IR TRACKING NERF SENTRY GUN

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Final Report for ECE 445, Senior Design, Spring 2018

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2 May 2018

Project No. 13

Abstract

The sentry gun project seeks to augment a NERF gun with several modifications, ultimately giving it the ability to autonomously acquire, track, and fire at targets all on its own. Using an ATMega328P microcontroller to drive the whole system, an IR sensor from Nintendo's Wiimote and PIR sensors for target acquisition and tracking, a servo mount to create pan-tilt movement, a custom PCB to house the electronics, and modifications done to the gun to allow it to be shot from the microcontroller, the goal was achieved. The design, construction, and testing process is documented in this report.

Contents

1. Introduction

Sentry guns, especially ones built with NERF guns, are not new. Online, it is easy to find various implementations of these sentries with varying degrees of complexity. More sophisticated systems need a separate computer to handle targeting. Simpler systems are more all-in-one, driven by a single microcontroller, but use simpler tracking systems, such as motion or proximity detection. This project aims to take the idea in new directions. First, create an all-in-one system driven by one microcontroller on a custom PCB, removing the need for a separate computer to do target acquisition and creating a neat hardware package. Second, use the Wii remote's IR sensor, which does a similar kind of blob tracking that more sophisticated systems rely on. Finally, incorporate a few modifications to the NERF gun itself to make it capable of automatic fire and increased range. With all these elements, we breathed new life into an old idea.

2 Design

The sentry gun's design can be broken up into three subsystem blocks - a power system, a targeting system, and a firing system. First, the power system supplies the entire system from a battery, meeting the varied needs of each subsystem through regulators if needed. Next, the targeting system has four elements: an IR camera sensor for active target detection of the IR target, an actuation mechanism that moves the sentry into firing position, PIR motion sensors for target range detection, and a microcontroller that orchestrates information and commands between the sensor, actuators, and firing system. Finally, the firing system consists of an actuation mechanism that moves darts into a propulsion mechanism. Overall, the system is meant to be built for portability and deployment on demand. A fourth block external to the system, the target, provides the system the identifying IR signal to target and shoot at. All of these components and their relation to one another is shown in Figure 1.

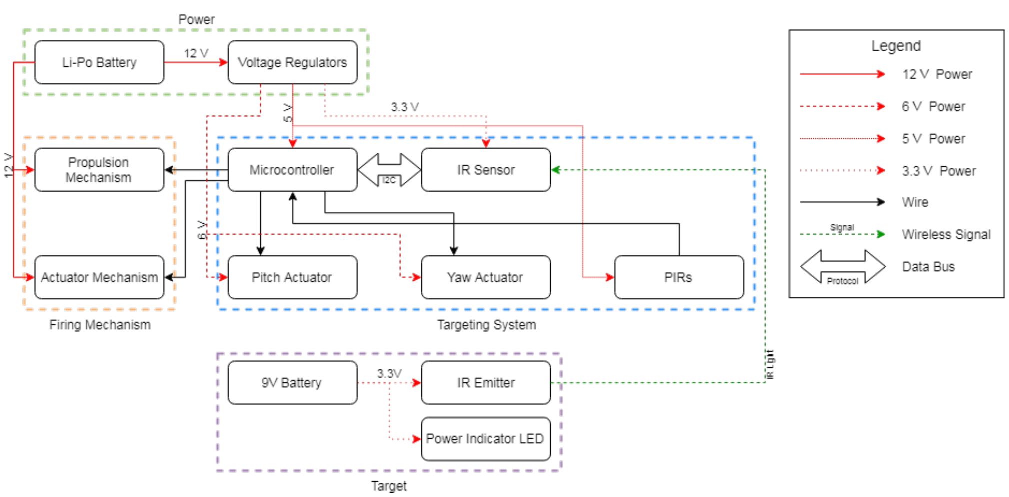

Figure 1: Complete Block Diagram

2.1 Power

The power system takes input from the LiPo battery connected through a commercially available monitor circuit. From here, regulators take the varying input voltage and bring it to the required level for its sub-block: 12 V for the three firing motors, two 6 V regulators for the targeting servos, 5 V for the microprocessor, and 3.3 V to power the IR sensor.

2.1.1 Battery Monitor and LiPo Battery

The monitor board performs four important functions; it prevents over charging, over discharging, and over current in addition to balancing the cells. This circuit prevents the battery from charging beyond 12.6 V or discharging below 9 V by shutting off the connection once the charge is about 0.2 V outside its limits. Due to the voltage rising and falling faster than the charge is actually moving, once disconnected, the battery's voltage returns to safe limits. It also cuts the battery off if the sustained current is above 20 A or if the instantaneous current jumps above 30 A. As the device charges or discharges, the board balances the three individual cells so as to prevent one cell from being over or under charged while the battery itself is within its correct range.

There remains the issue of overheating. The onboard microcontroller takes data from an attached thermistor and the output pin connects to the gate of an NMOS device. If the temperature of the battery is within a safe range, the output is HIGH, allowing current to flow through the PCB. Once the temperature exceeds its limits, the output drops to LOW and the MOSFET is shut off, disconnecting the battery

To improve portability, the battery must be able to provide at least one A for one hour so that it can be placed anywhere without the need of a power outlet or cords. The battery must also be capable of providing 28.6 A peak so that if the motors, servos, and microcontroller are pulling their max current, the battery will not experience overcurrent. The chosen LiPo device is rated at 5 Ah and 20 C meaning that it should be able to provide five A for one hour and 100 A peak discharge.

2.1.1 Regulators

The design of the 3 and 5 V regulators are straightforward and the example circuits provided in the datasheets require little adjustment. The 6 V and 12 V devices require additional calculations roughly laid out in their datasheets. LTspice models provided by linear technology were modified to evaluate the planned design and an example simulation output for the 12 V regulator starting up is shown in Figure 2 [1]. They helped verify that that the calculated values provided output voltages and currents within the specified ranges for the project.

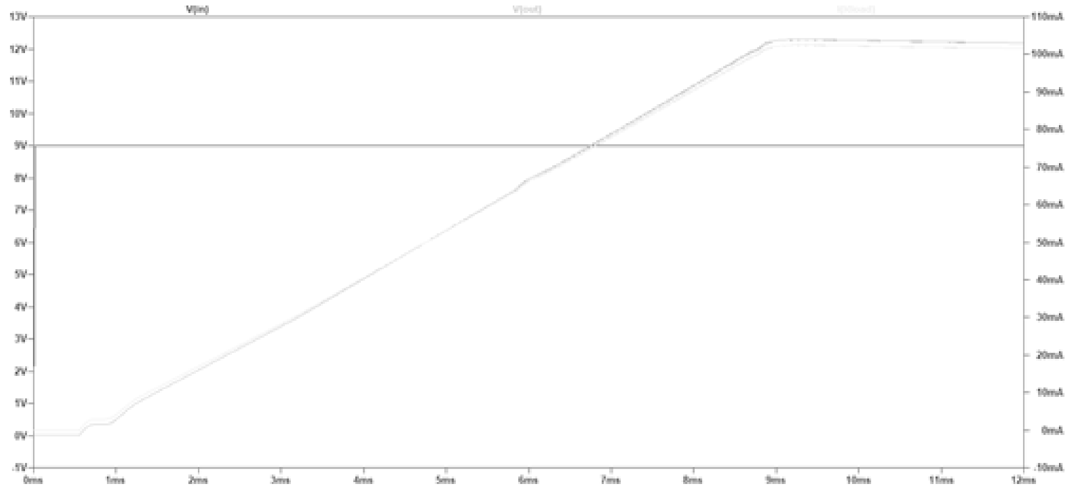

Figure 2: 12 V Regulator Startup, V_{out} settles at 12 V for V_{in} of 9 V

2.2 Firing Mechanism

The firing system consists of two components: a propulsion mechanism and an actuation mechanism. Any motors that were used by the gun before were switched out for more powerful motors. While the system was originally intended for automatic fire, a design change was made for semi-automatic fire. This change helped in maintaining control, reducing electrical strain, and prevented rapid ammunition consumption. The motors and assemblies are shown in Figure 3.

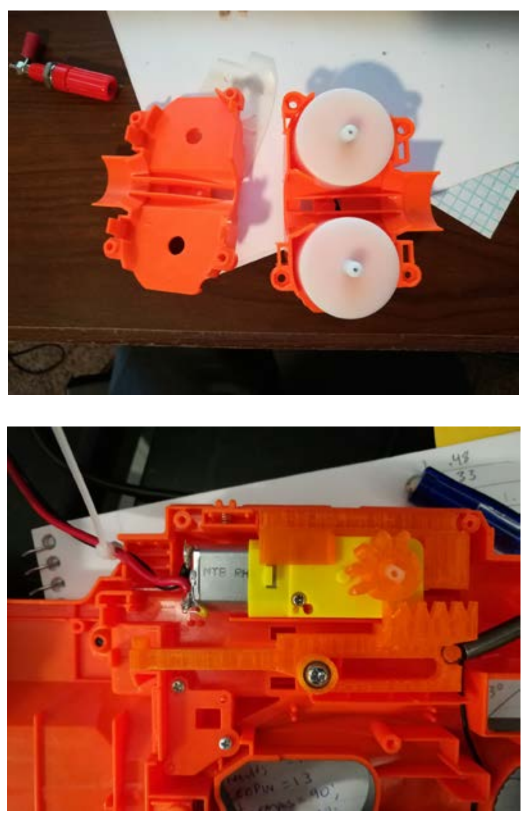

Figure 3: Propulsion (top) and actuation mechanisms (bottom)

2.2.1 Propulsion Mechanism

The propulsion mechanism consists of two DC motors. On their shafts, they have flywheels attached. With both motors spinning in opposite directions, a dart caught between the two flywheels would get caught and propelled forward. The original assembly was kept from the gun, though the motors were replaced with more powerful motors, the MTB Rhino [2].

2.2.2 Actuation Mechanism

The actuation mechanism, or more appropriately named from its Thingiverse page, the AutoStryfe mod kit [3], consists of a DC motor housed in a gearbox. Attached to the output of the gearbox is a partial gear. The teeth of this gear would get caught in the teeth on the pusher arm, extending it forward. The spring would then pull the arm back into its starting position after being fully extended. While an actuation mechanism salvaged from another NERF gun was on hand, this kit was ready to drop into the gun itself with minimal modification necessary and it fit snugly in a cavity of the gun.

2.3 Targeting System

The targeting system consists of five components including the microcontroller, the IR sensor, the pitch actuator, the yaw actuator, and the PIR motion sensors.

2.3.1 Microcontroller

An ATMega328P microcontroller was used to control the motors as well as monitor signals coming from the various sensors. For example, it is able to generate pulse widths for the servos and communicate over I2C. It also provided a means for external interrupts.

2.3.2 IR Sensor

The Nintendo Wii's IR sensor, an unnamed PixArt sensor, provided our primary sensing system. It internally does its own IR blob tracking for up to four sources. I2C is the communication protocol for the sensor. Again, while other sophisticated tracking systems exist, such as OpenCV, this requires the use of a computer.

2.3.3 Pitch and Yaw Actuators

The actuators were RG-SRV180 servos that were part of the RobotGeek Pan and Tilt Kit from Trossen Robotics [4]. They operate at 6 V and capable of 12 kg-cm of torque at stall. In an ideal scenario, a rig for stepper motors would have been more suitable, though manufacturing such a rig and obtaining stepper motors was cost prohibitive for the project.

2.3.3 Pitch and Yaw Actuators

Adafruit's PIR (Pyroelectric "Passive" InfraRed) Motion Sensors were used to determine how far away a target was from the NERF Gun. The PIR Motion Sensors have a range of about 20 ft, a horizontal field of view of 110°, and a vertical field of view of 70°. The PCBs that the sensors are attached to have 3.3 V regulators. A 5 V input is the ideal voltage, and the sensors produce a 3 V HIGH signal when motion is detected [5].

Since the Nintendo Wii's IR sensor only has a horizontal field of view of 33°, multiple ideas were brainstormed as to how to meet the requirement of having the gun track targets in a 180° area. The first idea that was explored was having the gun constantly pan the 180° area looking for IR targets. An initial goal of the project was having the gun be able to fire on a target within 1 second. This idea made this goal impossible as panning the entire 180° at a reasonable speed took longer than a second.

The second idea that was explored was using the PIR motion sensors to detect motion in certain areas, so the gun would not have to constantly move. One PIR motion sensor would be setup on each side of the gun to see a 60° area. Once motion was detected in one of these areas, the microcontroller would signal the pan-tilt motors to rotate until the gun was at the midpoint of these areas, 30° or 150°. Once the gun was in the area, the IR sensor would then search for the target. A layout for this idea can be seen in Figure 4. The blue areas represent the sections of the 180° space that the PIR motion sensors will cover, and the green lines represent where the gun will pan based on which signals are being sent to the microcontroller.

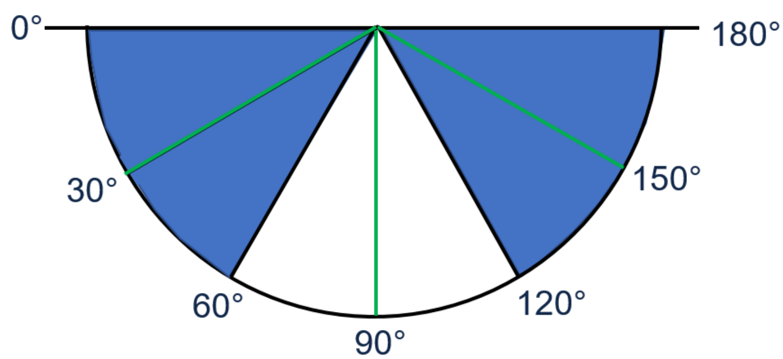

Figure 4: PIR Motion Sensor Placement Diagram

After setting up this layout and testing the targeting system, there were a lot of problems found with this design. The first problem was that since the field of view for the sensors is so large, shields made of out cardboard had to be built to try to limit the area that they covered. Also, these shields were not very reliable and would sometimes cause false positives for the sensors. Another problem was that sometimes the gun would get caught in a cycle where both sensors were sending a HIGH signal, which caused the gun to try to move to 30° and 150° as the same time. This resulted in the gun just jerking back and forth in the middle around 90°. Also, once we added the gun to the top of the pan-tilt system, the unit as a whole became jerkier and would overshoot the target if the gun was rotating fast enough.

Due to these problems, the project was implemented with the first idea of constantly panning the 180° area looking for IR targets. The PIR motion sensors were then used just for range detection. Each PIR sensor has 2 trimpots located on the back for sensitivity and timeout, respectively. These were both adjusted to the minimum setting. This allowed the range of the sensors to go from 20 ft to about 10.5 ft. It also allowed for the sensor to signal to the microcontroller to be updated as quickly and regularly as possible.

2.4 Target

The target is separate from the main body of the sentry and is meant to be worn on the user's body. Because of this, it had to be compact and less than 2.5 in on each side. It requires a power source that is able to supply the circuit for at least one hour; a 9 V battery was chosen for its longevity at lower currents as well as its plug and play capabilities. The target also required an IR emitter that was strong enough to be consistently seen by the IR sensor, but not so strong as to be hazardous to the user. Because the human eye cannot see or react to IR light, a red LED is wired in parallel with the IR emitter to indicate when the device is on. A 3.3 V regulator was used to bring the voltage down from 9 V for the IR emitter and LED as well limit the current to 100 mA, maximum.

2.4.3 IR Emitter

The intensity of the IR emitter was bounded by the minimum required for it to be seen by the IR sensor from 15 ft and the maximum allowable by the International Electrotechnical Commission. In terms of safety, there are two major concerns in regard to IR exposure: IR eye hazard and retinal thermal hazard. In order to be considered exempt from regulation, the former must not pose a hazard if exposure exceeds 10000 seconds whereas the latter must be safe for exposure longer than 10 s. Through Equations (1) and (2), the maximum allowable intensity is 4 W/sr, the minimum of the two hazards [6]. If the maximum current is applied to the emitter, (100 mA), the intensity would be 0.55 W/sr which exceeds the minimum of 0.2028 W/sr found using Equation (1) for an "E" of 0.0097 W/m^2 and "d" of 15 ft or 4.572 m. The actual current through the bulb is further restricted to 54 mA resulting in an intensity of 0.297 W/sr; the roughly 50 percent increase from the minimum ensures a stable connection with the IR sensor attached to the body of the gun while still being safe.

$$I_e = E * d^2 = 100 * 0.2^2 = 4\ \frac{W}{sr} \tag{1}$$

$$I_e = \frac{6000 * d * (L + W)}{2 * 10^{(700-\lambda)/500}} = \frac{6000 * 0.2 * (0.005 + 0.005)}{2 * 10^{(700-940)/500}} = 18.12\ \frac{W}{sr} \tag{2}$$

Where I_e is the intensity of the bulb, E is the irradiance of the device, d is the distance in meters, L and W are the length and width of the emitter respectively, and $\lambda$is the emitter's wavelength.

3. Design Verification

3.1 Power

3.1.1 Battery Monitor and LiPo Battery

The protection board was initially tested by connecting an electronic load to the positive and negative output terminals while 9 to 12.6 V were applied to the input terminals using a power supply. The electronic load was adjusted to 5 A, the maximum for the power supply, to verify that the PCB could be powered through the device. The load and the supply were then switched to verify that the battery could be charged through the board.

To test the battery, it was connected to an electronic load through the monitor circuit. The load drew a constant current for two hours or until the battery was depleted. Every five minutes, the voltage for each cell was recorded and the total voltage discharge curves are shown in Figure 5. The battery can easily supply 1 A for over an hour and 5 A for nearly an hour when it is charged to 12.3 V for safety.

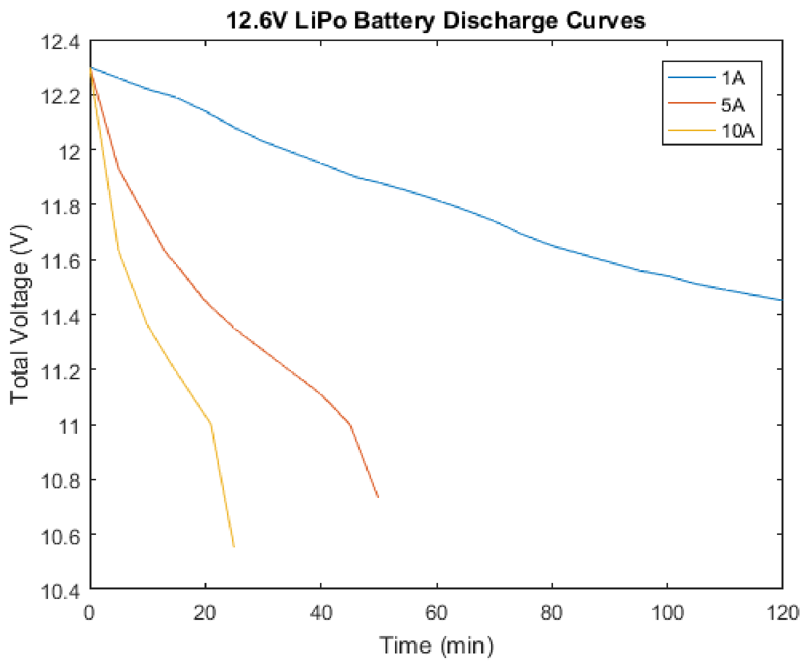

Figure 5: Discharge Curves of LiPo Battery for Various Loads

3.1.2 Regulators

All six regulators were tested using a similar process: an electronic load was connected to the positive and negative output terminals while 9 to 12.6 V were applied to the input terminals using a power supply. The load was adjusted to constantly use the peak required current for a given device, shown in Table 1. The maximum current that the power supply can provide is 5 A which did not allow us to examine the full capabilities of the 12 V regulator, however, at this maximum current the output voltage remained at 11.94 V for the entire range of the input. This suggests that output will only exceed the desired range under much heavier loads. One of the two 6 V regulators had a short from input to output, the cause of which could not be determined. The results shown in Table 1 are within the required bounds and the nonfunctioning 6 V regulator is excluded.

Table 1: Regulator Requirements and Results

Regulator (V)	Max Required Current (A)	Average Output Voltage (V)
12±5%	24±4%	11.94
6±5%	1.6±5%	6.25
5±5%	1±5%	5.049
3.3±5%	0.05±5%	3.286

3.2 Firing Mechanism

Both subsystems were tested separately before being tested together. Using measuring tape, a 15 ft distance was measured from the firing area. The propulsion system's motors were connected to 12 V provided by the toolbox power supply. Once it seemed like the motors were revved up to full speed, a dart was manually fed into the mechanism, and the dart's distance was observed. It was verified through consistency, being tested ten more times and exceeding the objective easily.

Rate of fire was verified through video analysis. The mechanism was recorded operating until the spring came loose from its shaft. Watching the video frame-by-frame, full extensions of the pusher arm were counted. With this count, the time elapsed during counting, and the frame rate of the video (36 extensions done in 3 s, 20 frames at a frame rate of 29.97 frames per second), the raw rate of fire of the system was about 9.816 darts per second.

Testing rate of fire and range together was simple. First, the propulsion motors were revved up to seemingly maximum speed. Then, the actuation motor was connected to 12 V, pushing the darts held in the magazine into the propulsion mechanism. This test was to check how firing rate and range were affected during actual operation. While all the darts still met the range requirement, there was a noticeable drop in both range and fire rate as consecutive darts were fired. As darts are pushed into the propulsion mechanism, an energy transfer occurs between the flywheels and the darts. The darts sap away a bit of the rotational energy in the flywheels in order to gain kinetic energy. This slows down the flywheels. Since the gun rapidly feeds more darts into the propulsion mechanism, the motors do not have time to recover this lost energy. This means the motors need to recover more and more energy as more and more darts are shot. Electrically, this creates a greater load on the system, slowing down the actuator mechanism in turn. All in all, while an automatic firing solution would be attractive, it would be impractical for the project for a few reasons. 1) NERF magazine capacities are rather small; the largest capacity, 35 darts, would be all shot out in about 4 seconds in ideal conditions. 2) The electrical noise from the motors becomes more and more prominent the longer they are run; this would compromise the microcontroller and servo operations. 3) From a practical standpoint, unloading a whole magazine on a single target would be by all definitions overkill. These observations during testing drove us towards a single-fire system.

3.3 Targeting System

3.3.1 IR Sensor

The IR sensor was initially tested for functionality through example code, mounting it on a stationary platform and checking sensor readings both through the Serial monitor and a Processing sketch, using a TV remote as an IR source [7]. It was then rapidly integrated into a prototype tracking system, mounted onto the pan-tilt system to follow the TV remote's IR emissions.

3.3.2 Pitch Actuator

The pitch actuator was tested by seeing if the pan-tilt system could rotate horizontally 180°, and it could.

3.3.3 Yaw Actuator

The yaw actuator was tested by seeing if the pan-tilt system could rotate vertically 70°, and it could.

3.3.4 PIR Motion Sensors

The PIR motion sensors were tested by connecting a LED to the circuit that would light up every time a target was within 10 ft of the sensors. A tape measure was put on the floor and measured out to 15 ft. The test included having a person holding the target start at 15 ft and keep walking towards the target until the LED lit up. Once the LED lit up, the person would stop moving and record the distance of how far away they were from the sensors. The results of these tests can be found in Table 2.

Table 2: PIR Maximum Distance for Detection

Trial #	Distance Away (ft)
1	10.50
2	08.92
3	11.83
4	11.58
5	09.92
6	10.92
7	09.83
8	10.08
9	10.50
10	10.75
Average	10.48

3.4 Target

The target was tested by seeing if the targeting system would lock on and follow the emitter 15 ft away, and it did.

4. Costs and Schedule

See Appendix B for schedule information.

4.1 Parts

Table 3: Part Costs

Part	Manufacturer	Retail Cost ($)	Actual Cost ($)
3.3V Regulator	STMicroelectronics	1.02	2.04
5V Regulator	Active-Semi	0.59	0.59
100uH Inductor	Wurth	2.12	4.24
6V Regulator	Linear Technology	4.22	8.44
2.2uH Inductor	Wurth	2.22	4.44
12V Regulator	Linear Technlogy	7.67	15.34
12V Power MOSFET A	Infineon Technologies	2.93	11.72
12V Power MOSFET B	Infineon Technologies	1.66	1.66
12V Power MOSFET C	ON Semiconductor	5.23	10.46
12V Power MOSFET D	Infineon Technologies	1.70	1.70
6.8uH Inductor	Bourns	3.65	3.65
High Power DPDT switch	NKK	22.82	22.82
14 AWG Wire	TE Connectivity	0.36	1.44
Ring Connector	TE Connectivity	0.34	1.02
10k Battery Thermistor	Murata	1.01	1.01
SPST Switch	C&K	0.98	0.98
10k Thermistor	Adafruit	7.56	7.56
ATMega328P-PU	Microchip Technology	2.20	2.20
ATMega Socket	On Shore Technology Inc.	0.33	0.33
SPST Switch	E-switch	0.53	0.53
16MHz Crystal	IQD	0.21	0.21
Motor MOSFET	Diodes Incorporated	0.61	1.83
LTL81HKEKNN	Lite-On	0.15	0.30
Heat Sink	Assmann WSW Components	6.03	6.03
Thermal Epoxy	MG Chemicals	12.35	12.35
5000mAh 3S 20C	Turnigy	32.13	32.13
LiPo Safety Bag	Teenitor	7.80	7.80
12AWG XT60 Pigtails	SIM&NAT	7.79	15.58
XT60 Plugs	Finware	8.45	8.45
XT60 Banana Plugs	Jrelecs	7.99	7.99
3S JST-XH Leads	Vanka	8.99	8.99
LiPo Protection Board	Knacro	11.50	11.50
9V Battery Holder	Keystone	3.03	3.03
SPST switch	CW Industries	0.74	0.74
9V Battery	Duracell	6.49	6.49
SMD 10k Thermistor	Abracon	0.25	0.25
1x4 Pin Heading	Sullins Connector Solutions	0.45	0.45

1x6 Pin Heading	Murata	0.50	1.00
Various Resistors, Capacitors, and Diodes	Various	-	22.53
PIR Motion Sensor	Adafruit	9.95	19.90
MTB Rhino DC Motor	MakeTestBattle	5.00	15.00
IR Positioning Camera	DFRobot	23.55	23.55
Robot Geek Pan and Tilt Kit	Trossen Robotics	49.95	63.32
3D Printing	Illinois MakerLab	7.00	7.00
Total			378.59

4.2 Labor

Table 4: Labor Costs

Name	Hourly Rate ($)	Hours	Total ($)
Ryan Alvaro	10.25	200	5125
Emily Dixon	10.25	200	5125
Lauren Klindworth	10.25	200	5125
Total			**15375**

5. Conclusion

5.1 Results

The project succeeded in implementing most of the requirements that were set. The main successes of the project include it was able to pick up targets within a 180° range of motion, it could determine when a target was within 10 ft, and it could fire on these targets.

5.2 Ethical Considerations

The nature of automated sentries presents a few ethical and safety concerns. The projectile has the potential to harm people and property, violating the IEEE Code of Ethics, #9 [8]. To minimize physical risks, we used NERF darts which are lightweight, frequently used safely by children, and are therefore unlikely to do damage during normal operation. During testing we were careful to never point it at any person or delicate object in case of an accidental firing.

There are also moving parts which could pinch fingers or catch on objects. Before testing, the area surrounding the physical aiming system was checked to verify that there were no wires or other objects that could jam the servos. In accordance with #1 of the IEEE Code of Ethics, we will disclose these possible dangers to the user [8].

We also wanted to make it clear to bystanders that this is a not a harmful firearm. Part 272 of Title 15 of the Code of Federal Regulations on foreign commerce and trade states, “toy, look-alike, and imitation firearms” must be marked with a “blaze orange” [9]. While this regulation does not require NERF guns to have orange tips on the muzzle, the orange coloring of the device makes it clear that it is a toy.

Since we will be using a LiPo battery, there are certain safety measures we implemented to prevent overheating, overcurrent, overcharging, and over discharging. In order to prevent overheating, a thermistor was used to regulate the battery and cut it off from the rest of the electronics if it ever became too hot. The battery was be selected provide more than enough current without the risk of overcurrent. We used a commercially available charging board in order to eliminate the risk of overcharging and over discharging as well as to balance cells as suggested by “Safe Practice for Lead Acid and Lithium Batteries” on the ECE 445 site. To prevent the battery from being plugged in the wrong way and damaging the device, directional XT-60 ports were used. During charging and discharging, the battery was placed in a LiPo safety bag, and all laboratory safety protocols were followed [10].

5.3 Future Work

Going further, there are several improvements that could be made the project. First, the size of the project could be reduced by adding mounts for the PCB and the sensors. This would also make the project more portable. Second, the accuracy of the gun could be improved by coming up with a better way to counter the weight of the gun. Currently, the base of the pan-tilt system is weighed down by batteries. This causes the gun to have jerky movements occasionally and rotate past the target. Having a counterweight directly on the gun could keep it from being so front heavy and lead to more accurate firings. Third, higher power motors could be used to rotate the gun back and forth. After constant use, the servos in the pan-tilt system began to wear out and the panning motion became less smooth. Fourth, the PIR motion sensors could be replaced with a less noisy and less sensitive alternative. With better sensors, the project could have implemented the idea to have sensors monitor certain areas of the 180° range of motion so that the gun would not have to constantly pan back and forth. More accurate sensors could also help improve range detection and get a more consistent run of firing when a target gets within 10 ft of the target. Overall, future improvements of the project would focus on size reduction and accuracy.

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Appendix A: Schematics

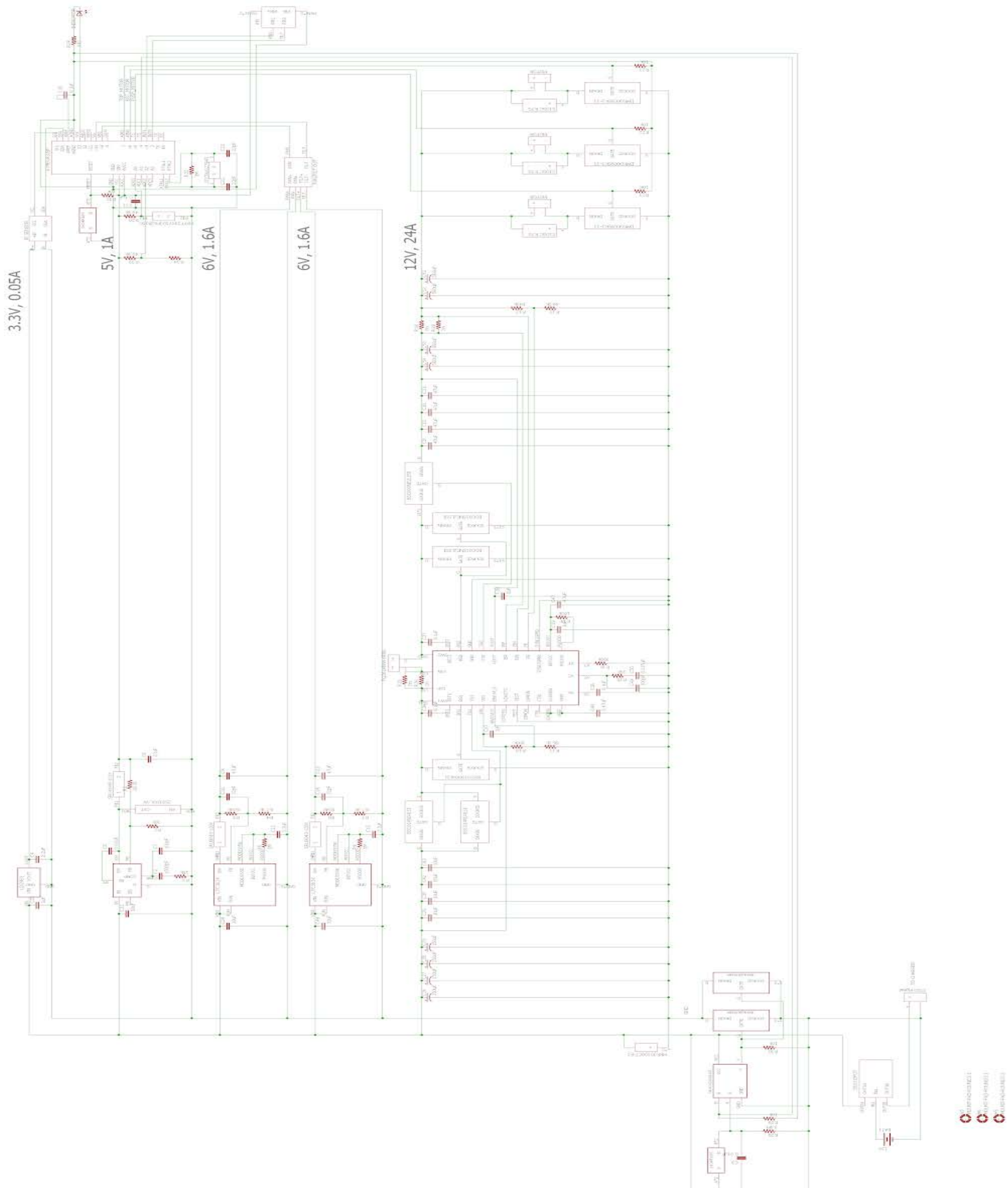

Figure 6: NERF Sentry Circuit Diagram

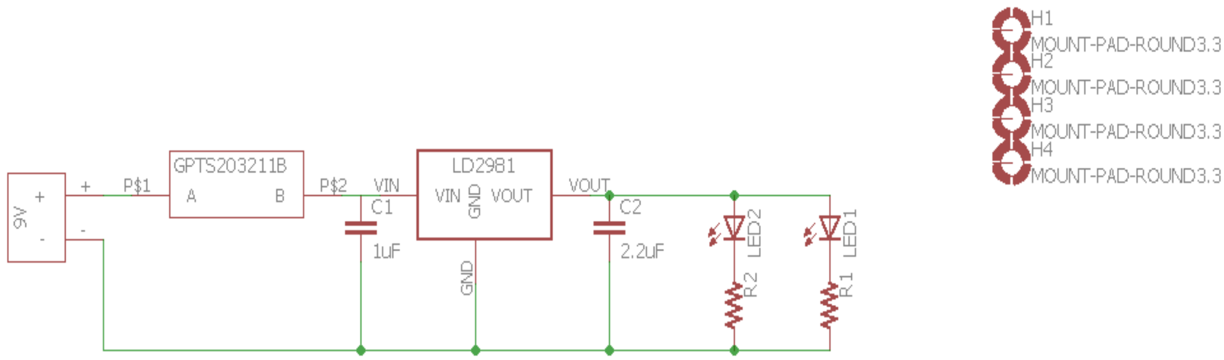

Figure 7: Target Circuit Diagram

Appendix B: Schedule

Week	Task	Person Responsible
2/19	• Research motors and materials needed for mechanical components	Ryan
	• Research IR Sensor and emitters	Emily
	• Research batteries and power supplies	Lauren
2/26	• Research requirements and specific external parts for regulators	Lauren
	• Create flowcharts for major software components	Emily
	• Order parts for pan-tilt system	Ryan
3/5	• Start working on schematics/PCB	Lauren
	• Start planning program for interfacing motors with sensor	Emily
	• Put together pan-tilt system	Ryan
3/12 (PCBway Orders Due)	• Continue work on PCB and correcting regulator circuits	Lauren

	• Continue writing programs for major software components	Emily
	• Order IR sensor and necessary connections	Ryan
3/19 (Spring Break)	• Continue work on PCB	Lauren
	• Attached IR sensor to gun and got it to aim	Ryan
	• Research ways to increase sensors detection area	Emily
3/26	• Finish PCB design • Order components	Lauren
	• Implement Panning motion for Gun	Emily
	• Build 3D parts	Ryan
4/2	• Submitted PCB • Evaluate incoming parts	Lauren
	• Order PIR motion sensors and begin researching them	Emily
	• Build dart propulsion mechanism • Build dart actuation mechanism	Ryan
4/9	• Continue testing incoming parts	Lauren
	• Test out PIR motion sensors and research how to modify them	Emily
	• Final check of assembly of actuators/firing mechanism/mounting platform	Ryan
4/16 (Mock Demo)	• PCBs are in! • Finish emitter board • Debug main PCB	Lauren
	• Add PIR motion sensors to targeting system and implement zones idea	Emily
	• Make necessary changes to firing system after mock demo, make 3D parts	Ryan

4/23	• Change targeting system back to panning idea, finalize all the software	Emily
	• Change firing system to single fire, fix gun/motors	Ryan
	• Debug 12V and 6V regulators	Lauren
4/30 (Final Paper Due and Demo Project)	• Finalize Final Presentation	Emily
	• Finalize Final Report	Ryan
	• Test Demo	Lauren

Appendix C: Requirements and Vertication Table

Li-Po Battery (5 pts.)

Requirement	Verification	Requirement Met? (Y/N)
Supplies 12V±5% at 1 A for at least 1 hour with peak current draw of 28.6 A. Minimum of 4000mAh so as not to deplete the cell too much.	1. Use an oscilloscope and electronic load to verify that the fully charged battery output is within the suitable range for both voltage and current. 2. Test the battery for an hour at rated load using an electronic load, checking the battery's voltage every five minutes. 3. Fully charge, repeat steps 1 and 2, increasing the load to see how the current draw changes. 4. Test again. Is it linear?	Yes

Voltage Regulators (5 pts.)

Requirement	**Verification**	**Requirement Met? (Y/N)**
12V to 3.3V±5% at 50±5% mA 5V±5% at 1±5% A 6V±5% at 1.6±5% A 12V±5% at 24±4% A	1. Input typical input voltage (12V), measuring across output pins with an oscilloscope ensuring that the output remains with ±5% of the desired voltage. 2. Measure several times, decreasing input voltage to the lower bound of the battery's output. Verify that the output remains with ±5% of the desired voltage and note when the regulator fails. 3. Return to the typical input voltage. 4. Verify output current through the same pins using a multimeter in series with a digital load set to the following: 3.3V: 66Ω 5V: 5Ω 6V: 1.2Ω 12V: 0.5Ω	Yes

IR Sensor (5 pts.)

Requirement	**Verification**	**Requirement Met? (Y/N)**
The IR sensor must be able to locate a target when it is within 15 feet at least 90% of the time. The IR sensor should have at least a 25 degree horizontal FOV and at least a 15 degree vertical FOV.	An IR Module will be placed 15 feet from the IR Sensor within the required FOV at 10 different points. Verification is achieved if the separate processing debugging program shows that the sensor detected the target at least 9 times. Verification is achieved for the required FOV if the target can be placed at the edge of the required horizontal and vertical FOV for the sensor and still be detected.	Yes
The IR sensor must be able to determine when a target is within 10 feet at least 90% of the time, so the gun can engage the target.	An IR Module will be placed 10 feet from the IR Sensor at 10 different points within the required FOV. Verification is achieved if the separate processing debugging program shows that the sensor detects the target and signals the gun to aim at the target at least 9 of the 10 times.	Yes

Microcontroller (6 pts.)

Requirement	**Verification**	**Requirement Met? (Y/N)**
The microcontroller should be able to communicate over I2C at a rate of 9600 baud to the system's sensor.	A processing debugging program will be setup to manually simulate the behavior of the sensor. Verification is achieved if the separate processing debugging program shows that when the simulated target is seen, the correct signals are sent to the microcontroller.	Yes
The microcontroller should be able to provide two 20 ms pulse widths to the targeting system's actuators.	A separate processing debugging program will be set up to sent signals to the microcontroller that indicate that a target has been found at a location within 15 feet. Verification is achieved if the separate processing debugging program shows that signals sent to the microcontroller result in the targeting system's actuators being moved to the correct locations.	Yes
The microcontroller should be able to communicate with the firing system's mechanisms at a rate that the target can be moving at walking speed and still be fired on.	A separate processing debugging program will be set up to sent signals to the microcontroller that indicate that a target has been found at a location within 10 feet. Verification is achieved if the separate processing debugging program shows that signals sent to the microcontroller result in the firing system's mechanisms propelling a dart correctly, even on a simulated moving target	Yes

Pitch Actuator (2.5 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The pitch actuator should be able to pitch over at least a 70° range of motion, or at least ±35° with respect to the ground.	The user will hold up the IR Module in directly in front of the gun, so the gun's body is parallel to the ground. The user will then raise the module up slowly, letting the gun follow. An observer will measure the angle the gun is at relative to the ground and verify its positive angular displacement if it can tilt at least 35°. A similar procedure will be done to verify that the gun can tilt down at least 35°.	Yes

Yaw Actuator (2.5 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The yaw actuator should be able to yaw over a 180° range of motion.	The user will walk in a half-circle with the IR around the gun (at most 15 feet away from the gun). Verification is achieved if the gun can follow the user all the way around the half circle.	Yes

Pitch and yaw assembly (7 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The assembly should be able to precisely move the system into position within a 15 cm by 15 cm square targeting area (an approximate area for a torso, where the target would be mounted).	The gun will be mounted with a low-power laser module close to the IR sensor. A tester with a 15 cm by 15 cm square target with an IR module in its center will hold the target within the sensor's field of view. The tester will then turn the module on, giving the gun a target to motion to. Accuracy is defined as the assembly's ability to move the laser's beam into this targeting square, while precision is the assembly's ability to not overshoot the bounds of this square. Verification is achieved by repetition with 100 trials done at various positions and ranges.	Yes

IR Module (5 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The signature generated should be strong enough to be acquirable from the targeting system from 15 feet away.	An IR Module will be placed 15 feet from the IR Sensor. Verification is achieved if the separate processing debugging program shows that the sensor detected the target.	Yes
The module should be as compact as possible, at most a 2.5" by 2.5" footprint.	Measure the length and width of the module. Verification is achieved if the length and width are under 2.5" by 2.5."	Yes

IR Module Battery (2 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The battery should be able to provide 3.3 V± 5% tolerance through a regulator at 100mA over its operating time of at least one hour.	Monitor and verify output current over a 0.33Ω load for an hour. 1. Use an oscilloscope and electronic load to verify that the battery output is within the suitable range for both voltage and current.	Yes

Propulsion Mechanism (5 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The propulsion mechanism should be able to fire darts at least ten feet.	A full magazine (18 darts) will be fired and measured from the muzzle to the darts' initial landing spots. Verification is achieved if the average distance of the darts collectively is at least ten feet.	Yes

Actuator Mechanism (5 pts.)

Requirement	Verification	Requirement Met? (Y/N)
The actuator mechanism should achieve a fire rate of at least 9 darts per second.	A stopwatch will time the system firing a full magazine (18 darts) continuously. If it can reliably push all these darts within 2 seconds each time, it receives verification.	Yes