

Final Proposal
Paintball Turret
ECE 582
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Team Paintballas

Forest Agostinelli
Larissa Borcz
Ben Buschmann
Brad D'Antonio
Adam Laroussi

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Abstract

A design for a paintball turret which can distinguish between friend and foe and can autonomously shoot enemies with paintballs and grenades is being proposed. The introduction will talk about the specifications of the turret. The specifications were made so that the turret can be moved by the average sized human and can shoot the average paintball player. Also, the specifications keep in mind that the turret must be able to seamlessly play a game of paintball. The elements that make up the solution will then be discussed. These elements range from the paintball gun being used to the microprocessor that will be controlling it. A block diagram will be provided to show how these parts interact. Next, the cost of the turret will be considered. Solutions such as buying parts in bulk will be considered. In addition, considerations of safety will be considered to make sure the turret does not hurt anybody or interfere with life outside of paintball games. Then, the testing of the turret will be discussed. The testing will be broken up into hardware and software. After the hardware and software are validated individually they will be integrated and the tests will be repeated. Rejected solutions will be provided and then the report will end with a conclusion that summarizes everything discussed.

Introduction

This document proposes a full system design and project plan for an autonomous paintball turret. This project proposal is in response to the design problem presented in the ECE 582 class as a degree requirement in the Electrical and Computer Engineering program at The Ohio State University.

Currently, paintball is a popular alternative recreational sport. The game involves participants firing .68 caliber balls of paint out of paintball guns at others in several different possible, often team, scenarios. To add a unique war-like element into the game play, there is a demand for sentry guns to automatically fire paintball at detected paintball players.

The project objective will be the development of an autonomous paintball turret. The key aspects of our teams design will be the ability to detect friend and foe by color and the ability to eliminate targets with one, three, or five round bursts with a maximum firing rate of 10 paintballs per second. The turret will house a standard 250 round hopper. The turret will be able to defend and engage threats within a 50-foot radius. The turret will be able to track and eliminate threats running up to 10 mph. The turret will include a grenade launcher, which is a feature that has never been implemented on a paintball turret, which is utilized when the system senses clusters of people.

Paintball Turret Specifications	
<i>Weight:</i>	40-60 lbs.
<i>Barrel Height:</i>	4 feet
<i>Rate of Fire:</i>	10 balls/sec

<i>Tracking Speed:</i>	10 mph
<i>Ammo Capacity:</i>	250 balls/hopper, 5 grenades
<i>Battery Life:</i>	3 hours
<i>Cost:</i>	\$999

Table 1 – Technical Specifications

The turret will be stationary with two axes of rotation. It can sense and rotate 360 degrees around its central axis. The turret system will weigh 40-60 lbs. and the barrel will stand at a height of 4 feet. The system will have a battery life of at least 3 hours. The system will be durable enough to withstand moderate weather hazards and paintball attacks. The turret has the ability to adapt to common paintball game play rules.

Our team consists of five senior level electrical and computer engineering students with specializations in software systems, digital signal processing, power systems, and control. With additional professional experience in programming, power systems and business management; we feel that we are more than capable of producing a proficient solution to the problem.

This proposal will include the technical details required to complete production of the paintball turret. A block diagram will be given to show how all these parts will come together. Considerations of expenses and safety will then be discussed. The plan for testing of the hardware and software will then be outlined. Additional solutions that were considered but ultimately rejected will be detailed. Finally, a business and management plan will accommodate the design plan in order to illustrate the optimal production plan.

Technical Discussion

The paintball turret will use the following parts: a paintball gun, acrylic and stainless steel protective coverings, a standard tri-pod, a pressurized air tank, four cameras, a rotational tray, target sensor, drive shaft and bearings, battery pack and charger, two motors, a motor controller, a microcontroller, a grenade launcher, and minor miscellaneous components. For a detailed table of specifications and prices of these parts see appendix A.

Solution Details

- **Paintball Gun (main weapon)**

The turret will be using a “Kingman Spyder .50 Caliber Advancer Electronic Marker” gun and a “Viewloader Evlution 4 Loader” hopper. This paintball gun is an electronic paintball gun whose system uses a solenoid to fire the gun and an electronic trigger. Since the hopper and trigger are both electronic, this provides better control and interfacing with the microcontroller [11].

- **Acrylic & Stainless Steel (framework)**

One of our main design goals for the turret is that it will be durable and remain in working order for the longest time period possible. With this objective in mind, the turret will use .220-.250” thick polymer/high-strength plastic to cover all lenses and .0625” (16 gauge) dull mill finish stainless steel. The polymer will be used due to its durability, scratch resistance, ease of working with, and see-through visibility. The stainless steel will be used due to its superior resistance to moisture and acidic conditions, rust resistance, strength, durability, weight and cost. Dull mill finish is unpolished stainless steel in its natural color and texture, and is ideal for general applications [1] [2] [3].

- **Tri-pod (stand)**

The turret will be built on a common single tri-pod. Since tripods are commonly used in firearms, a tri-pod is the simplest solution to mounting the gun and case. The extendable legs allow placement on uneven terrain and the ability to raise and lower the turret manually for concealment.

- **Pressurized Air Tank**

As paintball guns need pressurized air in order to shoot paintballs, the turret will be using a “Guerrilla Air 20oz CO2 Tank” that is compatible with any standard paintball tank connections. This allows ease and flexibility for refilling, usage, and air fittings [12].

- **Cameras**

The turret will use four “Wide View Color Infra-Red Camera with 9 IR LEDs”. This camera allows the greatest visual recognition for the price. The camera has a 105° viewing angle, 628 x 582 pixels per camera resolution, and compatibility with a 12V supply [9].

- **Rotational Tray**

The turret will be using a “Shepherd 6 in. Lazy-Susan Turntable” for gun and gear rotation. A Lazy Susan provides a drive method for the rotation on turret as well as a strong durable union between the control base and the turret. A Lazy Susan is also a common part that can be found at most hardware stores; hence, it is more cost effective [16].

- **Target Sensor**

The turret is equipped with a pressure sensitive target that is connected to a switch. This feature allows enemy players to “eliminate” the turret from the game for a user specified

amount of time. This allows the turret to adapt to various forms of paintball gameplay. A “Hi-tech Touch Sensor” attached to a target and a “Bit Switch” will be used for this area [17].

- **Drive Shaft & Barings**

In order to obtain smooth movement on elevation control for the paintball gun, .750” outer diameter and .250” inner diameter skate bearings will be used, with 11-14” precision .250 (1/4”) shaft to connect the drive sprocket to the upper turret elevator assembly. These choices are due to ease of use and ability to find the parts at most hardware stores, hence more cost effective.

- **Battery Packs & Charger**

In order to provide independent power for an average of 3 hours, the turret will use a “12.0 Volt Ni-MH 2800mAh Battery Pack”. This battery pack will provide power to the motor controller to drive motors, the computer unit, and the cameras. The battery pack is a rechargeable 12V Ni-MH battery system, and the charger, the “6.0 - 12vdc Ni-CD & Ni-MH Universal Smart Charger”, can fully charge the pack in 1 hour and thirty minutes. An independent power source allows the turret to be placed anywhere the paintball game takes someone, and with the battery pack being rechargeable it is more convenient and eco-friendly [14].

- **DC Motor**

There will be two motors in the turret: one to control the turret's left and right movement (X Axis) and one for the Y axis (up and down). The turret will be using two “Gear Head Motor - 12vdc 50:1 120rpm (6mm shaft)” motors, that are 12V DC compatible with a no load speed of 120 RPM, and approximately 100+ Oz-In of torque. These motors are

powerful enough to handle the type of movements required to orient the turret, but do not consume large amounts of power, which would drain the battery quickly [6].

- **Motor Controller**

The two motors will be controlled with a “Sabertooth Dual 5A Motor Driver”. It is a chip/board that comes with a 12V to 5V supply for powering the microcontroller.

Regenerative braking is included to charge batteries at the reversing of direction or braking, and it drives the motors at the desired speed direction according to a control signal generated by the control signal [10].

- **Microcontroller**

The turrets will use an “Arduino Mega 2560 Microcontroller” to interface with the sensors, motors, and cameras. The microcontroller contains 54 Digital I/O pins and 16 analog I/O pins to house all of the sensors and motor input/outputs needed to make tracking computations, and 256 Kb of flash memory to store previous and current image matrices. The microcontroller is USB compatible for easy programming and debugging [7].

- **Grenade Launcher**

The turret will be equipped with a grenade launcher that will be attached to the base of the turret. It will be a stainless steel bar with a “cup” at the end that is spring loaded, held in place by magnetic pin. When a large group of targets is acquired within a 25ft radius of the turret, a signal will be sent to release the magnetic pin holding the spring in place, thus firing the grenade. Since paintball grenades are expensive, the grenade launcher will be manually loaded and cocked in order to provide better user control over grenade usage.

- **Miscellaneous Components**

Other miscellaneous parts that will be used on the turret are sprockets, axels, screws, bolts, switches, wires, and standard air fittings.

The final design of the paintball turret can be seen in Figure 1. The four cameras will be connected to the computer microcontroller unit. The signals from the four cameras are digitally synced and processed. The cameras will have a back and forth communication with the computer microcontroller unit in order to determine relevant targets and their location. The color of the enemy's jerseys is pre-programmed into the control unit, and a complex scanning algorithm detects any motion and distinguishes whether the object is wearing enemy colors. The touch sensor and target are connected to the computer microcontroller unit and will determine when a paintball hits the sensor to deactivate the turret. The paintball gun has an electronic trigger; hence the gun will be rewired to take input from the microcontroller. The motor controller, which is in communication with the computer microcontroller unit, will control the movement of the gun turret and movement instructions will be relayed to the motors through the motor controller. Each motor controls a specific axis and specific equipped parts. The motor that is connected to gears and bearings controls the elevation of the turret, while the motor connected to the rotational tray controls the rotation of the turret. The grenade launcher will be a catapult like structure that will be manually loaded and cocked after each fire, launched using a spring, and held in place by a magnetic pin. The computer microcontroller unit will control the magnetic pin, and stay in place until directed to release. The grenade launcher will be loaded prior to game play. A battery pack will supply power to the turret for around two hours assuming the motors are constantly spinning. However, assuming that the motors will not be in constant motion; it is reasonable to say that the battery will last at least 3 hours.

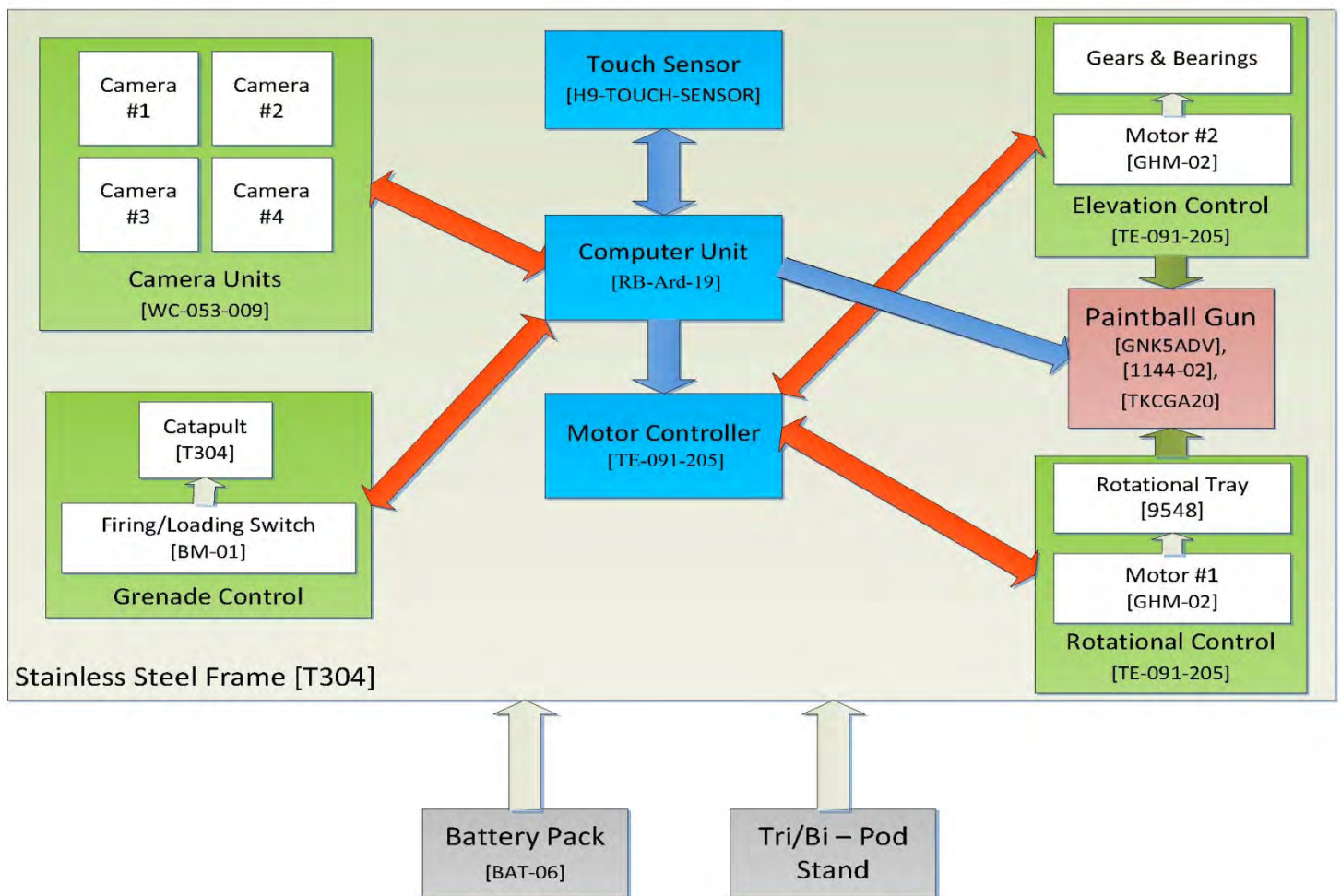


Figure 1 – Block Diagram of System

Considerations

The first major consideration that must be addressed is the cost of the turret. By purchasing most of our parts wholesale in larger quantities we can reduce the cost of our parts substantially. Even with purchasing our parts at discounted prices the cost of our turret will be above what the casual paintball player would spend, so our turret will be marketed to paintball parks and professional paintball teams. Paintball parks can rent out the paintball turret to private paintball parties for a unique game play experience or employ them in woodsball or scenario game play (capture the flag, king of the hill, etc.). Professional teams could use them as a device to help them hone their skills as it would provide a fairly standard way for the team to improve themselves.

Safety is another important aspect of the system that must be addressed. As with all paintball equipment it must be documented that certified paintball eye protection must be worn at all times when using the turret to prevent possibly severe eye injuries. The paintball marker itself must be correctly calibrated to fire at an average 290 feet/second to insure safety and prevent excessive bruising due to the paintballs. The turret uses a CO2 air system as opposed to a Nitrogen system due to the high cost of using a Nitrogen system. Unfortunately, this has the added effect of causing the marker's muzzle velocity to fluctuate. This effect must be taken into account when calibrating the muzzle velocity of the system. Only ammunition designated for use for playing paintball should be used and should be kept out of extreme humidity and heat to prevent deformation of the paintballs which may cause ruptures inside the chamber of the marker. In order to ensure that the gun fires at the correct velocity the gun should undergo weekly maintenance as recommended in its user manual.

Solution Analysis

The first major solution we will have to discuss is showing how the system identifies its targets. The four cameras on the turret will synchronously capture an image and relay this image to the micro-controller. The images sent will be at a resolution of 628 x 582 which will give us four matrices. Since the cameras are positioned at 90 degree increments and they have a viewing angle of 105 degrees we will run the pre-sizing algorithm that will cut the columns corresponding to the overlapping angles off. Next we will use the concatenation algorithm to concatenate all four of the image matrices together which will leave us with a matrix containing image data from all 360 degrees around the system. Finally the most important part is searching for targets. We can detect specific colors because they correlate to a certain range of numbers in the image matrix. The micro-controller will then use the search algorithm to locate the nearest

location that contains the enemy color and will save the position in radians of both the horizontal location and vertical position. This information will be used to allow the turret to track/point at the target.

The next important step is to create a controller that lets us turn a DC motor to a specific direction. We can calculate the transfer function of the position of a DC motor compared to its input voltage. This transfer function is written directly below in figure 2.

$$\frac{\theta}{V} = \frac{K}{s((Js + b)(Ls + R) + K^2)}$$

Figure 2: Transfer Function of a DC motor.

We can get the motor's inductance (L), resistance (R), motor constant (K), and friction coefficient (b) from its data sheet. We can calculate the moment of the gun, hopper and air tank (J) by approximating them as a rod with the center of mass in the center point. After this we will note that we end up with a system with three poles. One pole is past -1,000,000 and will not trouble us. The second pole is at zero and the third pole is on the left side of the jw-axis; however, is extremely close to zero. Before we create our controller we have to decide the maximum rate at which the turret must rotate. If we assume a minimum distance of two meters and use our maximum tracking speed of 10mph from our requirements specifications, we will determine that the turret must move 1 radian (57.3 degrees) in .84 seconds. With that in mind we can use the method of pole placement to move the two poles near zero farther left to speed our system up. Next we will add an integrator to remove steady state error. In order to use pole placement we will use a Luenberger observer to estimate the current states so we can drive supply our pole placement gain with the current states of the system. Finally we will compensate our reference input with a gain N and use root locus to select an appropriate final gain for our controller. A block diagram shown below in figure 3 illustrates the final control system setup.

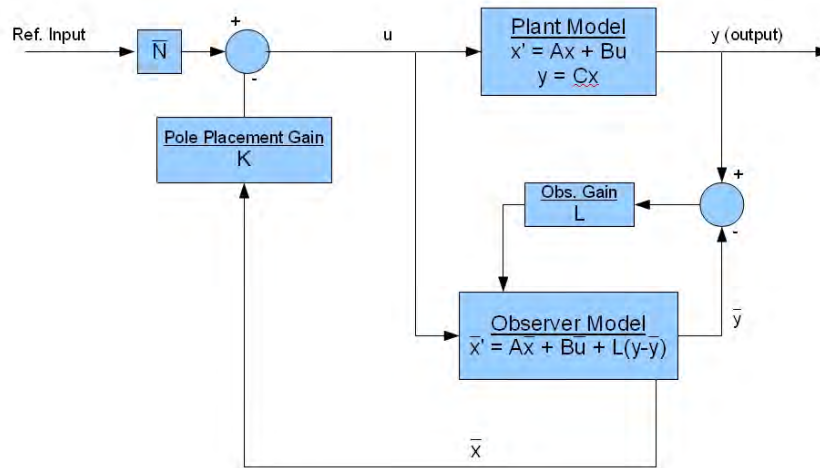


Figure 3: Block diagram of control system

We can test this system by running a simulation in MATLAB of our controller and plotting its unit step response. Shown in figure 4 is a simulation of the closed loop system's response to a 1V step.

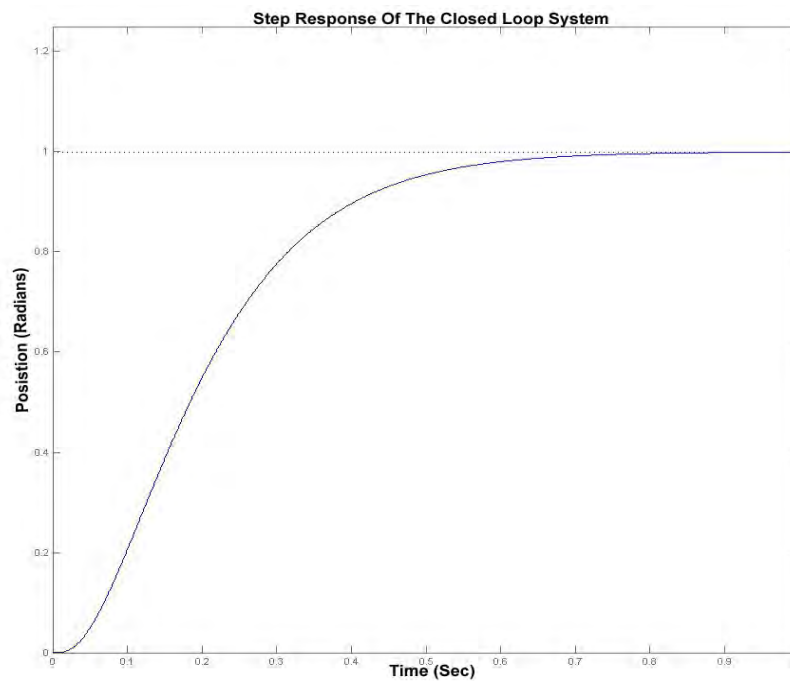


Figure 4: Matlab simulation of our turret's response to a 1V step.

As we can see in figure 4 our controller allows our turret to move to a desired angle for a given input voltage and meets our specification of tracking a 10 mph target. The final step is converting our continuous time controller by using either bi-linear-transform or a zero-order hold approximate. This will allow us to create control algorithms that we can implement in our micro controller for the observer and system controller. The output of this controller will go to the DC motor controller which will relay this information to the DC motor and cause it to move to the desired location.

We will now discuss how the gun fires after the turret has acquired a target and is pointed in the correct direction. The turret will then fire at the target in a one, three, or five round bursts. The marker we have chosen already has a one, three, or five round burst capability since it is a fully electronic marker. The only change we will make is we will replace the small electronic switch with a relay that we be triggered by the micro-controller when it has finished aiming the turret at the target. After firing a burst it will be set to “cool” off to prevent peppering the same target with too many paintballs (overshooting).

This section will discuss is the grenade launcher. The grenade launcher is a catapult that will fire a paint grenade out to 25 feet. This launcher will need to be manually reloaded and re armed after each round it fires. The launcher will fire when the micro-controller detects a large number of people in an area around 25 feet away from the turret.

Testing

The testing for the turret will be broken down into software and hardware before putting it all together and testing the final product. To test the friend and foe recognition, the camera will at first only have one subject standing in front of it. It will then test to see if it recognizes the enemy by the color. The person standing in front of the camera will then become mobile to

test the ability of the camera to track a mobile target and determine if it is friend or foe. The complexity will then be increased by adding more people, up to 5, of the same affiliation and seeing if it can track in a reasonable manner. Then the targets will be reduced to one friend and one foe to verify that the friendly will not interfere with the tracking. The complexity will then be increased until there are 5 total players which are a mix of friend and foe. After it has been verified that the friend and foe recognition is functional tracking with the turret will be tested. Once it recognizes a target as a foe, it must be verified that the software will control the turret to point at the target and compensate for the targets movement. The manner of increasing complexity will be similar to that of the friend and foe recognition test. The next test will be testing the signal to fire. The test will make sure that when the signal to fire comes on the software shows that the turret, which has yet to be attached, is pointing in the right direction. This will have to be accurate for a subject running up to 10 mph. Again, the manner of increasing complexity will be similar to that of the friend and foe recognition test. Then the signal to fire paint grenades will be tested with a cluster of people. First the cluster will contain only enemies to make sure that the signal to fire comes on at the right time. Then both friend and foe will be put in a cluster to make sure it does not fire a grenade when a friendly can get hit. Then these tests will be repeated except with some simulated weather condition such as rain or snow. Each subsequent software test is dependent on the functionality of the previous test. Therefore, these tests must be carried out in sequence. A flow chart of the software testing is provided in Appendix B.

The next part of the turret tested will be the hardware. The first test for the hardware will be its durability. Various weather conditions such as rain and snow will be simulated in order to make sure it can handle it without taking any significant damage. Then it will be dropped from

two feet to simulate someone dropping it while carrying the turret. The turret will be pushed over while standing to simulate someone running into it during a game of paintball. Then paintballs will be shot at it and it should still stand upright and not take any permanent damages. The chosen paintball gun to be on the turret will be tested for 50 foot accuracy and a 10 balls/sec fire rate. It will also be verified that the gun does not jam at this firing rate.

After the hardware and the software have been tested individually they will be integrated. First, the software and hardware interfacing will be tested. The first test will be to make sure that the software controls the turret head properly. This means that when the software denotes a certain movement the turret does that exact movement in a timely fashion. Then it will be tested that the signal to fire paintballs and paint grenades from the software corresponds to the turret firing and throwing grenades. The tests for the individual hardware and software will then be repeated with the hardware and software integrated. The battery life then be tested to make sure it lasts at least 3 hours. In the end the paintball turret will play various full length games of paintball before it is considered complete. In order to carry out this testing fake rain and fake snow are required. Volunteers to act as paintball players are required. Also, paintball gurus will be needed to make sure that the turret performing in a reasonable manner.

Rejected Solutions

The most major design choice made was the choice of the targeting system. Two targeting methods were discussed as viable options. The first method that was discussed was using color to detect the location of the enemy player. The second method discussed was using small wireless transmitters on all enemy players that would alert the turret of their presence. It was decided that the color sensing method was the better choice for multiple reasons. First, the need for every enemy player to carry around a wireless transmitter is both expensive and a major

hassle. Second, it is significantly more complicated to design the wireless transmitter/receiver system than the color imaging system which would cause the cost to increase even more in design time needed to complete the design. Finally, the skill set of the team was far better suited to deal with the signal processing and control problem using cameras than it was designing the wireless transmitter/receiver location system.

Another major design solution discussed was the number of axis of rotation the turret would have. Obviously the turret would be able to rotate the barrel around in order to track targets but the main dilemma was deciding if the turret would be to vertically raise and lower its barrel position. The argument for having only the major axis of rotation is its simplicity which would both reduce cost and time needed to design. The argument against having only one axis was that the turret would struggle to effectively hit a target that was prone which, in a woodsball scenario, is a very common position. The team decided that clearly the argument against having only one axis of rotation was far too big of an issue to ignore and instead opted for having two axis of rotation.

The grenade launcher went through numerous designs before settling on the catapult design. Initially we wanted to have the grenade launcher be automatic but cost became a major issue. We originally liked the idea of having a spring loaded tube that would fire the paintball grenades out. This tube would be fed a supply of paintball grenade by small tube filled with paintball grenades that would simply roll into the firing tube when it was empty. The major problem was the reloading of the spring required another motor and we simply could not afford to place a third motor onto the turret or we would have had to choose a much more expensive DC motor controller.

Conclusion

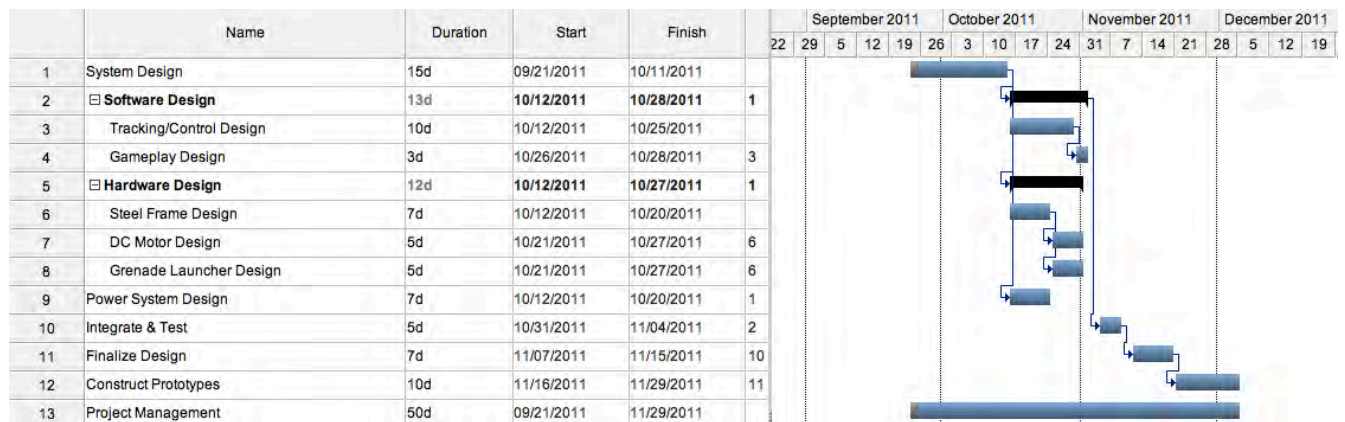
The proposed design of a 4 camera sensor system integrated with color distinguishing processing, accompanied by a 2 DC motor dual axis system meets the previously mentioned design specifications. In order to implement this design, 10 weeks and about \$47,000 are necessary, with the majority of the budget coming from the engineering and management skill required.

The proposed solution is unique to any paintball sentry gun options available on today's market. The main benefit that distinguishes this solution is the integrated 4 camera system allowing the ability to scan and fire a full 360 degrees and the grenade launching mechanism. The other options on the market only make use of one camera, limiting the firing range to only 105 degrees. This solution has the option of using 1-4 cameras, adding versatility to the sentry when deployed into combat. In addition the turret will have the ability to launch a paintball grenade short distances when there are near enemy threats.

In order to cut production cost, we suggest buying our hardware parts in bulk on wholesale directly from the manufacturing companies. Also, we stress the need for gaining government licensing and approval for this design to avoid legal safety liabilities. Finally, we recommend our combination of engineering skill and business expertise in order to see this project successfully carried out.

Managerial

Timeline



System Design

Choose and order materials needed for all phases of design. Three weeks given for procurement of materials. Design Engineer to write up plans for planned system design. 15 days at 8 hours a day is 120 Design Engineer hours for cost of \$4,200. Materials cost of \$4,000.

Software Design

-Tracking/Control Design

One software engineer is needed to write code for control system and camera friend of foe color recognition. 10 working days is 80 hours of engineering time for a total cost of \$2,800.

-Gameplay Design

One software engineer is needed to write code for turret gameplay shutdown feature. 3 working days is 24 hours at a cost of \$840.

Hardware Design

- Steel Frame Design

Design Engineer to create CAD drawings of steel frame and build a working structure. 56 hours for a cost of \$1,960.

- DC Motor Design

Design Engineer to design and mount DC motors to steel frame and to attach the paintball marker to the motor. 40 hours at a cost of \$1,400.

- Grenade Launcher Design

Design Engineer to design and attach catapult grenade launcher to steel frame. 40 hours at a cost of \$1,400.

- Power System Design

Power Engineer to document electrical schematic for power system and build battery pack and charging system. Power engineer needed to test actual electrical needs for system. 56 hours at a cost of \$1,960.

Integrate and Test

Test Engineer to install and interface control system with paintball marker and grenade launcher. Refer to testing section for detailed testing procedure. 40 hours at a cost of \$1,400.

Finalize Design

Design Engineer to update and finalize all design documentation. 56 hours at a cost of \$1,960.

Construct Prototypes

Build Engineer to construct the final working product. The product will be complete with documentation for the end user. 80 hours at a cost of \$2,800

Project Management

Project Manager is responsible for keeping project on schedule, making sure all materials needed for design and testing are available and ultimately responsible for ensuring the design meets the functional requirements and performance specifications. 400 hours at \$50/hr. for a cost of \$20,000.

Personnel

Adam Laroussi is specializing in control systems. He will work as a software engineer and Design Engineer on control system and DC motor design. Forest Agostinelli is specializing in software design. He will work as a software engineer on control systems and tracking systems. He will also be leading the testing of final product. Ben Buschmann is specializing power systems design and project management. He will work as a power engineer and will help out with testing and documentation. He will act as project manager for product design and build. Larissa Borcz is specializing in hardware design. She will work as a design engineer on steel frame and grenade launcher design. She will also be leading actual build of final design. Brad D'Antonio is specializing in digital signal processing. He will work as a software engineer on gameplay design. He will also be leading the finalizing design task.

Budgetary Costs

Personnel

	Hours	Cost/hr.	Total Cost
Design Engineer	312	\$35	\$11,232
Software Engineer	104	\$35	\$3,640
Power Engineer	56	\$35	\$1,960
Test Engineer	40	\$35	\$1,440
Build Engineer	80	\$35	\$2,880
Project Manager	400	\$50	\$20,000
TOTAL			\$41,152

Hardware

Costs

2X Parts List	\$1151
Test Equipment	\$1,000
Manufacturing	\$1,849
Equipment	
Total Materials	\$4,000

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Appendix

Appendix A. Parts and Specifications

Part Name	Part Model #	Specifications	Approx. Price
Gear Head Motor - 12vdc 50:1 120rpm (6mm shaft)	GHM-02	Voltage: 12vdc , RPM: 120 , Reduction: 50:1, Stall Torque: 123.20 oz-in (8.8 kg-cm), Outside Diameter: 37mm, Weight: 5.50 oz., Length (motor and gear): 1.92" (4.87cm), Length (shaft only): 0.89" (2.26 cm), Diameter (motor and gear): 1.45" (3.68 cm), Diameter (shaft): 6mm, Current (at 12v no load): 90mA, Current (at 12v locked shaft): 1.5A	\$21.95
Arduino Mega 2560 Microcontroller	RB-Ard-19	Operating Voltage: 5V, Input Voltage (recommended): 7-12V, Input Voltage (limits): 6-20V, Digital I/O Pins: 54 (of which 14 provide PWM output), Analog Input Pins: 16, DC Current per I/O Pin: 40 mA, DC Current for 3.3V Pin: 50 mA, Flash Memory: 256 KB of which 8 KB used by bootloader, SRAM: 8 KB, EEPROM: 4 KB, Clock Speed: 16 MHz	\$59.95
Bit Switch	BM-01	MOSFET based switch; Control loads up to 24VDC at 3Amp; 3 Modes of Control: hobby radio receiver, TTL or serial.	\$19.95
Wide View Color Infra Red Camera with 9 IR LEDs	WC-053-009	Diameter: 30mm, Image Device: 1/4 Inch Color CMOS OV7950, Effective Pixels: 628 x 582 Pixels/ 510 x 492 Pixels, Resolution: 420 TV Lines, Lens Angle: 105 deg, Minimum Illumination: 3Lux/F1.2 (0 Lux when infrared LED on), S/N Ratio: More than 48db, Night Vision range: 6m, Electronic Shutter: 1/60-1/15,000 Seconds, Video Output: RCA Connector, 1.0Vp-p, 75ohm, Current Consumption: 130mA, Power Required: DC 12V center positive 2.1x5.5mm plug, Temperature: -10°C ~ + 50°C with RH 95% Max	\$34.50
Sabertooth Dual 5A Motor Driver	TE-091-205	Input Voltage: 6V to 18V, 6-12 cell NiMH or NiCd, 2s-4s LiPo, 6V or 12V lead acid (not 18+V lead acid!), 5A continuous per channel, 10A peak, Synchronous regenerative drive, Ultra-sonic switching frequency, Thermal and over current protection, Lithium protection mode, Input modes: Analog, R/C, simplified serial, packetized serial: 19g / 0.7oz, Size: 1.8" x 1.6" x .5", 45 x 40 x 13 mm	\$59.99
Kingman Spyder .50 Caliber Advancer Electronic Marker	GNK5ADV	Advancer™ Electronic Competition Marker; Air Efficient EKO™ Valve System (Patent Pending); Break Beam Eye (Anti-Chop System); LEAP™ II Circuit Board with Rear Facing Color Access Mode; Display (CAMD) Developed by Tadao® Technologies with Semi-Auto and the current PSP and Millennium settings; Quick Release Bolt; 10" Micro Ported Barrel; Clamping Collar Feedneck; 3-Way; Adjustable Magnetic Response "Saber" Trigger; Recessed Dual Texture Grip Panels; All Aluminum Body Construction; High Impact Polymer Trigger Frame; Adjustable Fast Charge Low Pressure Inline Regulator; Standard Thread Vertical Adapter; External Velocity Adjuster; Tool Free Striker Plug Design; Steel Braided Hose; Inline Bottom-line ASA; Dual Ball Detents; Operates on CO2 or Compressed Air	\$139.99
Guerrilla Air 20oz CO2 Tank	TKCGA20	High quality aluminum cylinders; industry standard pin valves; DOT / TC Stamped; 5 year hydro date	\$18.95
ViewLoader EVLution 2 Hopper	1144-02	200 paintball loader	\$35.96
12.0 Volt Ni-MH 2800mAh Battery Pack	BAT-06	Pack measures 1.61" x 4.80" x 1.65", Full charge voltage: 14.5vdc, Nominal voltage: 12.0vdc, Nominal capacity: 2800mAh, Max discharge current: 28A, Rapid charge: 2800mA / 1.2 hours, Weight 17.92oz	\$39.95
6.0 - 12vdc Ni-CD & Ni- MH Universal Smart Charger	USC-02	Peak charges NiCad & NiMH 5-10 cell battery packs with either 900mA or 1.8amp charging rates; automatic V(Delta Peak) cutoff and automatic trickle charge; charger plugs into the wall for 110VAC operation (USA only)	\$25.95
Stainless Steel Sheet	T304	Length: 2x4 Ft., 16 GA. (.060+/-) thick, 2B Dull Mill Finish	\$102.00
Shepherd 6 in. Lazy-Susan Turntable	9548	360-degree swivel; load capacity of up to 500 lb; corrosion resistant zinc coating, pre-punched holes; square-frame ball bearing turntable; durably made from metal	\$4.49
HiTEC Touch Sensor	H9-TOUCH- SENSOR	powered up: sensor maintains a logic high on the signal output, detect input: logic low asserted on signal output; Operating voltage: 5V, Dimension: 12.9 x 29.0mm (PCB size), Weight: 7.5gm, Wire length: 318mm	\$11.49

Appendix B. Software test Plan

