon system, the servo motors, microcontrollers, alarms and the PCB. On the other hand, the software modules were based on the classes that are defined in the software design. Object detection, object tracking, turret, target identification, and track target were the five major modules of the ATS' software prototype.

Each module was than further broken down into sub-modules that are a small part of the whole module. For the software of the ATS system, these sub-modules were be the individual functions and methods used to complete the overall computer vision application. For example, for the track target module, there were two sub modules. The first sub-module was be tracking the movement of an object. Then, the second module was actually determining what whether or not the movement was deemed a target. To do this, the designers implemented a set of moving points to move with the target. If the target had enough points, the designers determined this target a threat and would track the movement of the target while in the field of view. For the hardware, the sub-modules were be broken down into specific parts, where applicable, of the modules. For example, the base and weapon system module was broken down into a sub-module for the base and then sub-modules for each component of the weapon, which consists of the gun, ammunition, co2 tank, hopper, barrel, and trigger.

Once all of the sub-modules for a given module are completed, the modules were then moved into testing to see how it functions. The prototype of the specific module were tested based on its own merits to determine if it completes all required tasks that were detailed for that given module. If all of the modules tests that are listed within the testing section are successful, it was to be integrated into the overall system. After all modules were completed, more integration testing was done to see how each module interacts with the rest of the ATS system.

In Figure number 21 below a proto-typing model was laid out for the designers to follow. The group followed this process model with the customer being the group. The initial requirements were the designed specifications and objectives. Once a component or system was designed, the prototype was to be implemented followed by an evaluation. If the group was satisfied with the results the team then moved to the development and testing. The last step was to properly maintain the product to ensure reliability.

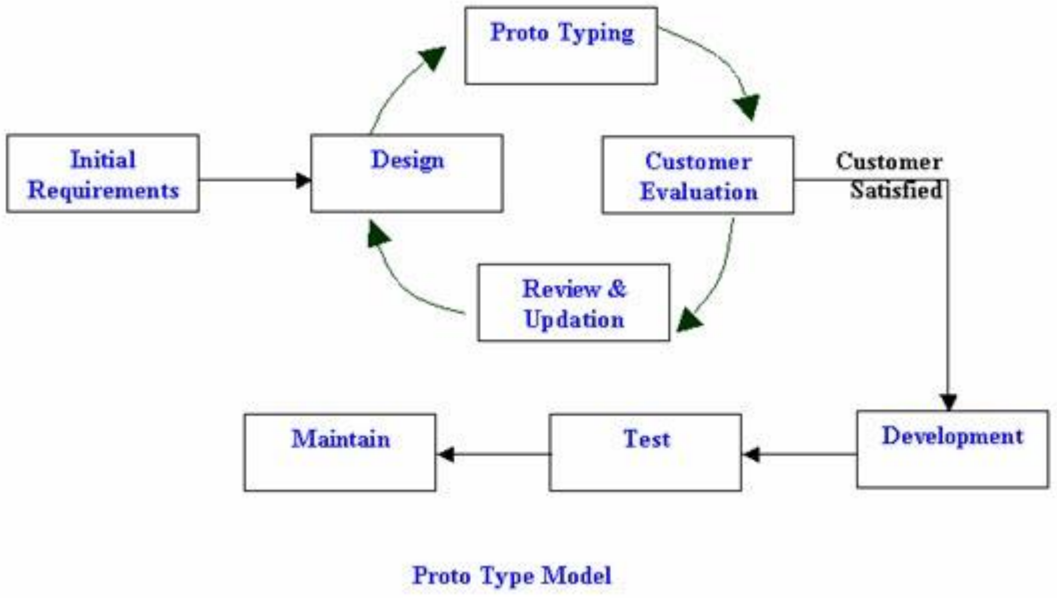


Figure 26 - Proto Type Model

7.0 Testing

The ATS system underwent extensive testing on both hardware and software components. Hardware components were to be tested individually prior to implementation. After each component passed with compliance, they were then integrated within the system. The software classes were tested individually. Once both software and hardware are fully tested individually, they were combined and the entire system went undergo overall system testing.

7.1 Hardware Testing

Hardware testing was an important part of testing to ensure reliability. To do so, the designers first tested each component individually prior to integration into the entire system. The hardware testing happened in a series of phases. First, each component would hooked up to the function generate to make sure the components worked properly under the proper voltages. If the components needs controlling the controllers were also hooked up to test. For example, the servo motors need to be controlled using pulse width modulation, the designers would hook up the servo motors and microcontrollers to the function generator to see a successful trial. These preliminary steps were requirement to testing each component before connecting to the power source because the designers didn't want to supply too much power to the individual components. The sections listed below describe the testing process per each component.

7.1.1 Servo Motors

Before attaching the servo motors to the base, the accuracy of each servo motor was measured. Since the autonomous turret only rotates while remaining in the same location, errors in direction become amplified at further distances. For example, an assumed target is located thirty degrees counter clockwise from the center ten feet away. In other words the target is located five feet from the center. If instead error was introduced and the servo motor was pointed thirty-one degrees counter clockwise from the center, the turret will fire 5.150 feet from the center as opposed to the previous 5.000 feet resulting in an error of 0.150 feet. Table 17 represents the resulting error at ten, twenty, fifty, and one-hundred feet at one, three, and five degrees.

Error/ Distance	1.000	3.000	5.000	Degrees
10	0.150	0.446	0.736	ft.
20	0.301	0.892	1.471	ft.
50	0.752	2.231	3.678	ft.
100	1.503	4.462	7.355	ft.

Table 11 - Error percentages

It should be noted that error percentages were not calculated at various distances since the error percentage remains the same. Instead, the errors were left in differential feet to give a more tangible result. As seen in the table above, the maximum error, assuming a max error of five degrees, results in 7.355 feet. Assuming the turret it attempting to fire at about human width, approximately two feet, the turret has a chance to miss at fifty and one-hundred feet, once again, assuming a max error of five degrees.

Error in the servo motor degrees came from two primary sources, an incorrect pulse width modulation from the servo motor microcontroller and the inaccuracy of the servo motors themselves. The inaccuracy from the servo motors minimum and maximum allowed pulse widths were fairly large. These inaccuracies were accounted for on the servo motor controller microcontroller by simply hard coding the maximum and minimum pulses. The servo motor testing procedure can be found in the proceeding statements. During testing, the servo motors had an operating voltage set to the five volts. This voltage was supplied a DC power supply in the senior design lab.

The signal line originally received a three volt square wave from the function generator. However, during testing this proved to be too low and was increased to a four volt square wave. The function generator was also hooked up to the oscilloscope to check for any noise during testing. Two sets of errors were measured. The first set of errors was small shifts in the pulse widths. With the function generator hooked up to the servo motors, the pulse widths were adjusted approximately ten milliseconds per shift. The second set of errors was large shifts in the pulse widths. These pulse width shifts ranged from a hundred milliseconds to a full 1500 milliseconds.

After performing the test, it was determined that the servo motors were highly accurate when performing small steps in the pulse widths. In addition to accuracy, the latency between the change in pulse width to the servo and the servo motor changing was immeasurable by the human eye. After performing the test with large pulse width differentials, larger errors in accuracy were noticed when the servo motor began to reach the final position. However, the servo motor did eventually reach consistent positions after a short time.

Since the servo motors operate at fifty hertz, a 20,000 microsecond period, with pulse width ranging from 900 to 2100 microseconds, there is a duty cycle ranging from 4.5% to 10.5%. In other words, for the 95.5% to 89.5% of the period that is not taken up by the pulse width signal is taken up by the dead band. During this dead band, the microcontroller controlling the servo motors cannot go high to maintain its fifty hertz frequency. Theoretically the servo motors were only updated every 20 milliseconds. It was originally feared the servo motor would not be able to keep with rapid short back and forth movements. However, this proved to not be a concern when performing a full system integration testing.

Once the above was adequately tested, the accuracy from the previous calculated equation to predict the required pulse width modulation for a required degree position were tested. This is required since the equation was not specified from the supplier. For a standard ninety degree rotation servo the equation was calculated to be pulse width = 900+40/3*A, where A is the required angle. For the 140 degree rotation servo the equation was calculated to be pulse width = 900+60/7*A, where A is the required angle. The results of this test can be found in the table 18 below.

Summary of theory and tested pulse widths					
Degree	**HS-8055**		**HS-8155**		
	Theory	**Tested**	**Theory**	**Tested**	
0	900	900	900	900	µS
15	1100	1150	1028	1066	µS
30	1300	1400	1157	1233	µS
45	1500	1650	1285	1400	µS
60	1700	1900	1414	1566	µS
75	1900	2150	1542	1733	µS
90	2100	2400	1671	1900	µS
105	NA		1800	2066	µS
120	NA		1928	2233	µS
135	NA		2057	2400	µS

Table 12 - Angle testing v theory

Judging from the table above, it was determined that the actual specified minimum and maximum pulse widths were incorrect. The reason for this was most likely due to the built in feedback. After these pulse widths were measured, they were hardcoded into the servo controls microcontroller.

The other source of error was originally predicted to come from the microcontroller sending an incorrect pulse width. Slight errors were actually measured on the MSP430 microcontrollers. One error measured was the PWM signal not perfectly clocked to fifty hertz. The other error measured was an incorrect pulse width due to the PWM signal not being perfectly clocked to fifty hertz. In the first revision of the servo controls code, this was hardcoded. However after multiple revision, the ability to save pulses into flash memory proved to clear the majority of the inaccuracy.

Once these errors were accounted for, the servo motors were attached to the base. The above procedures were repeated to see additional errors were introduced. For the most part by basic testing, it appeared that no additional errors were introduced. Even though there was an increase in torque, the servo motors appeared to actually be more accurate than when they were no attached to the base.

Once the servo motor is attached to the base, the servo motor speed was also measured in order to determine if the speed is reasonable. The speed of the servo motors were tested using a simple loop that changed the pulse widths from 900 milliseconds to 2400 milliseconds. After performing the test, the servo motor speed proved to be well more than adequate.

7.1.2 Microcontroller

Testing is always a critical step in designing a working prototype. By successfully testing the individual components of the ATS system, the designer can demonstrate reliability and confidence when constructing the prototype to properly achieve its specific purpose. Therefore, testing the microcontrollers, which essentially controls the mechanics of the ATS system, is an important procedure. The testing of the microcontroller should be a straightforward process. The entire testing process consisted of two sequential steps, implementation onto the printed circuit board and tying the microcontroller to the servo motors.

Originally, each MSP430 microcontroller was tested individually. The first microcontroller tested was the servo motors controls MCU. During testing, there were two main concerns. The first concern was that the microcontroller would not update pulse width signals fast enough. The second concern was the ability to correctly read data from the I2C bus. The second concern was dismissed after fifteen minutes of testing. To test the I2C bus, a separate microcontroller was programmed to transmit incrementing values to the bus. The servo controls MCU was left in the debug menu with breakpoints to constantly update the variable that holds the incoming data. After the fifteen minutes of testing, no errors were detected. However the first concern proved to be quite problematic. Adding breakpoints to update variables naturally slows down the operating speed of the microcontroller so servo motors had to be connected to the MCU. A separate MCU was used to transmit angle increments of the along both the pitch and yaw. In the first revision of the servo controls, the servo motors MCU appeared to have relatively large latency effects. By the fifth revision of the servo controls MCU, low power mode features were disabled and the programming was written to be optimized. After the fifth revision, the latency effects were dismissed as they were no longer noticeable.

The second MCU, the capacitive touch MCU was then tested. The original concerns were that the capacitive touch would be inaccurate at noticing which button was pressed. However, this proved to not be the case, and, in fact, most of the difficulties were in reaching an appropriate threshold to activate the buttons. In the original version of the code, the capacitive touch MCU was primarily based of TI API calls for baseline measurements for calibrations. However, these appeared to be inconsistent from day to day in that one day the capacitive touch may notice a touch and other days the same MCU cannot detect a touch. This was resolved by simply storing the raw capacitance into a separate array and a separate threshold for touch was hardcoded. In addition to reaching a solid threshold, testing the ability to increment the angle by one in a single touch was a concern. Originally, it was too difficult increment the ATS system only once since the capacitive touch microcontroller was operating too fast. This was quickly resolved by simply adding a delay function constant of a few for loops.

The third MCU implemented was the secondary controls MCU. The original concerns were that the microcontroller would not be able to supply an adequate voltage to either the alarm or the electronic solenoid. After testing, this proved to be a correct concern. This was quickly resolved by simply using bipolar junction transistors as a switch. The alarm was hooked up to a five volt power source and the trigger was hooked up directly to the electronic solenoid PCB. In both cases the base of the transistors were attached to the appropriate pins and the issue was resolved.

The final MCU implemented was the UART to I2C MCU. During implementation there were large concerns about latency of accepting incoming UART signals and the delay to transmit to the I2C bus. This MCU was tested in the debugging environment of code composer studio. Every time a transmission was sent from the laptop, the microcontroller would enter a breakpoint and instantly update the variable that stores the incoming data. After approximately 250 transmissions in the debugging environment, zero errors occurred so it was assumed the latency affects of accepting a 9600 baud UART signal were of no concern. In addition, the delay to transmit to the I2C bus was extremely low. These concerns were dismissed all together when full system integration was completed.

After all MCUs were tested separately, they were interfaced onto a bread board and the tests were repeated. Additional errors were discovered when anything transmitted to the I2C bus. After studying the built in I2C transmission code of the MSP430, it appeared that if an incoming I2C address did not match to a single MSP430, a NACK would occur. This NACK caused all MSP430 to be stuck waiting for data. This was resolved by simply disabling the NACK transmission. No negative side effects were witnessed.

7.1.2 Power Source

The battery source was no different than any other component when it came to testing. Testing procedure was always crucial to test per component as well as the entire system. The testing of the battery source was significantly easier than other component because to test the battery, it only needed to be connected properly to test the longevity of the battery. The battery connections were tested to ensure that no power was lost due to a faulty connection or improper soldering. This was measured by using a multimeter to measure the amount of power being output from the battery as well as the amount of power entering the microcontroller and servo motors. The make sure no power was lost, these two values proved to the same number.

Once the connection was properly connected, the designers next needed to test the longevity of the battery. This was a simple process of just letting the system run until the battery met the operation requirement. The system only required the system to last and perform for at least 4 hours and results satisfied this requirement. The designers had no issues with the battery for it was more than capable enough to last the desired requirement. This was not to be a problem since the designers were be able to run the system over and over to ensure it met the system requirement of longevity. Once the battery was drained, the designers recharged the battery since it will be a simple process. So the battery chosen was more than reliable enough to please the designers and committee members.

7.1.3 Alarm system

The alarm system testing was be a simple test. The first alarm to be tested was the set of speakers that will play an audio file directly from the laptop. The designers took a specific audio file warning the incoming target that they are in danger and should turn around. Once this audio file was created, the designers demonstrated its performance by first manually looping the file over and over, just to ensure it worked properly and can be heard from far enough away to properly warn incoming intruders.

Before attached, the second alarm to the ATS system, the designers needed to first ensure it is properly connected to the printed circuit board. Once connected to the PCB, a multimeter was used to make sure the proper voltages were being passed through the microcontroller to the alarm. Again, the designers need to make sure the alarm was audible from far enough to successfully warn incoming targets. Once these two alarms had successfully demonstrated compliance, they were attached to the system directly.

From here, the object detecting software was incorporated. The key threshold was when the software first started tracking an incoming object. So once the target was being successfully recognized as a target, the alarm sounded until the target moved out of this range. When the object was within this threshold, the object detecting software sent 2 signals, one to the microcontroller triggering the continuous alarm and the other to the audio file to play and audio file and continuous loop.

To test, the designers would consistently come in and out of the alarming zones to demonstrate compliance of the requirements. When an object was successfully being tracked, both alarms were triggered and continuous alarm would sound as long as they stay in that range. This was the minimum requirement, that the alarm was loud enough to be heard from at least 100 feet way. The results came out to be successful. When the software noticed a moving target in its field of view, an audio file was played saying “I see you”. This audio file was an interchangeable custom file to warn intruders and would continuously loop over and over until the target was no longer being tracked. At the same time, the continuous buzzing alarm played nonstop until the intruders were no longer being tracked by the software. So the tests were successful in meeting the system requirements.

7.1.4 Web camera

The web camera testing happened in a series of steps. Initially, the camera was connected directly to the laptop. Once connected, the designers needed to ensure the camera streams the video fed to the laptop screen in real time. From this point, the designers had assurance the web camera works properly. The designers continued using this video feed to implement the variety of software classes.

Once the designers were pleased with the results of the software implementation, the web camera was be tied to the base of the structure. Once secured, the design team continued testing to demonstrate the web camera's vision. This is continued to show the camera is stable on the base and of course, the vision isn't impaired for any reason.

7.1.5 Laser Pointer

The laser pointer testing was a simple, straight forward process. This was a non-technical technique of testing. The designers were to shoot the paintball gun to see where the paintballs hit. To demonstrate this, the designers just placed the laser pointer down the barrel of the gun. It would run on its own battery power and wherever the laser pointer would mark on a target, the designers deemed this satisfactory enough to meet compliance of accuracy. It was a simple process but was sufficient enough to ensure the laser pointer was properly calibrated to where the paintballs would impact the incoming target.

The results came out to be very successful during our demonstration of the working prototype. This was good enough to mimic exactly where the turret system was targeting. A proper implementation of a laser pointer was to become a future improvement due to the compressed time schedule the designers had to work around. The laser pointer was more a luxury than a necessity and the committee was satisfied with the accuracy capability demonstrated by the laser pointer.

7.1.6 Capacitive Touch Controller

Before incorporating the capacitive touch controller onto the autonomous turret, the controller itself must be tested for various cases. To begin, each function related to controlling the autonomous turret must be tested to see if the correct bit sequences are transmitted. Each pin dedicated to the specific bits will be measured with a digital multi-meter. When the microcontroller is first activated, the capacitive touch controller should reset back to 45 degrees. If this correctly happens the capacitive touch controller should transmit 00101101 across the transmission pins tapping the left sensor should increase the transmission to 00101110, then to 00101111, then to 00110000. When the capacitive touch controller is tapped right three times, the controller should transmit 00101111, then 00101110, and then back to the neutral 00101101. When the capacitive touch controller is tapped up three times, the controller should transmit 10001110, then 10001111, then 1001000. When the capacitive touch sensor is tapped down three times, the controller should transmit 10001111, then 10001110, then 10001101.

For the hold functions, the capacitive touch controller should increase by 10 or binary 1010. The microcontroller will be reset which should reset the position back to 45 degrees in the pitch and yaw direction. When the capacitive touch controller is held right, the controller should increase from 00101101 to 00110111, then to 01000001, and so forth until it reaches 140 degrees at binary 10001100.

The microcontroller should transmission bits should not increase if the right button is held. For the hold left function, the transmissions bits transmissions decrease by 10 degrees or binary 1010 similar to the hold right function. The process will be repeated for the hold up and hold down functions keeping minding to the starting and ending range found in the Summary of Angle Transmission for Method 2 table.

The capacitive touch controller will then need to be tested for the special user case if the user tries to press more than one sensor at a time. To test this special user case, the left sensor will be held and the up button will be tapped. If this special case works correctly, the capacitive touch controller should decrease to 00000000 until the left sensor is released. When the left sensor is released and the up sensor is tapped the touch controller should jump to a binary transmission between 10001101 and 111100111 in order to transmit the updated pitch angle. The capacitive touch controller will then be tapped in the middle which should cause the controller to transmit a 11111111 for 20 milliseconds and then return to its previous value.

Once each function and special user case has been tested, the entire process will be repeated once controller is implemented with the microcontroller controlling the servo motors.

7.2 Software Testing

The software testing for the ATS was conducted in a series of phases, which are detailed in figure 22. Step 1 and 2 have already completed a single iteration, the tests were planned and designed as per each test case listed below. The next step was to execute the tests that have been designed. The test execution was broken up into two major components. The first component is module testing. Each section of the computer vision tracking was tested alone to see if it properly completed its individual task in the process. These modules consist of object detection, object tracking track point creation and group creation. After each module has successfully completed its module testing, the modules were integrated with one another to execute the full system test. Each component and task was given a set of test cases they had to complete to ensure the component would work properly when integrated with other components. Once the entire system passed the test cases it was deemed complete.

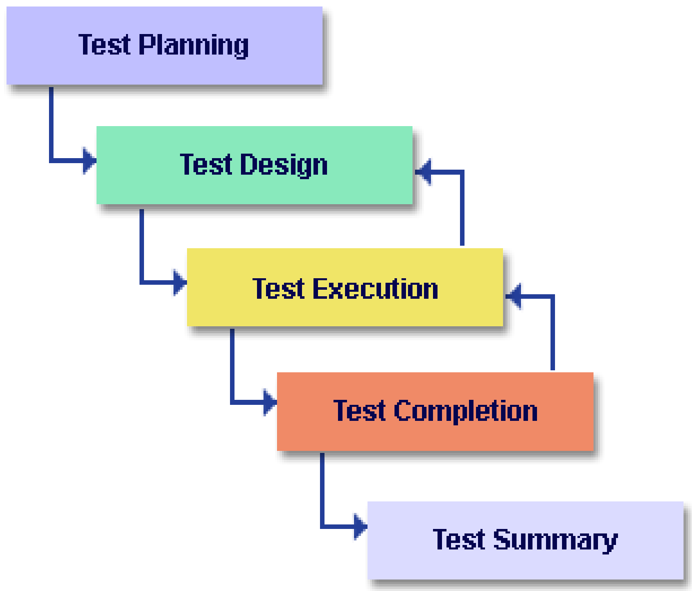


Figure 27 - Testing process

7.2.1 Color Detection Testing

7.2.1.1 Detecting the color of a single colored object

Test Case Description: Given a frame from the web camera, the color detection class was able to accurately determine the hue of the given object.

Success – The class should return the corresponding value of the color of the object.

Failure – An incorrect value or no value is determined for the object.

Result – color detection was not used due to time constraints and its lack of importance to the project.

7.2.1.2 Detecting the color of a multi - colored object

Test Case Description: Given a frame from the web camera with an object containing multiple colors the class should be able to determine the hue that is most prevalent in the frame.

Success – For this test to be considered a success the class must successfully return the most prevalent hue value of the object in the frame.

Failure – The class returns the wrong hue, minority hue, or no hue at all.

Result – color dection was not used due to time constraints and its lack of importance to the project.

7.2.1.3 Detecting the color of multiple objects in the field of vision simultaneously

Test Case Description: Given a frame from the web camera with multiple targets the color detection class was able to accurately determine the hue of each target.

Success -The class should return the corresponding value of the color of each object in the given frame.

Failure -The class does not identify each target, or an incorrect value or no color is determined for the objects.

Result – color dection was not used due to time constraints and its lack of importance to the project.

7.2.2 Object Detection Testing

7.2.2.1 Detecting one object in the field of vision

Test Case Description: Given a frame from the web camera the object detection class must identify a potential target using Haar-like features, and placing a rectangle around the object.

Success –The object detection class places a rectangle around the object.

Failure – The class fails to recognize the target or places a rectangle in the wrong location on the frame.

Result – During testing objects were detected, the group chose to place a crosshair on the target rather than drawing a rectangle around it.

7.2.2.2 Detecting multiple objects in the field of vision

Test Case Description: Given a frame from the web camera the object detection class must identify potential targets using Haar-like features, and placing a rectangle around each object.

Success – The class places a rectangle around each object in the frame.

Failure – The class fails to recognize targets or places rectangles in the wrong locations of the frame.

Result – Multiple targets were detected and the crosshair was placed around the most threatening object.

7.2.2.3 Detecting objects that leave and re-enter the field of vision

Test Case Description: When an object exits the field of vision of the web camera its rectangle and target identification is destroyed. When another object or the same object re-enters a new rectangle and target ID is created.

Success – The class recognizes that the object has left the field of vision and destroys the correct rectangle and corresponding target ID. The class creates a new rectangle and target ID for objects entering the field of vision.

Failure – The class fails to destroy the objects rectangle and target ID when they have exited the field of vision. The class fails to assign a new rectangle and target ID to objects entering the field of vision.

Result – Since the trackPoints of the optical flow algorithm reset themselves once they are taken off screen they are then able to detect new or old targets entering the screen.

7.2.2.4 Detecting objects that are partially occluded from the field of vision

Test Case Description: A Kalman filter is a recursive filter that projects the path of objects by using the objects previous locations to determine its path. This is useful when objects are obscured and moving behind obstacles.

Success – The class must be able to successfully project the path of an object and update the position of the object's rectangle even when the object moves behind an obstacle or is obscured from the web camera.

Failure – The class loses the object and destroys its rectangle and target ID when moving behind an obstacle. The class incorrectly predicts the targets path.

Result – As long as part of the object remained in the field of view the system continued to track the target.

7.2.2.5 No objects in the field of vision

Test Case Description: The ATS will be placed in an open area with no targets present in the field of vision. Everything in the area will be purely background.

Success – The sentry gun does not pick up anything else as a target and does not fire at anything.

Failure - The sentry gun determines that there is a target, when there is none, or fires upon anything in the field of vision.

Result – At first ATS detected and tracked small movements in the field of vision. After increasing the thresholds for a moving target the system remained quiet when no targets appear on screen.

7.2.3 Manual Control Testing

7.2.3.1 Rotating the sentry gun left and right

Test Case Description: This test involved sending pulse signals to the horizontal servo motor to rotate the turret to the left or right.

Success – The turret increased or decreased its horizontal angle when a specified amount was entered. The angle must change by the specified increment and with the different input methods capacitive touch, keyboard keys, and the xbox controller buttons.

Failure – A failure was defined as the turret not responding to any of the three input methods. Failures also included the turret rotating too much or too little, and not stopping after rotating.

Result – The results of the system did not experience any failures of horizontal movement during prototype testing.

7.2.3.2 Panning the sentry gun up and down

Test Case Description: This test involved sending pulse signals to the vertical servo motor to rotate the turret to the up or down.

Success -The turret increased or decreased its vertical angle when a specified amount was entered. The angle needed to change by the specified increment and with the different input methods capacitive touch, keyboard keys, and the xbox controller buttons.

Failure – A failure was defined as the turret not responding to any of the three input methods. Failures also included the turret rotating too much or too little, and not stopping after rotating.

Result – The results of the system did not experience any failures of vertical movement during prototype testing.

7.2.3.3 Altering the rate of fire of the sentry gun

Test Case Description: This test consists of altering the rate of fire of ATS by using the list menu on the Windows Form Application. There are three rates of fire fully automatic, burst, and single shot.

Success – A success is defined by the turret’s rate of fire. In order to pass this test the turret must accurately react to the changing of fire rate by adjusting the speed that the trigger servo fires and adding delays or stops as necessary.

Failure – The test is a failure if the turrets rate of fire does not change after selecting an alternative rate of fire. The test also fails if ATS fires at a rate that does not correspond to the selected rate of fire for instance the turret is firing in bursts when single shot is selected

Results – The results of the test proved that alternate rate of fires via the GUI were correctly implemented. In addition, the dip sockets on the electronic solenoid were also changed to alter the rate of automatic fire without having to flash the program back onto the secondary controls MCU.

7.2.3.4 Firing the sentry gun.

Test Case Description: This test would ensure that the Manual Control class fires the turret when the user either presses the Fire button located on the different controlling methods

Success – A success was defined by the gun firing when pressing either the button on the application or the spacebar. The gun must also fire at the correct rate.

Failure – A failure occurred if the gun does not fire when using either the button or spacebar. A failure was also defined if the turret did not fire at the specified rate or does not stop firing once starting.

Results – The results of the ATS system did not experience any firing problems. The system responded properly when the fire buttons were selected on all the different manual controls, the keyboard, capacitive touch and xbox controller.

7.2.3.5 Alerting the target with a warning

Test Case Description: The alert button on the Windows Form application is used to warn intruders that they are entering a restricted area, and that they should leave the area immediately.

Success – A success occurs when the correct audio file is played through the speakers when pressing the alert button on the application.

Failure – The wrong audio file or no audio is played at all. The audio does not play clearly or plays in a continuous loop.

Result – The application was successful in alarming targets 2 seconds before firing on them.

7.2.3.6 Alerting the target that the sentry gun is about to attack

Test Case Description: A fire warning alarm was used to warn intruders that they were about to fired upon by the turret.

Success - A success occured when the correct audio file is played through the speakers when pressing the alert button on the application.

Failure – The wrong audio file or no audio was played at all. The audio did not play clearly or plays in a continuous loop.

Results – The results of the ATS system was didn’t go as originally planned. The designers chose not to have a control that controlled the alarm. Instead, they relied upon the software to signal the alarm when an object started to get tracked.

7.2.4 Object Tracking Testing

7.2.4.1 Tracking a single, walking target

Test Case Description: One target walked through the field of vision for a short period at a constant speed. The target was to be change directions on multiple occasions.

Success – The sentry gun was able to keep up with the target for the entire duration of the test, following all movements in any different direction.

Failure - The sentry gun lost track of the target, aims in the wrong direction, or cannot keep up with the speed of the target.

Result – The results during prototype testing did not experience any failures in tracking singular walking targets.

7.2.4.2 Tracking multiple, walking targets

Test Case Description: Three targets were able to walk through the field of vision for a short period at the same, constant speed. Each target was capable of changing their direction and pass one another throughout the test.

Success - The sentry gun tracks the target with the highest priority, most points, and if another target becomes higher priority, it switched to that target.

Failure - The sentry gun tracked no targets, or tracked a target with lower priority than another, or if the sentry gun failed to switch targets upon a change of the highest priority target.

Result – The results during prototype testing did not experience any failures in tracking multiple walking targets. The ATS system would automatically switch to the target with the most points, highest priority.

7.2.4.3 Tracking a single, running target

Test Case Description: One target would run through the field of vision for a short period at a fast speed. The target would change its direction on multiple occasions during the test.

Success - The sentry gun kept aim on the target throughout the duration of the test and never loses track of the fast moving target.

Failure – The sentry gun failed to keep up with the target, or does not correctly track the target.

Result – The results during prototype testing did not experience any failures in tracking singular, fast moving targets.

7.2.4.4 Tracking multiple, running targets

Test Case Description: Three targets would run through the field of vision for a short period at a fast speed. Each target would alter its direction on multiple occasions.

Success – The sentry gun kept up with the highest priority target, the target with the most points, and switched targets whenever another target becomes more important.

Failure – The sentry gun failed to keep up with the target it was tracking, tracked the wrong target, or failed to switch targets when another gains higher priority.

Result – The results during prototype testing did not experience any failures in tracking multiple running targets.

7.2.4.5 Tracking multiple targets with varying velocities

Test Case Description: Three targets would run, jog, or walk through the field of vision for a short period. Each target would change its speed and direction during the test.

Success - The sentry gun tracked the highest priority target and kept track of them regardless of the speed. Also it switched between targets when the priority changes.

Failure – The sentry gun failed to track targets, keep up with them, switched targets when another gains priority or tracked the wrong target.

Result – The results during prototype testing did not experience any failures in tracking multiple targets with varying velocities.

7.2.4.6 Tracking a high speed object

Test Case Description: An object would enter the system's field of vision, at a high rate of speed (a ball thrown by a person). The ball would cross through the field of vision from one side and exit on the other side.

Success – The sentry gun would detect, track, and hit the high speed target.

Failure – The sentry gun failed to register the object as a target, could not keep up with the speed of the object or failed to aim at the target properly.

Result – The results during prototype testing did not experience any failures in tracking high speed objects. The system was not able to track the object during its entire trajectory but was capable of locking onto the target sometime during its path.

7.2.4.7 Tracking targets that stop moving for a period of time

Test Case Description: Three targets would enter the field of vision of the ATS and at some point during the test, stop moving for a short duration and then continued moving.

Success - The sentry gun kept firing at the stationary targets and then proceeded to track their movement once it resumed.

Failure - The sentry gun lost the target because it is no longer moving or failed to continue tracking it once movement resumes.

Result – The results during prototype testing did not experience any failures in losing the targets and the ATS system was able to track movement once it resumed.

7.2.5 Fire Rate Testing

7.2.5.1 Single shot

Test Case Description: The fire rate was initialized to represent a single shot rate of fire.

Success – The system registers the rate of fire command and sends the correct signal to the servo motors to replicate a single shot.

Failure – The system does not register the rate of fire command or inaccurately commands the servo motors to fire the weapon.

Results – During testing, the trigger was attached to the oscilloscope. Multiple single shots were tested. During the initial test, it appeared the trigger fired repeatedly. This was resolved by simply changing single shot on the secondary controls MCU to push the pin high rather than rely on having a timer shoot on shot and disable immediately after.

7.2.5.2 Burst fire

Test Case Description: The fire rate was initialized to represent a burst fire (three to five shots) rate of fire.

Success – The system registers the rate of fire command and sends the correct signal to the servo motors to replicate a burst fire.

Failure – The system does not register the rate of fire command or inaccurately commands the servo motors to fire the weapon.

Results – During testing, the trigger was attached to the oscilloscope. The trigger was recorded to shoot approximately four shots before becoming disabled again. This proved the burst fire was correctly working with the GUI.

7.2.5.3 Automatic fire

Test Case Description: The fire rate was initialized to represent an automatic rate of fire.

Success – The system registers the rate of fire command and sends the correct signal to the servo motors to replicate a fully automatic weapon system.

Failure – The system does not register the rate of fire command or inaccurately commands the servo motors to fire the weapon.

Results – During testing, the trigger was hooked up to the oscilloscope. It was confirmed that automatic fire was properly working when the command was sent from the GUI. The automatic fire only failed when the external battery of the electronic solenoid accidently became disconnected. This was resolved by making sure the battery was correctly attached.

7.2.6 Threat Level Testing

7.2.6.1 A single non-threat target

Test Case Description: One target, that is a non-threatening target, entered the field of vision and moved throughout the area for a short duration.

Success - The target is detected, determined to be a non-threatening target and therefore not fired upon.

Failure - The target is not detected, or detected and determined to be a threatening target, or if the target is determined to be non-threatening but still fired upon.

Result: If a target too small to pick up 3 points, entered the field of vision, it was not fired upon.

7.2.6.2 A single threatening target

Test Case Description: One target, that is a threatening target, entered the field of vision and moved throughout the area for a short duration.

Success - The target is detected, determined to be a threatening target and therefore fired upon by the weapon system.

Failure – The target is not detected, determined to be a non-threatening target or is not fired upon entry to the field of vision.

Result – The threatening target was quickly picked up, accurately, and within 2 seconds under fire from the system.

7.2.6.3 Multiple non-threat targets

Test Case Description: Three non-threatening targets entered the ATS' field of vision and moved around for a short duration.

Success – The system accurately detects all targets in the field of vision and determines that they are of no threat and therefore does not fire upon any of the targets.

Failure – The system does not detect all targets, or if the system determines one of the non-threatening targets to be a threat. Also a failure occurs if the system fires upon any non-threatening targets.

Result – The system did not implement complex threat levels so this test was not used.

7.2.6.4 Multiple threatening targets

Test Case Description: Three threatening targets entered the ATS' field of vision and moved around for a short duration.

Success – The system accurately detects all targets in the field of vision and determines that they are all threatening targets, and then chooses the one with the highest priority to fire upon.

Failure – The system fails to detect all targets or incorrectly determines any of their threat levels. Also a failure occurs if a target with the most priority is not fired upon.

Result – The system accurately picked up and tracked all three targets. Also, it prioritized the one with the most points and fired upon it.

7.2.6.5 Mix of threatening and non-threat targets

Test Case Description: Two separate tests were run for this case. Two non-threatening targets and one threatening target entered the field of vision and moved around for a short duration. Then one non-threatening target and two threatening targets entered the field of vision and moved around for a short duration.

Success – The sentry gun determines the threat level of all targets in the field of vision and fires upon only threatening targets with the highest priority (in the case of one threatening target, it only fires on that target, and, in the other case, it chooses the most important of the two threatening targets).

Failure – The sentry gun incorrectly determines the threat level of any of the targets in the field of vision or fires upon a target that was deemed non-threatening. Also a failure occurs if a threatening target without the highest priority is fired upon.

Result – the targets too small to be picked up, went unscathed while the threatening targets were picked up and shortly eliminated.

7.2.7 Facial Recognition Testing

7.2.7.1 Detecting a Face Using the On-board Computer Camera

Test Case Description: When the user wanted to access the manual control class the user would be asked to position their face in the frame. The facial detection and recognition class would acknowledge that the image is indeed the face of a proper user.

Success -The class would recognize the presence of a face and move to step two which would match the image with one in the database full of images of faces. If no face is not in the frame the class would prompt the user to position their face in the center of the screen. The identification processes would time out after one minute.

Failure –The facial detection class failed to recognize the face in a given frame. The class did not prompt the user to re-position or falsely identifies a non-face as a human face. The class failed to time out after one minute.

Result – The results during prototype testing were that the designers chose not to implement the facial recognition security protocol due to a shorten timeline of completion.

7.2.7.2 Matching a Face with a Face in the Database

Test Case Description: After confirming that the image was indeed a face, the class should correctly match the face with an image of the face in the database. The class would also refuse access to anyone trying to access the manual controls that wasn't not in the database.

Success -The class correctly matched a face in the web camera frame to a face in the facial database. The class denied access to anyone not in the facial database.

Failure – The class falsely granted access to a person not in the database. The class denied access to those persons in the database.

Result – The results during prototype testing were that the designers chose not to implement the facial recognition security protocol due to a shorten timeline of completion.

7.2.8 Integrated Software System Testing

Another testing criterion the ATS designers wanted to implement into the overall system testing was integrated software system testing. This involved the overall system testing to ensure the designers created a successfully working prototype. The following are test cases that test one and multiple targets in the field of vision as well as testing targets entering and leaving the field of vision. The test cases as well as results for integrated software system testing are listed below.

7.2.8.1 One target in the system

Test Case Description: A single target would enter the field of vision and move throughout it for a duration of time.

Success – the target whould be detected, tracked, and if tracked, fired upon. If not a threat then the weapon would not fire at all.

Failure – Any component of the software failed to complete its specified task. i.e. if the target was not detected, if the threat level was incorrectly determined, if it was not properly tracked, or if the target was fired/not fired upon when it should be the opposite.

Result – The results during prototype testing did not experience any failures in detecting, tracking and firing upon a target in the field of vision.

7.2.8.2 Multiple Targets in the system

Test Case Description: Three targets would enter the field of vision and move throughout it, at varying speeds and directions, for a duration of time.

Success – All targets would be detected, determined, and tracked, the weapon would fire on the most important target, with the most points. If there were no moving objects then the weapon would not fire at all.

Failure – Any component of the software failed to complete its specified task. i.e. if any of the targets were not detected, if the threat level for any target is incorrectly determined, if the highest priority target was not properly tracked, or if the target with the most priority was fired/not fired upon when it should be the opposite.

Result – The results during prototype testing did not experience any failures in detecting, tracking and firing upon multiple targets in the field of vision.

7.2.8.3 Targets entering and leaving the system

Test Case Description: Three targets would enter the field of vision and move throughout it, in varying speeds and directions, for a duration of time. Then some exited the field of vision, come back in, others would do the same a short time after.

Success – All targets would be detected, determined, tracked, and if any are threats, the weapon should fire on the most important target, with the most points. If there were no threats then the weapon would not fire at all. Whenever a target left the field of vision, all of its data points would be reset and if the object happened to re-enter, then new fields would be created.

Failure – Any component of the software failed to complete its specified task. I.e. if any of the targets were not detected, if the threat level for any target was incorrectly determined, if the highest priority target was not properly tracked, or if the target with the most priority was fired/not fired upon when it should be the opposite. Also if the system failed to reset or create new data for targets exiting or entering the field of vision, respectively.

Result – The results during prototype testing did not experience any failures in detecting, tracking and firing upon targeting entering and leaving the field of vision.

7.3 Software and Hardware Communication Testing

The software of the ATS will have to control the hardware on multiple occasions to get the intended result of the system. The microcontrollers and servo motors will both need to be sent signals to be told what to do.

7.3.1 Pitch Servo Motor Communication

Test Case Description: The servo motor that controls the pitch is sent a series of signals that tell it how much to move. These positions covered the full range that the servo motor is required to operate within.

Success – The servo motor responds correctly to all signals, moves to the correct position and rotates with the necessary speed.

Failure – The servo motor goes to a wrong position, the wrong signal is sent to the servo motor or if the servo motor rotates too slowly to keep up with moving objects.

Results – During testing, the servo controls MCU was attached to the oscilloscope. The calibration GUI was started and a user attempted to send different commands to the servo. The GUI correctly decreased the pulse widths, increased the pulse widths, and changed the angles. In addition the save to flash memory feature also passed.

7.3.2 Yaw Servo Motor Communication

Test Case Description: The servo motor that controls the yaw was sent a series of signals that tell it how much to move. These positions covered the full range that the servo motor is required to operate within.

Success – The servo motor responds correctly to all signals, moves to the correct position and rotates with the necessary speed.

Failure – The servo motor goes to a wrong position, the wrong signal is sent to the servo motor or if the servo motor rotates too slowly to keep up with moving objects.

Results – During testing, the servo controls MCU was attached to the oscilloscope. The calibration GUI was started and a user attempted to send different commands to the servo. The GUI correctly decreased the pulse widths, increased the pulse widths, and changed the angles. In addition the save to flash memory feature also passed.

7.3.3 Trigger Servo Motor Communication

Test Case Description: The servo motor that controlled the trigger will be sent a series of signals that tell it when to pull the trigger. These signals would test all three of the fire rates to be used (automatic, burst, and single shot).

Success – The servo motor responded correctly to all signals, pulling the trigger to simulate an automatic, burst, or single shot fire rate as specified.

Failure – The servo motor did not simulate the correct fire rate or does not fire the weapon at all. Also a failure occurs if the wrong signal is sent to the servo motor.

Results – The designers did not implement a servo motor to control the trigger. Instead the designers send the signal to an on board MC that controlled the trigger of the paintball gun.

7.3.4 Microcontroller Communication

Test Case Description: The microcontroller software would send the microcontroller signals to let it know what to do.

Success – The microcontroller accurately received all signals sent to it and responds accordingly.

Failure – The incorrect signals were sent or received or the microcontroller operates in the wrong manner.

Results – The designers were capable of accurately sending and receiving all signals sent to and from microcontrollers. From there the system responded as expected.

7.3.5 Web Camera Communication

Test Case Description: The web camera was hooked up to the computer running the program and it needed to send its video stream into the program through the videoCapture class.

Success – The web camera sends its video stream to the videoCapture class and all frames of the video are received from the web camera and are able to be used in the computer vision application.

Failure – The web camera fails to send its video stream to the software, or the videoCapture class does not correctly interface the device with the program. Also a failure occurs if the frames received from the web camera are not able to be used in the program for whatever reason.

Result – the web camera functioned correctly and the software was able to get the necessary data from the camera and output the feed to the screen.

7.4 Overall System Testing

Once ATS's components were tested individually it was time to start assembling the individual components to test their interactions with one another. The first thing the group tested was the interaction between the microcontroller and the servo motors. In order to create an automated turret it is imperative that the microcontroller can send signals to the servo motors to move them. The next step was to start assembling the base; once this is completed the group tested the motors again to ensure they have enough torque to move the turret. The next step was to hook up the on-board computer and test the object tracking is working with the web camera. Various software components were checked starting with manual control, to ensure that the microcontroller is processing the information correctly and sending signals to the servo motors. Once the full system is assembled the group began testing the turret and the interactions that the individual components have with each other. The systems longevity and durability must also be tested. These tests demonstrated that the turret held up to the recoil of the gun and the system remained running at least thirty minutes on battery power.

Overall system testing was done by the group as a whole. The test cases were recorded and reviewed. Errors were corrected in a timely matter. Having the entire group for testing allowed each member to work on their respective components and correct issues in a uniform environment. To ensure functionality the tests were performed several times and in different testing environments to account for weather and environmental variables. A few environments included the senior design lab, outside the engineering building, and in the atrium. System testing occurred throughout the semester by adding components passed their respective test cases. Full system testing with all components took place the month before final presentations. This ensured that there was enough time to catch any problems that and guaranteed that ATS was ready for demonstration day.

7.4.1 Using manual control test the turret's movement

Description- To test the interactions between the onboard computer and the microcontroller, and the interaction with the microcontroller and the servo motors the turret will be moved left, right, up, and down.

Success – The turret moves in the specified direction incrementing the angle by a set degree every time. The turret must move in all four directions and do so in a time efficient manner. The turret must also be able to be controlled using the various forms of manual control including the keyboard, xbox controller, and capacitive touch.

Failure –The turret does not move, or moves in the wrong direction. The turret adjusts its angle by too much or too little. The turret gets stuck or the weight of the turret is too much for the motors. The turret does not stop moving once it has reached its correct position. The turret does not respond to one of the forms of manual control.

Result – The system was first tested with the capacitive touch controller and responded fairly well, but even better after re-calibrating the controller. The system was easily controlled through the keyboard by simply mapping keys to increment or decrement the angle values, and shoot. Once the keyboard controls were implemented hooking up the xbox controller was done by mapping the buttons of the controller to the existing keyboard controls.

7.4.2 Using the object tracking class to detect objects and move the turret accordingly

Description – Once the manual controls were working the next step was to integrate the computer vision software to move the turret. The web camera would be used to detect targets while the object detection and tracking classes would send the coordinates to the microcontroller to process. Once the coordinates are processed the microcontroller would move the servo motors accordingly.

Success – The object detection class successfully picked up targets in the camera's field of vision. The object tracking class continuously sent coordinates to the microcontroller which in turn moves the servo motors.

Failure – The object detection class failed to identify any targets or the object tracking class did not send the coordinates to the microcontroller. The servos failed to move or incorrectly interpret the coordinates and move in the wrong direction.

Results – The results of the test were a success. The system was able to successfully pick up targets in the camera's field of vision. From there, the object tracking class would continuously send coordinates to the microcontroller which would accurately track the moving object.

7.4.3 Battery testing

Description – The system has the ability sustain four hours of operation powered by nothing but the battery. The four hour duration was tested multiple times to ensure the battery was not degrading and charging correctly.

Success – The system remained up and running for at least four hours of tracking targets and regular use of the gun.

Failure – The system did not remain operational for four hours or encountered an error that forced the group to recharge the battery and retest.

Result – The results during prototype testing did not experience any failures in battery testing to meet compliance with the system requirements.

7.4.4 Power Regulators

Due to breaking multiple switching regulators, multiple stress tests were performed to reduce the cost of breaking multiple parts. Originally heat sinks were avoided and the voltage regulators quickly fried multiple components. This was caused by nearly 2.5 amps being drawn when the servo motors were originally starting up. When the voltage regulators were fried, they no longer regulated and, instead, applied a full 12 volts to multiple MCUs and servo motors. In this process, approximately four microcontrollers were lost as well as two servo motors.

After the above failure, large heat sinks along with thermal paste were applied to keep temperatures well below the operating threshold. With heat sinks, the voltage regulators were hooked up to a power supply and a programmable electronic DC load available in the senior design lab. The power supply was set to 13 volts with maximum current draw of three amps. The DC electric load was set to five volts and 2.5 amps to simulate servo motors on full load. This test was originally only supposed to last approximately fifteen minutes, but due to complexity in ordering sandwiches, the test lasted well over an hour. During a food run, the voltage regulators were monitored by a fellow senior design group. During the test, multiple temperature measurements were taken. However, after an hour of stress testing, the temperature of the TO220 package never exceeded 55 degrees Celsius. This was well within the specified operating temperature.

7.4.5 Durability testing

Description – The system including the base, hardware plexiglass box and the turret would hold up the vibration and rigor caused by the recoil of the gun. This stress test would take place throughout the rest of the testing. If the components are still functioning and the base was still sturdy, the test was passed.

Success – The hardware components and base was able to hold up to the week of system testing. This ensured that the turret would function on demonstration day.

Failure – The hardware components would malfunction due to vibration or the bases stability would be compromised. If the testing failed the group was forced to reinforce the turret and re-test.

Result – The results during prototype testing did not experience any failures in durability testing to meet the design specifications.

7.4.6 Single target testing

Description – The system will first be tested using a single target. Once the system is powered on a target will walk or jog at a temperate pace. Once the system has acquired the target and added the object to the target list it will warn the target that it is entering restricted five seconds after entering the field of vision. After fifteen seconds the turret will play another audio file informing the user it is going to fire. The turret will fire upon the threat until the target has exited the field of vision or until the target is covered in enough green paint to deem the target no longer a threat.

Success – ATS acknowledges the target and adds it to the target list once entering the field of vision. The warning audio file plays after five seconds and the commence firing audio file plays after fifteen seconds of acquiring the target. ATS begins firing on the target until the target either exits the field of vision or is marked with enough green paint.

Failure – There are numerous actions that would deem this test a failure. The first is that ATS does not recognize the target and does not add the threat to the target list. The audio files do not play, or the gun does not track the target are also considered failures. Issues concerning the gun not shooting or ceasing to fire are also considered failures.

Result – Once the target entered the field of vision it was alerted by audible alarm and verbal warnings. After the warning the gun began to fire upon the target. Through calibration and adjusting the thresholds the team was able to align the paintball marker to make the system highly accurate.

7.4.7 Multiple target testing

Description – Once the group is confident that ATS is capable of handling single targets the multiple target testing will take place. Multiple target testing involves several objects or threats entering the field of vision. ATS will then add them to the target list and rank their priority by time spent in the field of vision. ATS will track the target that spent the most time in the system playing the warning audio file at five seconds and the commence firing audio file at fifteen seconds. Once the target ATS is tracking exits the field of vision or is deemed no longer a threat the turret will focus its attention on tracking the next target in the priority list.

Success –Multiple target testing is considered a success if all targets are either eliminated or exit the field of vision. The targets must be eliminated in the order they enter the system’s target list.

Failure – ATS fails to recognize any targets or focuses the entire time on just one target. ATS does not delete eliminated targets from the priority resulting in only one target being shot at. The system gets confused with conflicting targets and loses the target it is currently tracking.

Result – The system tracks the target that contained the most trackpoints in its groupID. If a second target walked in front of the currently tracked target the turret would switch targets to track the closer higher threat target. The system did have some trouble when there was more than three targets or when the targets were closely clumped together resulting in one large target.

7.4.8 Demonstration testing

Description – The demonstration of the system was successfully demonstrated all of the features of ATS. The group will prepare the demonstration ahead of time including all of the features of ATS and test the full demonstration a minimum of ten times.

Success – ATS successfully demonstrated its capabilities and functionality all ten times.

Failure – ATS failed a step in the demonstration. If this occurs the group would resolve the issue and retest. It is imperative that the ATS demonstration succeeded ten times in succession to ensure without a doubt that the system was function on demonstration day.

Results – The ATS designers were able to successfully demonstrate a fully working prototype more than the ten times originally planned. So during the demonstration day, the designers were confident in their product and surely enough, the prototype worked flawlessly because the ATS system was able to demonstrate all the required specification for the committee of professors.

7.5 Environmental Testing

Environmental testing was a method to ensure the ATS system was capable to withstand a variety of different environments. Since the weather was a dynamic element that was rarely understood and typically unpredictable, the designers need to test under different circumstances to make sure the system would perform properly. By exposing the system to a wide variety of environments, the designers were able to be reassured of the reliability which is an important aspect of any prototype owned.

7.5.1 Indoor testing

The ATS system was tested both inside and outside, outside mainly to demonstrate the system was be able to continually perform even when exposed to a variety of environmental weather conditions. The ideal condition for the prototype testing was to be demonstrated within doors, mainly so the designers can control the environment. The system was intended for both indoor and outdoor use so by demonstrating the system can perform within doors where the external conditions were controlled, the designers could successfully demonstrate a working prototype for at least the ideal situation. Outdoor testing would add more difficultly just because the uncontrollable weather conditions.

7.5.2 Outdoor testing

The ideal condition for any prototype was a controlled environment such as within doors where the conditions are monitored accordingly. However, the ATS system was intended to have multiple uses, including properly functioning even in the outdoors. Therefore, the designers tested outside to ensure the system can handle the unpredictable weather when left exposed to natural elements. The initial concern was going to be the outdoor lighting and how it would affect the camera. But the results during outdoor testing did not experience any failures in meeting compliance of a successful working prototype.

7.5.3 Dim lighting testing

The ATS was to have the ability to perform in dim lighting so the system was tested during evenings as well as day time settings. The camera was not a full on night vision camera so the system's performance maybe affected based on the amount of natural lighting during the night. Ideally, the system would perform with the same success as during day time testing, however; the designers did not know until the prototype is successfully built and the system was be tested. If it was completely black out and the camera will not be able to successfully identify the targets so the designers anticipated the ATS system that would not perform under this specific situation. The results during dim light testing did not experience any failures in meeting compliance with the system requirements.

8.0 Administrative Content

8.1 Timeline

The designers created a master schedule to follow to ensure the production of the ATS system. Two separate schedules were developed for the fall and the spring. The fall schedule primarily focused in research and design. The spring schedule's main focus was the development and testing. Each schedule was outlined with starting and completion target dates.

8.1.1 Fall 2011

In the first week of September, the group was chosen. Members were chosen based on the skills each person possessed, and how they could be applied to the project. After the group was chosen, the design proposal was written up over the next week. The month of October was to be spent doing mostly research for the project and beginning the technical documentation required for the semester. The research was broken up into sections for each member, and they were responsible for relaying the vital information of that section to the rest of the team members. James and Daniel handled the majority of the software research, while Stephen and Ethan each took the lead on the hardware research. The month of November was dedicated to the design of the system, while finishing the technical documentation, simultaneously. The same team strategy was utilized for the design section, which means that James and Daniel would handle software design and Ethan and Stephen would handle the hardware design. The whole team collaborated on important design decisions but the details were be handled by individual team members in control of that section. The weekend before the submission deadline was allocated for reviewing and formatting the document with a one day buffer for any last minute problems. This was the ideal scenario so that there are no last minute changes needed, but if there did happen to be, there was time to make the necessary changes. The fall semester was a more strict schedule than the spring semester, meaning that the full allotted time for each section was be spent and no extra time unless necessary. This was to keep the design process organized and efficient and to help to prevent the group from falling behind at any point. Overall, the group stuck to this schedule fairly well. The fall schedule can be found in table 19 below.

Fall 2011 notional schedule		
Task	**Start Date**	**Completion Date**
Group Selection	September 5, 2011	September 9, 2011
Design Proposal	September 15, 2011	September 22, 2011
Research	October 3, 2011	November 4, 2011
Technical Documentation	October 17, 2011	December 2, 2011
Design	November 4, 2011	December 2, 2011
Review/format documentation	December 2, 2011	December 4, 2011
Document Submission	December 5, 2011	December 5, 2011

Table 13 - Fall 2011 Schedule

8.1.2 Spring 2012

The initial purchasing of materials began shortly right when the designers started the spring 2012 semester. Minor materials, such as regulators, transistors, etc, were obtained throughout the spring semester, but the essential components were initially bought in the first month, such as servo motors, web cameras, battery, etc. At the same time, the coding for the microcontrollers for the capacitive touch and servo motors began. These were completed by the end of January. From a software perspective, the initial coding began with the basic object detection and object tracking algorithms. These were completed by the end of Spring break the latest as the designers worked on this aspect extensively to ensure the highest quality. Towards the end of February, the design team had a critical design review with the group's mentor to establish the team still had the proper path forward towards completion.

The hardware assembly began at the start of January and continued for two months. The base construction was initially started in the middle of January. James led this action with a complete working base structure, fully built by the end of February. Ethan and Stephen worked with the servo motors and microcontrollers. Once completed, they combined their work to assemble the overall structure of the system. Also the tracking software was coded in the month of January through the beginning of March by James and Daniel. Once the rest of the coding was completed, the tracking software was integrated with the hardware be tested in full for final testing.

During this final testing, the design team handled the PCB design and fabrication for the final presentation. Note that several stages testing happened throughout the process, but the periods listed were solely dedicated to testing all possible cases the ATS could encounter.

Finally the website was added and the final presentations occurred April. The final presentation for the ATS design team was in the middle of April with entire engineering college having a design day demonstration, which followed later that week. The timeline for this semester was be strict due to the compressed time scheduled for the engineering college design day demonstration. The spring schedule can be found in table 20 below.

Spring 2011 schedule		
Task	**Start Date**	**Completion Date**
Purchase Materials (initial)	January 2, 2012	January 20, 2012
Servo and Microcontroller set-up	January 9, 2012	January 31, 2012
Critical Design Review	February 21, 2012	February 21, 2012
Build base structure	January 16, 2012	February 23, 2012
Code the object detection and tracking algorithms	January 9, 2012	March 9, 2012
Integrate Hardware and Software	March 10, 2012	March 19, 2012
PCB Design / Fabrication	March 26, 2012	March 30, 2012
Test/debug	March 19, 2012	April 9, 2012
Demonstration for committee board	April 10, 2012	April 10, 2012
Demonstration design for engineering college	April 13, 2012	April 13, 2012
Review/format documentation	April 16, 2012	April 20, 2012
Website	April 19, 2012	April 20, 2012
Submission	April 23, 2012	April 23, 2012

Table 14 - Spring 2012 Schedule

8.2 Budget

ATS was funded entirely by the group. The cost of the parts, materials, and service costs were shared equally by the four group members. This was a big decision, but in the end the group felt that this was the best option because of the extra paperwork and stipulations of having a sponsor. The original budget was set at $1000, or $250 dollars each. While researching and comparing parts it was clear the team overestimated the budget. The cost of all the required parts was $336 dollars. Many components including the paintball gun and all of its accessories are already owned by a friend of the group. The group ran into unforeseen costs because they had to replace several microcontrollers and servo motors after shorting two pins on the voltage regulator. ATS will be given to a friend of the groups who assisted in the mechanical design of the project. The budget can be found in table 21.

ATS Budget		
Part	**Cost**	**Obtained by**
Servo Motors	$102.97	Purchased
MSP-EXP430 LaunchPad	$4.30	Donated
MSP430 Capacitive Touch Booster Pack	$10.00	Donated
Logitec C310 HD Webcam	$29.99	Purchased
GH1213 Lead Acid Battery	$15.99	Purchased
Turbo series TMC-86-530-W Alarm	$9.64	Purchased
HK – E03358 Laser Pointer	$14.99	Donated
PCB	$33.00	Purchased
Mounting Mats	$100.00	Purchased
E-Matrix, Hopper, Nitrogen tank.	$150.00	Donated
Paintballs	$29.99	Donated
Extra Electrical Components	$30.00	Purchased
Total retail cost	**$530.87**	

Table 15 - ATS component planned expenditures

9.0 Reflections

By the end of the semester, there were many reflections on overall improvements to the ATS system. These are broken up into features left out of the original design and overall improvements. These are discussed in the following sections.

9.1 Features left out

Throughout the research and design process of the ATS, there have been many decisions on what extra features to utilize within the project to enhance its quality. Some were agree upon, while others did not make it into the design of the system. The first major design decision made was the choice to use openCV software or FPGA hardware to complete the task of computer vision within the ATS. This was perhaps the most difficult decision that the group made because it was the basis of the whole project and a choice between a hardware-heavy or software-heavy project. OpenCV was chosen because of the preference for software within the group and the enhanced capabilities of the computer vision application if software is used. Although, using hardware to complete the computer vision makes that part considerably faster, due to hardware being faster than software, it did not fit the teams goals with this project. Even within the choice of software there was a decision to be made between openCV and Aforge.net software for the computer vision application. The group made the decision to go with openCV based on the fact that it uses C++ rather than C#. Also, openCV has a larger library of computer vision functions and has been more thoroughly tested so the group knows it relies on the functionality of the openCV classes and methods that was used in the ATS' software. Overall, openCV has the best characteristics out of the three computer vision options of FPGA hardware, openCV software, and Aforge software.

Another feature that did not make it into the final design is the android application for manual control. Two members have worked with android applications before and it seemed like an interesting way to control the turret manually, however the process of interfacing the on-board computer that is running the main program with the phone running the android application seemed to be a challenge. A database is needed, which adds another large component to the project just for a small amount of data sharing between the two devices. Furthermore, the android application basically operates exactly the same as a user interface for the on-board computer so it does really add a new element in that sense to the project. The database is a new element in the ATS design, which is also used for other features like recording engagement history statistics. In light of this decision, a capacitive touch controller has been decided to be used to control the turret manually, which is seen in detail in the hardware research and design sections.

A range finder was also initially proposed in the design of the system. This is used to find the range of the targets so the system warns the targets when they were entering a danger zone. Also they are warned before they were fired upon.

The range finder was also going to be used to determine when to disengage a target (once they exited the range of 75 feet from the sentry gun). However, due to cost and budget limitations this is not planned for the final prototype of the ATS. It is still a possibility for the design of the ATS and is the first feature that is added back in if there is a way to implement it, given the budget that has been set for the system. It adds a nice touch to the sentry gun without much overhead so hopefully it finds its way back in.

Lastly, some extra software features failed to make it into the final design of the ATS. The reason for this is because only so many were implemented given the time for the project, so some of the features had to be left out. Included in the design, color detection and facial recognition (for the manual control) add an extra layer to the project providing a more decision based system than without. One of the features that the team chose not to add was facial recognition of targets due to the challenge of recognizing faces at such long range. Instead the team came up with the idea of using it as a security measure for unlocking the ability to manually control the sentry gun.

Overall, the ATS has quite a few cool features added to its core concept of an automated sentry gun, but some others did not make it into the design. The main reasons for leaving some features out are time constraints, but for the range finder it is more of a budget issue rather than a time or other issue. The group wishes it used the range finder as it enhances the projects capabilities significantly but just costs too much. The rest of the features were left out due to time constraints and replaced by other features that added similar benefits to the design. In the end, some of these features may make their way back into the project if there is extra time left at the end of the second semester, but if not they are not used for future improvements if the group decides to continue working on the ATS after senior design is complete.

9.2 Future Improvements

The ATS system has plenty of room for improvement, and, since it has been designed with modifiability and upgradability in mind, it is capable of handling those improvements. Also, the ability to have interchangeable parts is an objective of the ATS so switching to a new and improved part will be relatively easy. The first improvement that should be made is adding the range finder discussed in the features left out section. This would add another factor to the decision of when to attack and when not to attack the targets in the field of vision (this would be based on very specific ranges for warning, engaging, and disengaging).

The next improvement that should be made on the ATS is hardware upgrades to the weapon system. The paintball gun and equipment used for the design was already owned so to minimize the budget it was used. However, with a more hi-tech paintball gun, a more efficient system could be built around it. This would help make the system more lightweight and efficient. Also, in terms of hardware improvements, the servo motors only cover a certain range to rotate so it would be a great improvement to give the system a larger range of vision (if possible 360 degrees by rotating it around constantly). Being able to cover all directions of the area would be an improvement on just a wide range in front of the sentry gun. The camera is also in need of a large upgrade due to the limited field of vision given by the camera the group could not utilize the full range of the servo motors. Furthermore, the base could probably be improved upon by housing the components in a safe and secure location. This would only be a minor improvement though and would probably be one the lower end of the priority list of upgrades to the ATS system.

As for software improvements, the computer vision application could easily become more robust, making more complex decisions based on more variables. The system, as it currently stands, was designed to be in a middle ground of robust and lightweight. This was chosen to make the system feasible, given the time period, while still having a good feature set to make the software for the ATS unique. As of right now, the system only takes into account a few variables to determine whether or not to shoot the target such as velocity and size. So, if it were to base its decision-making process on more factors like distance, uniform detection, better path prediction, and other important variables, the system would have greatly enhanced functionality and application. On top of that, extra computer vision features could be added, like the android application discussed in the research section or a database of engagement history could be stored so the user has a complete file on all of the activity of the system. One feature the group would have liked to include was the facial recognition security system, due to time constraints this feature had to be excluded.

Faster microcontrollers to handle real-time processing would improve the speed of ATS and eliminate the need to use multiple MCUs to accomplish the task. A higher resolution of angles would give ATS greater accuracy by allowing the servos to access more points.

In conclusion, the ATS system is a great project but still has much room for improvement in both hardware and software sections. Only so many features and components that have been researched could be added to the system in the design phase. Due to the constraints of the project, which include budget, time, man-power, etc..., only so much could be added into the final design. If the group decides to take this project beyond the scope of this class, then these hardware and software upgrades are definitely some of the improvements that would be made to the system. Since ATS is being passed onto a colleague of the team these features will be up to him to implement. The group will inform and educate the future owner of the turret and he can then begin to improve the system and refine the prototype.

10.0 User Manual

The following sections discuss how to operate and maintain the ATS system. They will cover setting up the turret, calibration of the turret, running the tracking software and the various modes of manual control.

10.1 Hardware Setup

First connect the servo motors to the header pins on the PCB. To turn the system on flip the on/off switch located between the positive terminal of the battery and the PCB. Once the hardware has powered the system is ready to begin tracking. In order to fire the paintball marker the air tank valve must be opened and the power button on the trigger board must be turned on. In order for the system to be accurate it must first be calibrated using the ATS calibration software.

10.2 Calibration

For the hardware and software to be accurately in sync, the embedded system must be calibrated. To calibrate the hardware, start the ATSCAL.exe program. Use the GUI to point ATS to the left center edge of the screen, and push save pulse. Use the GUI to point the ATS to the right center edge of the screen and push save pulse. Point the ATS to the top center edge of the screen and push save pulse. Point ATS to the bottom center edge of the screen and push save pulse. Saving these pulses will save the timer registers values into flash so that calibration does not need to be performed after each hardware restart.

10.3 Autonomous Mode

To start the systems autonomous mode open ATS.exe. The computer will use the default camera and begin tracking moving objects in the field of vision. To connect the tracking software to the systems hardware start the ATScomm.exe program, this is stored in the same folder as ATS.exe. Select the correct COM port corresponding to the serial port that the RS232 cable is connected to. If multiple COM ports are connected the correct one can be found using the device manager in Windows. If the corresponding port is 5 type in COM5 where prompted. Then select any name for the following line and press ENTER. The tracking program will then begin sending commands to the hardware and the system will begin tracking targets.

10.4 Manual Controls

There are various ways to enter manual control mode. This section includes directions on how to operate the various methods of manual controls and some useful tips. In the table below the manual controls of the turret can be found for both the keyboard and the xbox360 controller. When using the xbox 360 controller you will achieve the best results by tapping the control pad or analog sticks rather than holding them down. Once the user exits manual control the system will revert back to autonomous mode and begin tracking again.

Manual Controls			
Function	Keyboard	Xbox360 Controller	Capacitive Touch
Toggle Modes	M	Start	N/A
Rotate Right	D	D-pad Right or R-Analog Right	Right Arrow
Rotate Left	A	D-pad Left or R-Analog Left	Left Arrow
Pan Up	W	D-pad Up or R-Analog Up	Up Arrow
Pan Down	S	D-pad Down or R-Analog Down	Down Arrow
Toggle Fire	SPACEBAR	Right Trigger	Center Circle
Reset TrackPoints	R	B button	N/A

Table 16 - Manual Controls

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