Battlebot: Autonomous Target Recognition System

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***Abstract*— Autonomous Targeting or Automatic Target Recognition (ATR) utilizes advanced technology to independently identify specific objects. ATR is achieved through complex intercommunication between computing algorithms and various sensors. Target specification can vary greatly depending on the type of detection algorithms and sensors employed. To receive accurate classification as an autonomous system, the said deployed unit must have the capability to fulfill its intended purpose free from external human influence. The purpose-built algorithm serves to correctly distinguish between targets and non-targets; protecting against complications in object recognition. Furthermore, several sensors may be integrated, primarily functioning as the line of sight. Factors such as environment and objective type are considered when choosing the best sensors for the job. Environmental considerations affecting sensor choice include altitude, distance, temperature, visibility, etc. Additionally, it is important for designers to know whether the intended targets are of biological or inanimate nature.**

***Index Terms* – PCB, LIDAR, ATR, PWM, Blob Detection**

I. Introduction

Initially introduced as a solution to searching for and destroying military targets in the 20th Century, ATR has evolved into a fully mature product in the Aerospace and Defense industry and finding newer innovative and useful applications in the domestic consumer market. Defense contractor Lockheed Martin alone, currently produces and delivers a diverse portfolio of targeting products which support a wide range of combat operations for its customers. Worldwide, the automotive industry recently began incorporating ATR in its domestically sold luxury vehicles to automatically detect and avoid collisions with pedestrians and other vehicles. Almost every major automotive manufacturer is now investing heavily in such technologies to help deliver fully autonomous vehicles by the year 2020 [1,2,3,4,5].

In simplistic terms, successful ATR is achieved using at least one sensor mode and a detection algorithm. Long range systems might approach target acquisition using radar. Visible spectrum imagery requires sufficient light and has limited range but radar3 doesn't rely on external factors to function as it sends and receives self-generated signals to track objects. Forward Looking Infrared can be combined with visible spectrum imagery to produce a capability that overcomes the impairment of poor visibility conditions such as fog. If the target in mind produces a distinct thermal signature, infrared provides an attractive solution. Once a mode of sensing is selected, an algorithm will need to be developed to mitigate error in target selection. The detection algorithm4 will then be thoroughly developed and trained by example. A compiled database of these experimental scenarios will provide the background information required to judge whether a detected object is the intended target.

The primary specification of the project is to produce a fully functioning ATR, the system to compete in a final Battlebots competition at Lockheed Martin MFC. The autonomous targeting system will allow a synced projectile-launching device to engage and accurately hit two long range targets, and a mobile enemy vehicle. The all-up system will provide a user-interface that utilizes wireless video imagery overlays, allowing the user to both manually control the movement of the robot and simultaneously determine when the weapon has achieved target lock.6

A block diagram showing the main components of our system is shown in Figure 1. A list of the major design specifications is given below:

- Modular power distribution between subsystems
- Sufficient Battery Life (10 minute rounds)
- Reliable range detection of at least 15 feet
- Accurate color acquisition of a 1 ft^2 object
- Accurate target impact within 12 inches of centroid
- Total robot cost of less than $1000
- Custom Fire Control PCB smaller than $100mm^2$

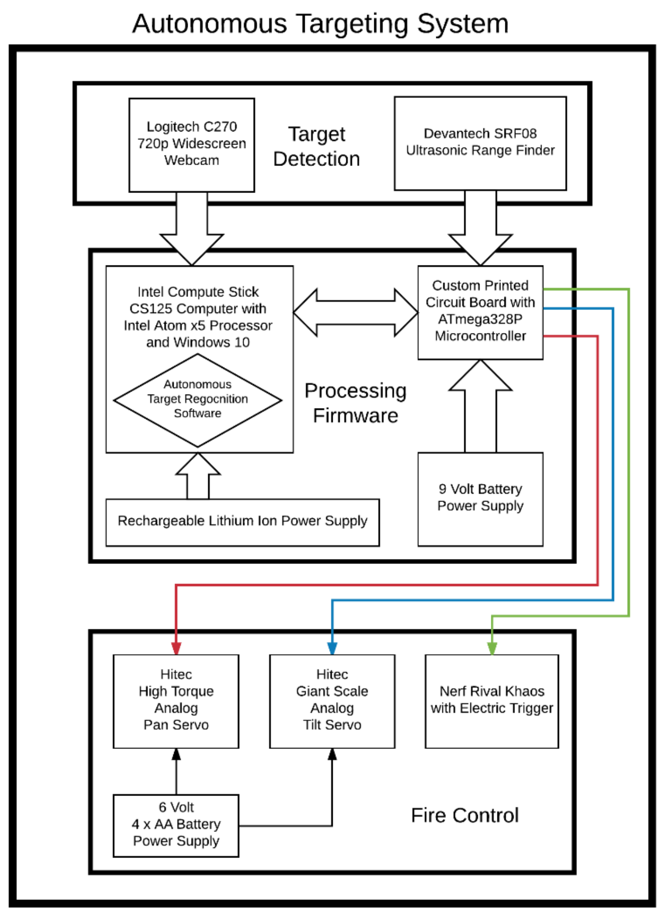

Fig. 1. Autonomous Targeting System

The rest of the paper is organized as follows. First, the introduction to the project in section I. The Fire Control System Components will be introduced in II. The Computer Architecture details will be presented in III. Next, System Testing will be presented in IV. The printed circuit board and schematic will be detailed in V. A conclusion and acknowledgements will be contained in sections VI and VII.

II. FIRE CONTROL SYSTEM COMPONENTS

The Fire Control Subsystem occupies most space available on the robot. This subsystem gets most of its size from the NERF gun, which is roughly two feet. This takes up about two-thirds of the length. An option was available to shorten the gun without losing the purpose of it. Shortening the length of the gun will help reduce torque experienced by the pan/tilt servos. The Fire Control Subsystem includes the pan and tilt servos, the NERF Rival Khaos weapon, their power supplies, LIDAR, a camera for visual detection, PCB, and an on-board computer. The information received will direct the pan/tilt servos to align the NERF Rival Khaos with the target. Once aligned, the system will fire and hit the target.

A. LIDAR: Range Detection

Light Detection and Ranging (LiDAR) is another type of sensor that can be used to serve the purpose of determining the distance of an object. Usually, LiDAR’s are part of a bigger system that can use data to create billions of points. The LiDAR shoots a laser light at an object. Its distance is then calculated by using the time it takes from leaving the sensor to return to the sensor. These points can then be used to create a point cloud. Depending on the distance (or elevation) a different color is used to display the point; from this an image is created [6]. LIDAR has great accuracy, but can be very expensive to implement. Regardless, the accuracy of LIDAR far surpasses that of other range sensing technologies and was therefore selected by Group 02.

B. Camera: Color Detection

Another important part of the robot is a webcam. This will essentially be the “eyes” of the robot. By using a webcam, the robot will have eyes like that of our own. The video feed from the webcam will be able to be viewed in real-time. A color detection algorithm will then be applied to the video frame. From this, desired objects that are found will be highlighted on the screen. This information will then be used, along with the LIDAR sensor, to determine if the object should be fired upon.

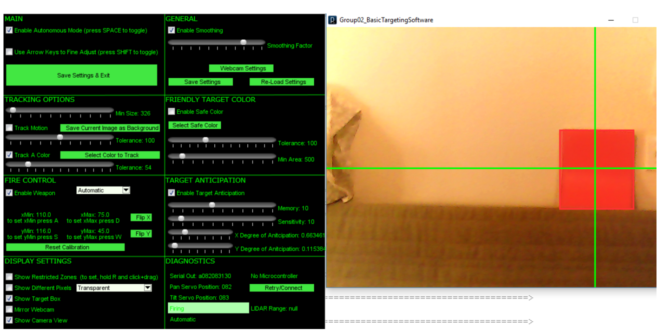

Fig. 2. Tracking red color with Processing: Blob Detection

C. Servo Motor

To move the position of the gun on the robot a servo motor will need to be used. This motor will pan and tilt the gun and its assembly so it can hit its desired target. A great type of motor to use will be a servo motor. A servo motor is small, but is very efficient. They are perfect for controlling the position of a nerf gun. They are cost effective and are simple to incorporate.

They are made up of a few different parts. There is a DC motor, control circuit, and a potentiometer. The DC motor is attached by gears to the control wheel. When the wheel rotates, the potentiometers resistance changes. The control circuit can then control and regulate how much movement there should be. The shaft of the motor will dictate when the motor is in its desired position [7]. Fig. 3 depicts the internal components of a servo motor that aligns it to the position.

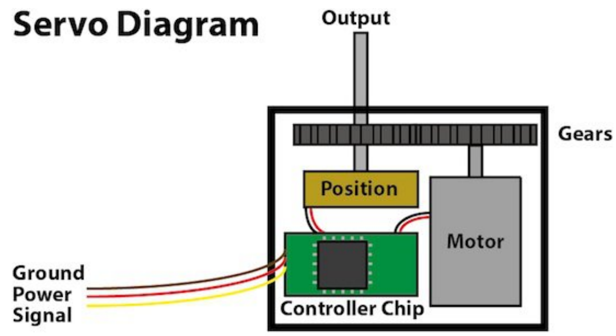

Fig. 3. Internal Components of a Servo Motor

When it is in its desired position, the power is cut off. If it is not at its desired position, then the motor is turned in the correct direction. This desired position is sent via electrical pulses through the signal wire. Fig. 4 displays servo PWM generation that corresponds to a specific degree of rotation.

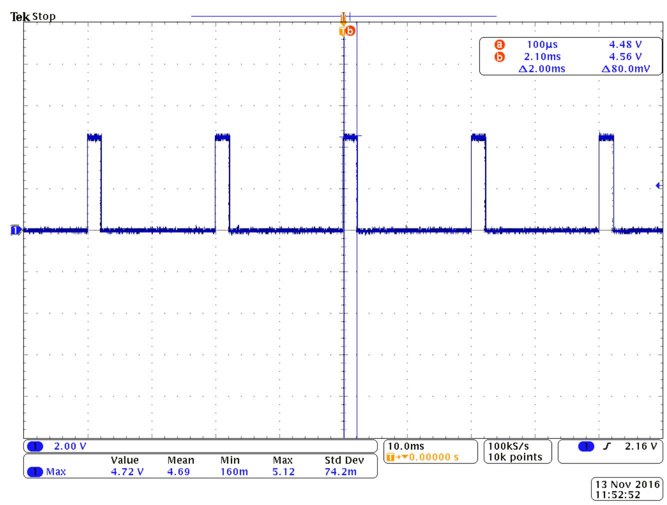

Fig. 4. Hitec HS-645MG Servo 180° CW using PWM

D. Microcontroller: Hardware Integration

Perhaps the most integral part of this project is the microcontroller (MCU). This is the “brain” of the robot. Without this the robot, cannot “think”. This means that it will not be able to process the information from the webcam and sensors. If it does not process this information it will not be able to send signals to the servo motors and the trigger of the nerf gun. This device will be used to perform a few tasks for this project. It will need to be able to communicate with the program used to control the LIDAR, servos, and gun fire.

E. Intel Compute Stick

The Intel Compute Stick schematic, shown in Fig. 5, is 118 x 38 mm in size. The computer is comprised of five I/O ports. It has a standard HDMI output and three USB ports. The USB ports are comprised of a Micro USB power port, a USB 2.0 part, and a USB 3.0 port. In addition, the Intel Stick has a Micro SD card slot on its side. Bluetooth 4.0 is also a compatibility featured with the Intel Compute Stick. This pocket-sized-quad-core computer comes stock with 2GB RAM, along with 32GB of storage and a clock running at a speed of 1.44GHz. A plus is the computer's portability. This would easily fit on top of our robot to control our system. It is also powerful enough to process our targeting algorithms and video stream. Though it only has 2GB of RAM, this is still achievable from its power and Bluetooth compatibility. Another issue is that the Intel Stick will need its own power supply. The purpose of the stick will be for the software to detect a color and to relay the video stream to a user application.

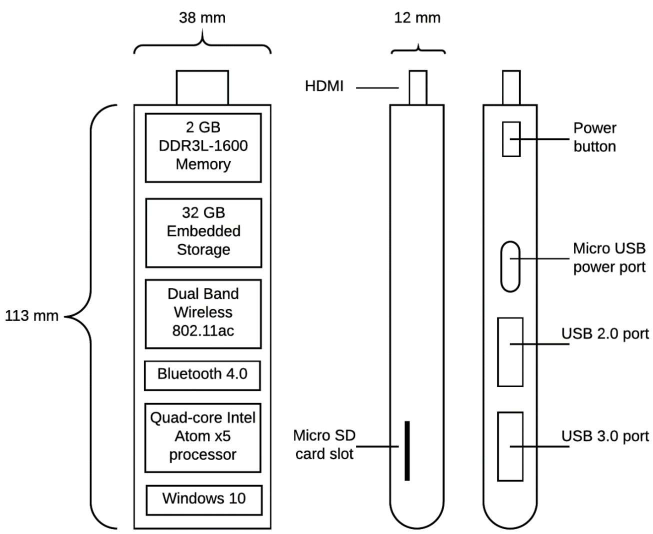

Fig. 5. Intel Compute Stick Schematic

F. Power

A major component of this project is power. Without power, nothing can be used. This section will describe a few of the different options available for powering the numerous components.

A power supply will be needed to power the Intel stick, webcam, LIDAR, and the microcontroller. This power supply must supply at least 5V to power everything. There are various options when choosing what kind of battery pack to be used. External battery packs provide sufficient output voltage for the needs of this project. These packs are also rechargeable, so they provide an advantage to battery packs because if you run out of power you can charge it back to full strength within a few hours. We chose the RAVPower 13000mAh external battery pack. This pack provides the necessary voltage output to power what is needed. It also has a long battery length.

The last portion that needs to be powered are the servos. These require at least 5V of input power – supplied by the battery pack. These come in different voltage variations and some have switches while others do not. The system uses a 4 x AA battery holder case, which outputs 6V. It also has an on/off switch with a cover, so the batteries are protected and we can conserve battery life.

III. COMPUTER ARCHITECTURE

Computer Vision gives a computer the ability to visualize the world given several available parameters. The way humans see the world and the way computers see the world are not similar in any respect. Humans see the world as defined by experience, knowledge learned, feelings/emotions, and so on. Computers see things based on how they are programed to. The programmer defines for the computer how to see and recognize this. The programmer tells the computer that there are gray areas for a computer to recognize an object.

A. Blob Detection

The focus for Group 2 will be looking at how to detect an object of a specific color. One way to accomplish this is by using a method called blob detection. Blob detection is based off a detection method called the Laplacian of the Gaussian.

This process can be used to detect rapid changes in the image and to find out the edges of what is in the image. This method is out of the scope of the project to thoroughly explain. However, OpenCV has a library called cvblob which uses this process described. The cvblob library is capable of distinguishing different colors from the video feed of the camera. From the predetermined color that the user sets, the camera will process the image and will turn anything that matches the color to white. Anything else that is not in that color range will be turned into black to distinguish the two for each other. This library breaks down the video image into a separate processed image that is viewable to see what the cvblob is doing. Fig. 6 shows an example of what cvblob is capable of capturing.

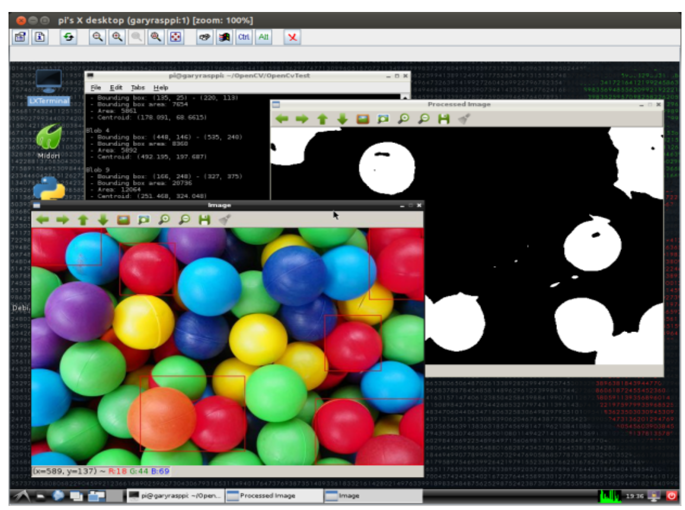
Fig. 6. Targeting Red Color using Blob Detection

B. Arduino

An Arduino board is used to build digital interactive devices. It uses standard connectors, which lets the Arduino connect to a wide variety of modules called shields. Most of these shields connect to the Arduino using various pins and the CPU chip on board the Arduino can use these pins to access the shields. The Arduino has both digital inputs and analog pins. These analog pins can be used to read in a range of different sensors.

These sensors can be read in more accurately as analog signal does not just read binary, it measures the change in voltage. While the digital pins allow the board to control and communicate other interfaces. The Arduino controller can connect using Universal Serial Bus (USB) cable. The script runs on board the receiver computer, and would Serial communication to "talk" to the Arduino. By "talk", it means the computer would be able to relay data back and forth with the Arduino. The serial communication also allows the script running C++ code to read in inputs from the sensors and send commands to the servo motors. Arduino is fully compatible with Windows. The Arduino will also read in inputs from the LIDAR sensor and send it back to the Intel stick

The many digital and analog pins on the microcontroller will serve mostly to connect the peripherals including the servo, LIDAR, and trigger. These assignments will be broken up for the Arduino microcontroller as seen in Table 1.

Item	**Pin #**
Pan Servo	8
Tilt Servo	9
Firing Indicator LED	12
USB Indicator LED	11
Mode Indicator LED	13
Electric Trigger Pin	7
Flywheel Trigger Pin	6

Table 1. Arduino Analog Pin Assignments

C. Design Summary

Stability and Vibration avoidance as it relates to the webcam and image processing. The webcam should not be interfered with by the servos, gun, robot movement, etc. The first subsystem mentioned was the fire control subsystem. This is the system that will handle the actual firing of the weapon. Along with this, it is also the system that will move the weapon from left to right with the pan and tilt servos. The next subsystem is the target detection system. The target detection system is what will give the weapon the eyes and how the weapon will know which direction to orient itself in to hit the target that is in front of it. To do this, there will be the webcam that will provide video that the user will be able to see objects. The ultrasonic sensor in this system will be what will receive the distance information from any object that moves in front of the weapon. The LIDAR sensor will be mounted on the nerf gun itself so it will act as the sights of the weapon without the aid of a human operating the weapon. The webcam will be in a fixed position so that it can see everything that is in front of it. This will also prevent that webcam from getting dislodged from the system. The final subsystem is the software processing subsystem. This is the most vital part of the entire overall system because this is essentially the brains of the system. Here is where all the information that is gathered through the target detection system will be analyzed. After this information is analyzed it will then relay that information back to the fire control subsystem to tell the weapon when and where to fire.

The decision was made to split the system in three parts is to ensure that it will be modular. This is so that it can be easily changed and adapted to fit the need of any platform. Also, it allows for improvement with individual components because you will be able to simply take it apart without disabling the entire system.

Altogether these subsystems must all work individually as well as with one another. If one of the subsystems fail, the entire system will fail. It is crucial that each subsystem is in working condition to maximize the success of the overall goal of the entire weapon system. This is mounted on a robot that can support the size and weight of the system.

IV. SYSTEM TESTING

Each component of the system is tested to ensure proper functionality of the weapon system.

A. Hardware Test

Hardware testing is one of the most important aspects of any type of project. This is when each individual component of the overall project will be tested. There will be different subsystems of the overall project and each subsystem has its own individual components. It is crucial that each of the components in the subsystems are working properly as in Fig. 7 to ensure that overall system is working properly.

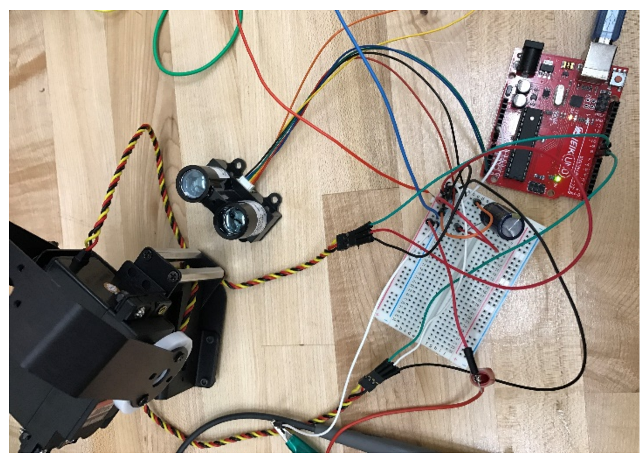

Fig. 7. All Inclusive Breadboard Circuit Test

If this is any individual hardware failure, it can prove to be catastrophic to the overall system. For this project, each of the individual hardware components will be tested inside a laboratory. In this lab, an oscilloscope, a multimeter, IEIK Uno and a computer will be used to conduct these tests. The oscilloscope along with the IEIK Uno and computer will be used to test both the pan and tilt servos. The IEIK Uno and computer will be used to test the LIDAR sensor and both digital triggers. The multimeter will be used to test the power supplies. The IEIK Uno and computer will be used to test the Intel stick and the webcam. In the section below, there will be a more in depth description of these tests and their results.

B. *Wireless Computer Communication Test*

Received information from the sensors will need to be processed on-board the remote system in real time and then viewed wirelessly from a mobile device. To test this functionality, the computer [which is mounted on the robot] was powered on via battery pack and wirelessly logged into with a tablet. Fig. 8 proves this functionality. Range was also tested to ensure the devices could communicate when placed at distances of up to 30' apart. The range test proves that a user will be able to view any processing information that occurs on-board the robot in real time

Fig. 8. Battery Powered Intel Stick that is Logged-in via the Tablet

C. *NERF Fire Control Test*

Tests were conducted to have the trigger and flywheels of the weapon be controlled by the IEIK Uno. For the weapon to fire, there is a separate trigger to spin the flywheels to propel the ammo out of the gun and a separate trigger to feed in more ammo. It was determined to be better to have both triggers activated on command. To accomplish this, both triggers needed to be bypassed and two switching circuits needed to be designed to create digital triggers. The nerf gun was first disassembled to reveal the electronics of the weapon itself. The first step that was taken was mapping out what each component of the weapon is doing and what the wires are connected to. After this was completed the trigger was the first part to be taken apart. The goal was to be able to bypass the physical trigger on the weapon itself to have it fully controlled by the IEIK Uno. To accomplish this the correct wires needed to be found and cut to break the connection between the motor of the conveyor belt and the physical button. The positive and negative terminals of the motor were found and the leads to them as well. To bypass the physical trigger, the wires of the positive and negative terminals were cut to break this connection. This will ensure that the physical trigger no longer controls when the motor will be running to feed the ammo to the flywheels. Instead of the physical trigger, a simple switching circuit was constructed on a breadboard as seen in Fig. 9.

The switching circuit consisted of a resistor, diode and BJT transistor. The leads of the motor were connected to this switching circuit to become the new digital switch. When no voltage is supplied to this circuit, the switch would act as if it were opened, not completing the circuit. When voltage is applied to the circuit, the switch will be closed, completing the circuit. In return, when the switch is opened, the motor will not be running and when the switch is closed, the motor will begin to run.

The program uses pin 7 on the IEIK Uno as the digital trigger. The program has a manual fire mode that works with any webcam. When you click on the video window of the webcam, the weapon will begin to fire, sending a HIGH signal to the pin. When you release the mouse the weapon will cease fire, sending a LOW signal to the pin. With the circuit constructed the program was ran to verify that the digital trigger is working properly.

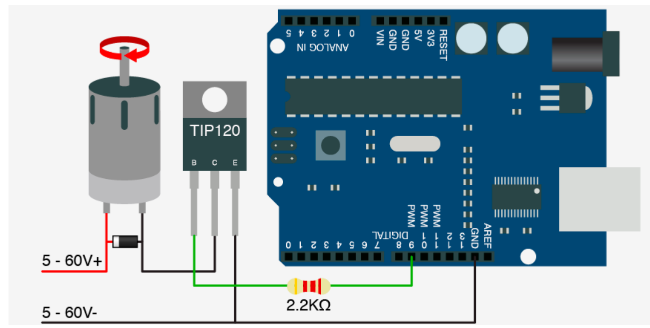

Fig. 9. Motor Control Circuit

The test was successful and the motor ran while the mouse was clicked and did not run when the mouse was not clicked. Initially, the same plan was used, but instead of cutting the wires between the negative and positive terminals of the motor, a wire was conducted to each terminal to the switching circuit. When this plan was used, the motor would always be running the conveyor belt, no matter what the status of pin 7 was set to. This was since the terminals were already wired to the physical trigger, always having a complete connection. To fix this issue, it was determined that those connections needed to cut to disrupt the signal. After this issue was fixed, the same process was used to create a digital switch to control the flywheels.

The flywheels on the weapon work in a similar way to that of the conveyor belt and the fire trigger. The flywheels are connected to its own trigger independent of the physical fire trigger. The result was to have this physical flywheel trigger be replaced with a digital trigger controlled by the IEIK Uno. The same process above was used to create this digital switch.

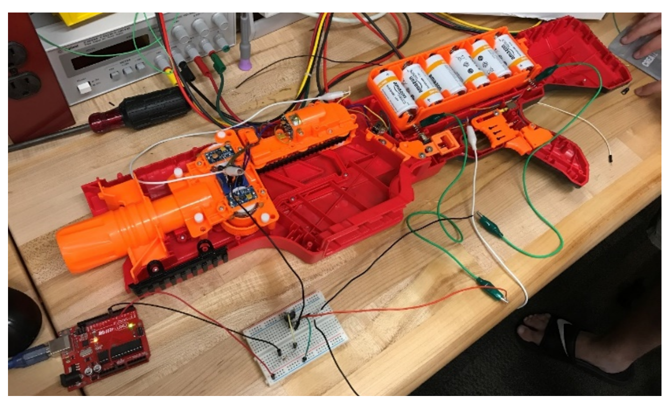

Fig. 10. Testing the NERF gun

During the first test of this digital switch, the group noticed that the flywheels were noticeably turning slower than the original test of the weapon.

To troubleshoot this issue, a digital multimeter was used to measure the voltage across the flywheels connected to the weapon in the original out of the box state. With this test, the voltage was above six volts. However, with the switching circuit, the voltage was about five volts, which was significantly lower.

During this test, a noticeable smell was coming from the switching circuit. It was found that this smell was coming from one of the wires of the circuit, due to the wire becoming very hot. It was deemed that this wire was not in complete working order and the wire was then replaced. After the wire was replaced the test was conducted again. During this test, the voltage across the flywheels were back around six volts. The digital switch for the flywheels were now working as intended. The final test of the weapon was having both digital switches connected at the same time to the IEIK Uno. Fig. 10 shows

V. PRINTED CIRCUIT BOARD AND SCHEMATIC

Group 02 is responsible for designing a custom Fire Control board. This section outlines the various components that make up the Fire Control board. The custom board will simply the connections and allow the overall system to be more modular. The simplification of connections will speed up testing and additional tweaking of software. In summary, the servos, LIDAR, and NERF gun will all connect to the Fire Control Circuit Board. Eliminating the use of a breadboard for these tasks will drastically reduce probability for human error and other electrical malfunctions.

A. Top Level Schematic

Fig 11 shows revision 1 of the top-level Eagle schematic for the preliminary design of the printed circuit board.

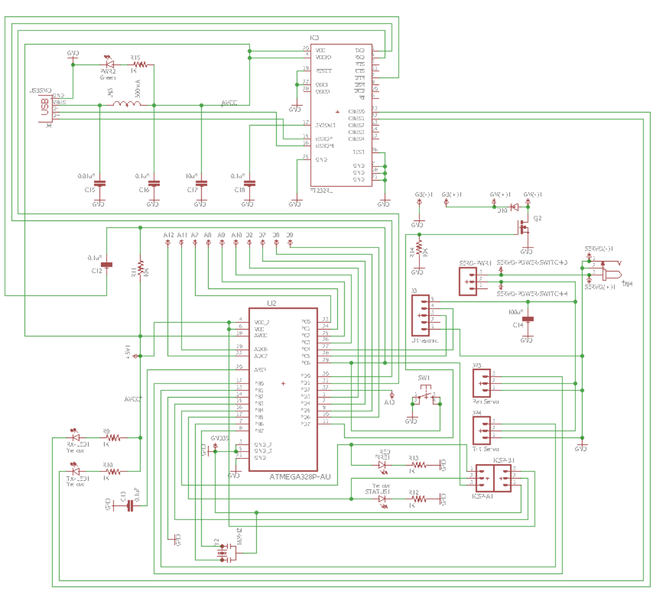

Fig. 11. Top-level schematic

This schematic shows all the to-be-integrated systems. Some highlights from the schematic include areas for several peripherals to be connected. Not included in Fig 11 are the additional transistor for flywheel control and the upgrade to LIDAR from Ultrasonic.

The robot needs connections for the pan and tilt servos so there are two separate 3-pin areas for the servos to be connected. Additionally, there is an area for the ultrasonic sensor to be connected. The heart of the circuit board will be the ATmega328 microprocessor. The surface mounted microprocessor will allow USB programming and will talk to the servos and LIDAR sensor. The USB connection will be used to talk to the Intel Stick. This is very important because the system will need to constantly receive and transmit information to controller the servos and transfer ultrasonic sensor data.

B. Microcontroller Main Input / Output Circuit

Fig 12 shows all the connections to the microcontroller. As can be seen in the labels, there are pins going to the ultrasonic (upgraded to LIDAR*) sensor, the servo motors, the electric trigger, and a crystal oscillator among other things like power and the USB controller. The crystal oscillator will create an electric signal with a precise frequency of 16 megahertz to provide a stable clock signal for the integrated circuit.

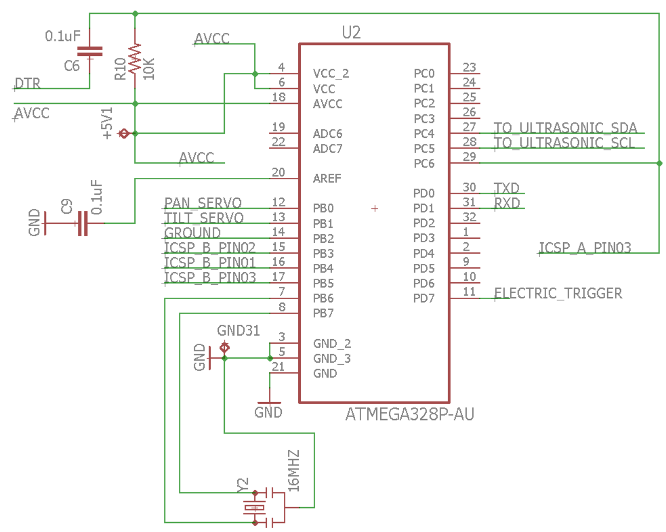

Fig. 12. Microcontroller Circuit

C. Switching Circuit

For the nerf gun to be autonomous both the trigger and the flywheel need to be controlled via the microcontroller. It is relatively simple to do this. A transistor will be used as a switch. When the microcontroller sends a high signal to the switch portion of the trigger it closes and completes the circuit. This will then fire the gun. The microcontroller will then send a low signal to open the switch which will stop the gun from shooting. This same transistor switch is applied to the flywheel. The plus and minus portions of the gun battery, trigger motor, and flywheel motor are used to complete the switch. Fig 13 shows the schematic of the trigger and flywheel.

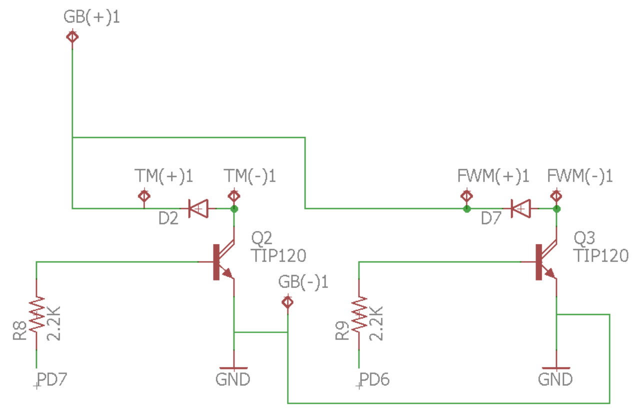

Fig. 13. NERF Switching Circuit for Motor(s) Control

D. Servo and Sensor Control

The last portion of the schematic is the servo and sensor control. These three peripherals are powered by the 6V battery pack. The data outputs of these devices are connected into various inputs of the microcontroller. The microcontroller can now send and receive data from these peripherals. Fig 14 shows the schematic for the servo and sensor control.

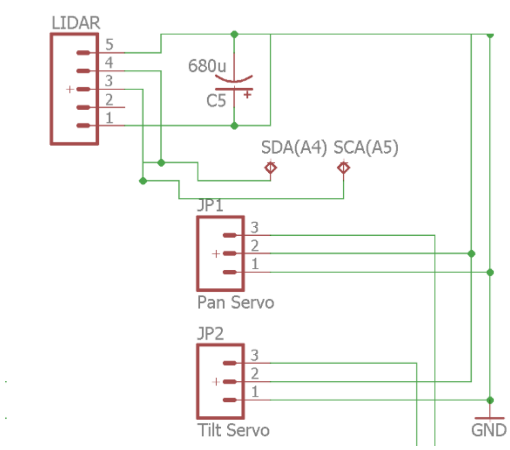

Fig. 14. Connections for Fire Control Peripherals

E. Printed Circuit Board Design

Fig 15 shows the final design of the PCB. Each part of the PCB needs to be placed in such a way that parts are not overlapping one another. You also want parts that need to be connected to one another are close enough to do so. If any of the same color traces do not touch the PCB layout will be sufficient.

The PCB consists of various elements that make up the circuit. This design is a two-layer design. This reduces the overall cost of manufacturing the PCB. The parts themselves are mainly surface mounted parts. These allow the PCB to be smaller in size, which will reduce the cost of the PCB.

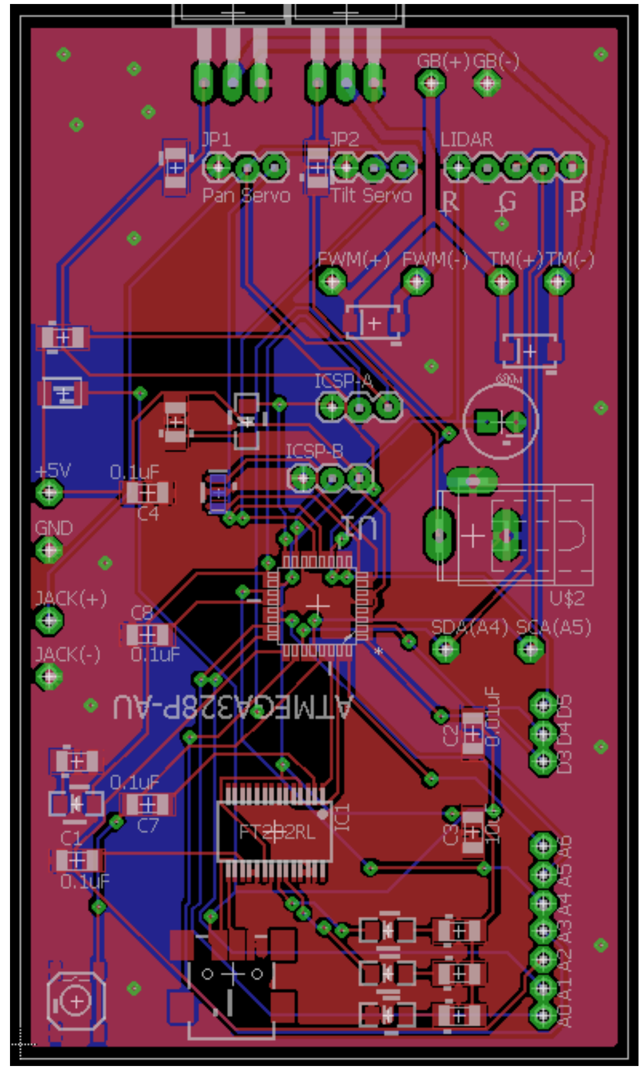

Fig. 15. Finalized PCB Design

VI. Conclusion

Group 02 worked with three UCF Computer Science Students and five UCF Mechanical Engineering Students to complete a final robot build. The final robot was made to compete against several robot teams on April 14th, 2017. Group 02 will host a faculty demo to confirm engineering specifications stated earlier in the conference paper. The final system will be capable of being driven manually by a user and will autonomously target various colors upon selection. After confirming that the colored target is within a predefined range, the robot will fire NERF ball ammunition at the target. The system is highly modular and capable of future upgrades and modification. All software and hardware design details are available at: github.com/aperez41907/LM-Autonomous-Vehicle.

VII. Aknowledgements

Group 02 thanks all the UCF Faculty and Mentors that were involved for their assistance and guidance with this project. Additionally, Group 02 sends high regards for their sponsors Kenny Chen and Johnathan Tucker of Lockheed Martin: Applied Research, for sponsoring the robot and providing their industry-level insight.

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IX. Biographies

Corey Nelson is an Electrical Engineer receiving his Bachelor of Science in May of 2017. He hopes to receive a job at a well-known engineering company as a technician.

Kyle Nelson is an Electrical Engineer receiving his Bachelor of Science in May of 2017. He hopes to begin a career at an engineering company

Clayton Cuteri is graduating on May 4th, 2017 with a Bachelors in Computer Engineering. From Pittsburgh, PA. his drive for learning about everything computer-related and creating the innovative solutions of tomorrow encouraged him to become a Computer Engineer. He has loved it ever since.

Alexander Perez is graduating on May 4th, 2017 with a Bachelors in Computer Engineering. While working towards his degree, he spent several years at Lockheed Martin as a CWEP student: working in Master Planning and Product Support Engineering. Currently interning as a Computer Engineer at Hoverfly Inc., Alex is programming and configuring flight management systems and supporting other efforts in drone development. Alex will continue to hone his engineering and management skill set over the next several years.