# Motion-Detecting Sentry Turret

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***Abstract* — This paper serves to outline the design methodology of the Motion-Detecting Sentry Turret. This project will aim to combine the talents of both electrical and computer engineering students to create autonomous tracking with entertainment and security possibilities. The main intent of this project is for entertainment with an emphasis on the competitive sport of Paintball. The goal would be to enhance gameplay with adding another element of surprise for players. With the use of OpenCV for computer vision, the prototype will identify and track targets to fire upon. Paintballs will be used for the prototype as non-lethal ammunition is a requirement of the project. A computer will be used for image processing which will then communicate with a microcontroller to issue commands to motors for tracking and firing. The prototype will structurally employ a tripod for stability and hold a chassis containing the motors and paintball gun.**

***Index Terms* — Autonomous systems, Computer vision, Mechanical systems, Microcontrollers, Motors.**

## I. INTRODUCTION

The initial inspiration of the project was to make a robot that could play Cornhole which involves tossing a fabric bean bag onto a raised platform with the aim of the bean bag going into a hole at the far end. After some research and pricing of materials, a Cornhole robot would require more time and resources, so the project was then focused on keeping the entertainment aspect but thinking of alternative games that could be improved with automation.

After brainstorming, a turret was decided on for the use of its various electrical components, and to make the project innovative computer vison could be used. The idea was then formed to create a turret that detects a target and follows their movements. It was later refined to be used in Paintball to enhance gameplay. The game of Paintball itself is relatively simple. Opposing teams will try to eliminate the other team by shooting them with brightly colored paintballs. The paintballs themselves are made of food grade materials such as polyethylene glycol, minerals oils, calcium, ethylene glycol, iodine, and food coloring which are biodegradable and non-toxic to humans and animals. [1]

In consideration of using non-lethal ammunition safety procedures must be followed. For testing, the safety features of a normal paintball match will be put into place which are googles or paintball masks always worn when firing the paintball gun. It is up to the player's discretion if a vest is needed. Also paintball guns may not fire more than 285 feet per second at most paintball ranges. [2]

With all aspects of Paintball considered the prototype of the Motion-Detecting Sentry Turret will incorporate computer vison using OpenCV and various hardware components to make the turret move.

## II. HARDWARE COMPONENTS

For the basis of the prototype hardware components were either made or purchased to support the design of the project. The following subsections will go into detail of the major hardware components.

### *A. Microcontroller*

For controlling the main hardware components of the project, the Atmel ATmega328P was chosen. The decision to pick this microcontroller chip was because of its low cost, integration with the Arduino IDE, easy to use, built in functions, and operating temperature. It provides 32KBytes of flash program memory, 2KBytes of Internal SRAM, and with features such as SPI, I2C, and USART. These features fit the needs of the project and with the use of the Arduino IDE there is not a big learning curve to use its functions. The operating temperature is -40°C to 105°C which is more than sufficient for testing in an outdoor environment in Florida. [3]

### *B. Arduino Uno*

The project will utilize the Arduino Uno Development board. For the various hardware components such as an LED light, and several motors an Arduino Uno will be an indispensable tool in assisting the functions of our project. It has both easy-to-use hardware and software, and the pins of the Atmel ATmega328p are easy to locate. In testing and development when there are many wires for connections it is invaluable to have all pin outs organized and the Arduino Uno helps with this. The Arduino Uno is relatively inexpensive and can be bought in many development kits. The Arduino IDE is also cross platform making it ideal for different types of operating systems. For this project the open-source software greatly helped to design functioning code for our hardware components. The Arduino Uno will also communicate with the laptop that will be running computer vision. The serial communication between laptop and Arduino will trigger actions to move motors up and down or left to right, fire the paintball gun, and turn on the warning led light.

*C. Warning Light*

To show that the Motion-Detecting Sentry is detecting a person a light will turn on. When a person is not detected the light will remain off. To accomplish this a simple light made up of three bright LEDs is chosen. The Bolt Beam 12mm LED Light was chosen because it was cost effective and could be easily hooked up to the hardware system. The red LEDs are covered by glass and is weatherproof. The glass disperses light evenly in a 110° beam at 55 lumens with an operating range of 9V to 14.5V. In the Arduino IDE it was very simple to set up a short function that would send a high signal when a target was detected.

*D. Stepper Motors*

The Motion-Detecting Sentry Turret will have to track a target, and this will be done via a stepper motor system. Two stepper motors will be used one to move horizontally in 180° and another to move vertically 45°. The stepper motors were chosen for this task because of their capability to set a position and provide holding torque to maintain the position. For sufficient torque and turret size a NEMA 23 stepper was selected. A sufficient stepper motor driver was selected, TB67S128FTG, to provide protection against under-voltage, over-current, over-temperature, shorting, and reverse-voltage protection.

*E. Servo Motor*

In order for the paintball gun to fire when the signal is received from the laptop, a servo motor will be used to engage the trigger. The one selected is a standard Tower Pro MG995 which is very low in cost and comes with an assortment of servo horns. It has a rotation angle of 180° which is more than sufficient. It will be programmed via the Arduino to rotate back and forth to hit the trigger. The speed of the servo motor is 60° in 0.2 secs which is fast enough to meet the needs of the project. The size of the servo is also relatively small so it can be mounted close to the trigger of the paintball gun with the use of a servo extender cable. It has an operating range of 4.8V to 6V which is a very lower draw for our power supply.

*F. Power Supply*

The project will be supplied power via two methods. The webcam and Arduino Uno will both be powered by the laptop which are plugged directly in via USB. The other hardware peripherals will be powered by a much greater power source. The Duracell Ultra DURDC 12-55P was kindly offered at no cost to help with the expenses of the project. Two 12V batteries will be used in series to provide a total voltage of 24V which will supply enough power for operation and testing. This will be directly hooked up to the PCB and two voltage regulators.

*G. Paintball Gun*

The projectile device for this project will be a paintball gun, as the main intent for the Motion-Detecting Sentry will be used for Paintball games. The model of the chosen paintball gun is the Tippman Model 98 Paintball gun. This paintball gun fires 8 paintballs per second and uses a compressed air tank to fire. It weighs 3 pounds without the air tank, so a decision was made to buy a hose extender to place the air tank lower on the turret. This is necessary as the paintball gun will be placed at the top with the stepper motors that need to move. It must be light enough for the turret to traverse and accurately aim. This is one of the components used that was quite costly especially with the air tank being sold separately. However, the paintball gun utilized in the project was purchased used to cut down on costs.

*H. Laptop*

To be able to efficiently run the computer vision program, a laptop with a modern CPU is needed. It was decided within the group that the members' laptops would be used for testing and demos. The two that were utilized are a Lenovo ThinkPad E570 with Intel Core i5 -7200U, 2 cores @ 2.5-3.1 GHz, and an Acer Predator Helios 300 with Intel core i7 9750H, 6 cores @ 2.6 - 4.5GHz. These both ran the OpenCV software when testing. The laptop would also interact with the webcam as an input device to provide a live feed for image processing and sending information to the Arduino Uno to control the functions of the turret such, as traverse, turn light on, and shoot.

Fig. 1. An overview of the structure of the Motion-Detecting Sentry Turret. The chassis will house most of the hardware components.

*I. Webcam*

For this project a webcam was used as an input device. The webcam chosen was a Logitech C920s. It was one of the more expensive components, but for the price point it has very good features. It provides a flexible resolution at either 1080p or 720p with a capability of 30 frames per second, and a field of view at 78°. It is also relatively lightweight at 5.71 ounces. This will plug directly into the laptop and provide a feed for computer vision to analyze.

## III. STRUCTURE

The building of the project was fairly complex. From Fig. 1, each part of the Motion-Detecting Sentry Turret is shown. For the structural components, they were made with steel to withstand the weather and to make the turret more robust. Starting from the bottom, the entire structure is supported by a tripod. This is made by welding three steel rods to a flat plate of metal. Going towards the mid-section where the plate is located, there is a gear reduction system attached. There are two located on the turret and this one will be for the horizontal axis. The first stepper motor will be attached here to track left and right movement. This will move the top of the turret side to side in a range of 180°. At the top in light brown is the chassis that contains the second stepper motor for the vertical axis. This will also be connected to a gear reduction system to move up and down in an angle of 45°.

This is also the structure to where the paintball gun will be attached. Much like the base it is also made of steel that is welded together. It will be securely bolted to the top on a central point so it will still be able to be move when the turret moves up and down. It will also be balanced for proper movement and aiming. The trigger servo motor will also be attached inside the chassis as close as possible to the trigger for responsive firing. The paintball gun is already built with two essential features needed for this project first the top of the paintball gun is a structure called a hopper that can hold 180 paintballs. For testing purposes only approximately 30 will be filled at a time. Secondly there is a rear bolt that need to recoil to fire again which limits rapid firing.

Since the turret is mostly made of steel it will be durable enough to support the gun while firing. The webcam will also be placed on a stationary spot of the base plate to track targets. If the webcam is placed on a moving part of the turret tracking will become inaccurate causing the aim to be miscalculated. The warning light will also be on a stationary front facing part of the turret for targets to see. The air tank used to fire the gun is placed lower on the turret as not add additional weight to the chassis as it may cause drag and lead to misfiring. An extension hose will be used to supply compressed air to the paintball gun for firing.

## IV. HARDWARE DETAIL

In this section the hardware flow and power distribution will covered. The interactions between each hardware component will be discussed.

*A. Mechanical System*

The hardware flow of the system starts when the Arduino Uno gets a signal that a target is present. It will then engage the stepper motors to move and track the target, turn on the warning light and finally send a signal to the servo motor which will fire the paintball gun. In Fig. 2 below, the diagram shows all the hardware components of the turret system and how they interact with each other.

When computer vision detects that a person is present it will send a binary number to the Arduino to process. From this the stepper motors for both the

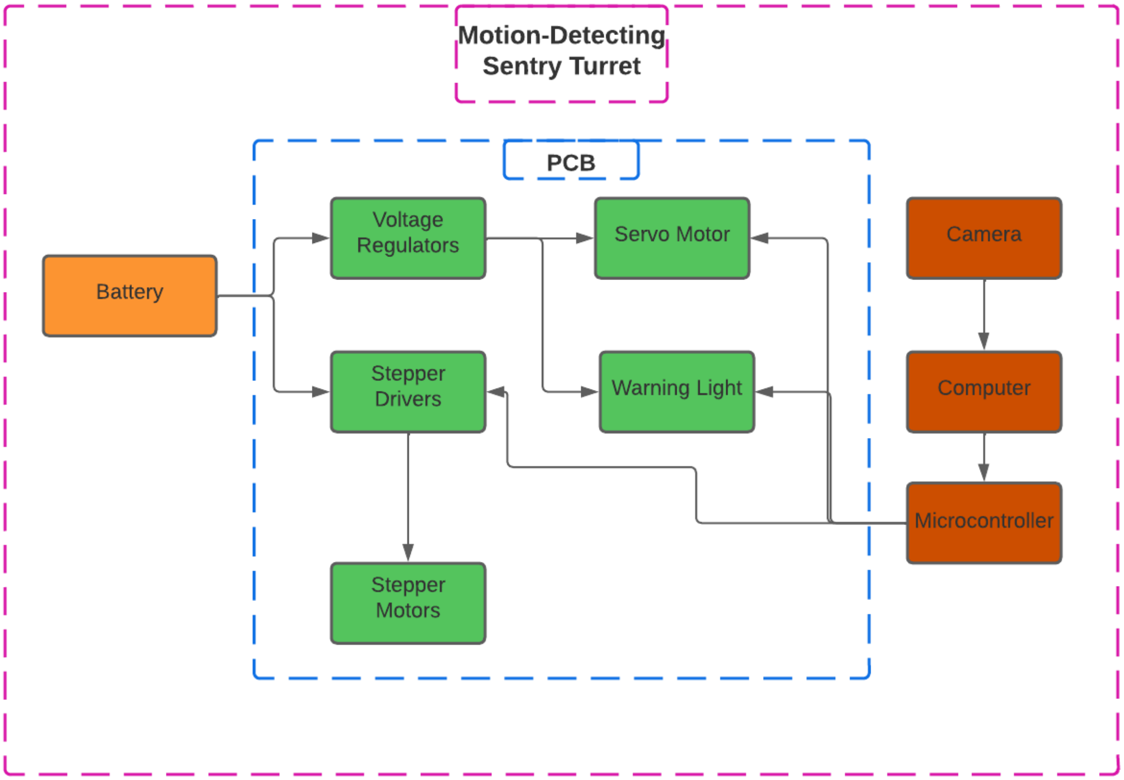


Fig. 2. An overview of the hardware flow of the Motion Detecting Sentry Turret. Each of the hardware components is listed and their relationship to the other components in the system.

horizontal and vertical axes will be engaged and start the tracking process. The NEMA 23 stepper motors

angle the number of resulting steps is 400. This value will be used in the Arduino Uno code to determine how many steps each stepper motor will take to reach its target. This will be done automatically via the code. The gear reduction system was chosen as a 6 because a higher ratio would allow for greater accuracy.

The stepper drivers are used to communicate between the microcontroller and the stepper motors themselves. The driver can affect the performance of the motor. If the controller is not able to deliver more power than it can handle, then the motor will not be able to achieve its maximum possible mechanical performance. The driver must also be specific to the stepper motor selected, so for this project the driver selected is the TB67S128FTG and was selected as 24V was in the operating range. The operating voltage is 6.5V to 44V. Two were used for the horizontal and vertical stepper motors.

have a step angle degree of 0.9° and when the full rotation of 360° is divided by the value of the step

The trigger mechanism was rather easy to design because of the position control of the Tower Pro MG995. It has the ability to do a sweep between 0° to 180° which was more than sufficient for programming on the Arduino IDE. The ideal sweep is a 45° to 90° to hit the trigger of the paintball gun and have the rear bolt to recoil back to fire again. The servo horn is custom printed, so it is designed to precisely hit the trigger and move back. The trigger will keep engaging as long as the target remains in view of the camera. The Tippman 98 paintball gun which is used in the project requires a trigger pull of 2.5 pounds. Although pounds will not covert directly into pound-inches, it can be estimated that the trigger would need 2.5-pound inches to pull. The equivalent of 2.5 pound-inches is 2.88 kg-cm or 40 oz-inches. The Tower Pro MG995 has a torque of 8.5kg-cm at 4.8V, which it be sufficient to pull the paintball gun's trigger.

The warning light is designed to alert the target that

TABLE I
A SUMMARY OF VOLTAGE SUPPLIED BY THE POWER SUPPLY

| Load on the 24-Volt Source | |
|---|---|
| Microcontroller | 5V |
| Stepper Motors (2) | 24V |
| Servo Motor | 5V |
| Warning Light | 12V |
| Stepper Motor Drivers | 5V |

the turret is tracking them. When a target is not in view it remains off until the Arduino code triggers it on. It will remain on until the target is out of view. It provides a quality-of-life change for the turret, but it is not necessary for the operational function. A transistor is used to divert and supply 12V to power the warning light.

From the battery to the PCB two voltage regulators are connected to. The first one provides power to the stepper motors and servo motor and drops down to 5V. The second will drop down to 12V for the warning light.

*B. Power System (PCB)*

For the Motion-Detecting Sentry Turret, it is imperative to have the appropriate amount of voltage going to each component. Over-voltage or under-voltage may cause components to work improperly, not work at all, or permanently damage them. Fig. 2, gives a breakdown of the load of the 24V power supply.

Voltage regulation plays a major role in protecting the components of our project. Two different voltage regulators will ensure that all the hardware components connected to the PCB receive the correct voltage at a current rate. Each Duracell Ultra DURDC 12-55P is 12V and when connected in series supplies 24V. This was necessary due to the two stepper motors that needed 24V each to be in the operational range. The voltage regulators help convert the incoming 24V down to supply other components of the PCB.

The first voltage regulator steps down from 24V to 5V. This needs to be a very accurate step in calculation as the logic chips on the drivers do not allow for much fluctuations in voltage before failure. The second voltage regulator steps down 24V to 12V. This is exclusively used for the warning light. The voltage regulator will supply a steady 12V, but accuracy is not needed on this regulator as the Bolt Beam 12mm LED Light used for the warning light, has an operating range of 9V to 14.5V. For the DC-to-DC conversion calculations required for the power system the WEBENCH application developed by Texas Instruments was used. Schematics of the voltage regulators chosen are shown in Fig. 3.

*C. Power System (Laptop)*

To provide power to the other components used for computer vision, the laptop will be used as a power source. It is not the most effective source of power as it stays powered approximately two hours off internal battery power. However, it is sufficient to be used in testing. It is also advantageous to use the laptop as a power supply as the webcam plugs directly in via USB and does not require any additional hardware to use. The Arduino Uno is also supplied power from the laptop, so there is very little chance of it being damaged. Because an auxiliary device is used to power both the webcam and Arduino safely, their voltage draw is not considered critical as compared to the power system of the PCB and the attached components.

## V. SOFTWARE DETAIL

This section will entail the software system of the Motion-Detecting Sentry Turret. It will describe its interactions will the hardware system that cause the

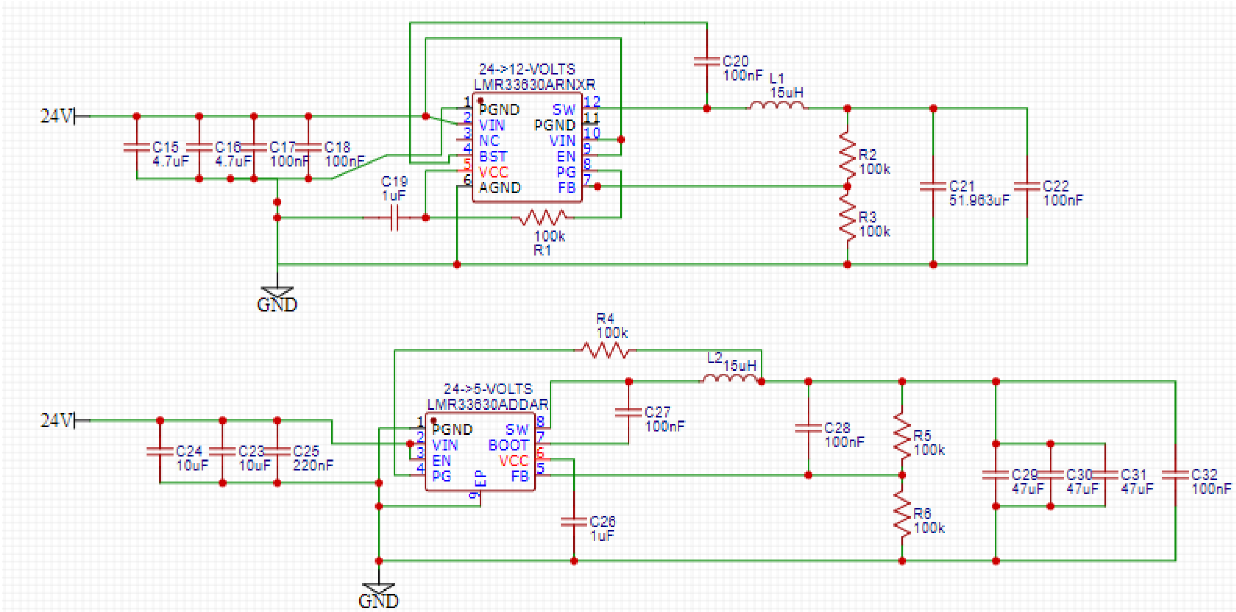


Fig. 3. Shows the Texas Instruments WEBENCH schematics generated and used for the power system (PCB). These schematics provide reliable DC to DC conversions needed for voltage regulation.

cascade of events when a target is detected.

*A. OpenCV*

For target detecting, motion detecting, and image processing the Motion-Detecting Sentry Turret used the open-source library OpenCV. This gave access to Histogram of Gradients (HOG) and Linear Support Vector (SVM).

*B. Histogram of Gradients (HOG)*

HOG is an algorithm that takes an image and outputs feature vectors. Feature vectors indicate the position and curvature of different objects and parts recognized in an image. There are feature descriptors that encode information into a series of numbers and act as a numerical “fingerprint” used to differentiate one feature from another. It focuses on the shape of an object to provide both edge features and edge direction by extracting the gradient and orientation of the edges. The orientations are then calculated into localized portions and broken down into smaller regions. Histograms are then created using gradients and orientations for each separate region. To start the whole process of HOG the image is first preferable resized to 64 x 128 pixels. with a width of height ratio of 1:2. The next step is to divide the image into 8 8 and 16 x 16 patches to extract the features which makes calculations much easier for the 64 x 128. Gradients are then calculated for the pixels in the image. The gradient is calculated by combining the magnitude of and angle from the image. It considers a 3 x 3 block of pixels as Gx and Gy respectively, using (1) and (2), where r refers to rows and c refers to columns.

$$Gx\,(r, c) = I\,(r, c{+}1) - I\,(r, c{-}1) \qquad (1)$$

$$Gy\,(r, c) = I\,(r{-}1, c) - I\,(r{+}1, c) \qquad (2)$$

After the calculation of Gx and Gy the magnitude and angle of each pixel is calculated using (3) and (4).

$$Magnitude(\mu) = \sqrt{[(Gx)^2 + (Gy)^2]} \qquad (3)$$

$$Angle(\Theta) = |\tan^{-1}\left(\frac{Gy}{Gx}\right)| \qquad (4)$$

Gradient matrices are then calculated from the magnitude and angle and divided into 8 x 8 cells to form a block. A histogram is calculated and split into 9 bins witch corresponding angles from 0 to 180 in increments of 20. A bin is selected depending on the pixel’s angle, and the vale that is placed inside the bin is dependent on the pixel’s magnitude. If it happens that a pixel is between two bins, the magnitude is split accordingly on the distance from each of the bins.

Histograms are then concatenated in groups of four into a 36-feature vector that is normalized reduce the

effect changes in contrast between images of the same object. This is then fed into the Linear SVM which will classify a human target. [4]

*C. Linear Support Vector Machine (SVM)*

SVM is an algorithm that is used to recognize pedestrians from the HOG feature. Given the HOG feature vector x, of a window in an image, SVM assigns a score that determines how accurately the algorithm can identify a pedestrian or not. To classify a window with a feature of vector x, SVM computes (5), with w, as the weight vector and b is the bias.

$$h(x) = w^t x + b \tag{5}$$

These parameters give rise to a hyperplane in feature space which separates windows containing pedestrians from background windows in a sliding-window format. A binary decision is achieved by using the sine function on the output of the SVM (6).

$$g(x) = \sin\big(h(x)\big) = \sin\,(w^t x + b) \tag{6}$$

*D. Computer Integration*

From the computer, the HOG pedestrian detector will initialize via the python program on the laptop. It will receive an input video stream from the camera frame by frame. The frames are then resized and converted to greyscale for faster detection. The program then puts bounding boxes of the detected humans using pretrained HOG stored in a NumPy array. The bounding box has x and y coordinates of the four corners. The center of the bounding box can then be determined from the x and y coordinates and calculate the required steps for the stepper motors to move and aim the paintball gun based on the current position.

These steps are then relayed through USB serial connection to the Arduino Uno to the Atmeaga328P. The ATmega328P runs on its own code via the Arduino IDE that will convert the inputs from the python program into commands for the warning light, steppers motors to move the turret, and the servo motor to fire. The laptop will send a number to the Arduino code where modulus is used to find remainders to issue commands to the turret. A sample of the Arduino code for modulus calculations is shown in Fig.4.

To account for a moving target, the turret will be constantly comparing where the paintball gun is

```
if (Serial.available() > 0) {
  String str = Serial.readString();
  int input = str.toInt();
  light = input%10;
  tilt = (input/10)%10;
  pan = (input/100)%10;
  fire = (input/1000)%10;
}
```

Fig. 4. A snippet of Arduino code showing how modulus is perform for the actions of the turret.

currently aimed, and where the target is located. The turret will then keep moving to keep the paintball gun's aim at the target. The computer vision algorithm is always calculating the current frame received from the camera, and the communication is not instantaneous so there is some lag expected between target and turret tracking. When motion is triggered, the microcontroller will check its connection with the laptop for new commands. Fig. 5 below outlines how messages are received from the software system to the hardware system.

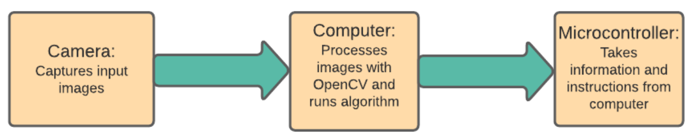


Fig. 5. Shows the software flow of the system. It shows the path of when an image is first received to the microcontroller.

## VI. PCB DESIGN

Several PCB prototypes were created for versions to fit the need to the evolving project. The PCB consists of an input for the 24V power supply, two voltage regulators. One that steps down 24V to 12V and another 24V to 5V. Limit switches to prevent the turret from moving out of the 180° range for horizontal and 45° range for vertical, stepper motor windings for pull, direction, and enable for two stepper motors, wires for the warning light, the servo motor, the ATmega328P, and a USB connection. These were all put onto a two-layer PCB board, using the bottom layer for a ground

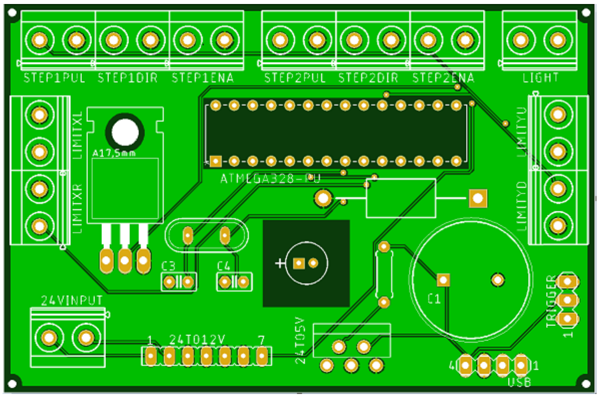

Fig. 6. A layout of the final PCB schematic for the Motion-Detecting Sentry Turret

copper pour. Fig. 6 shows the final PCB and all the components. Schematics were made using both Eagle and EasyEDA, and it was found that EasyEDA was more user friendly and had a preferable view of board files. The main company used for manufacturing the PCB was JLCPCB. However, due to another variant of Covid-19 there was a risk of the PCBs being delayed as JLCPCB is based in China where there is currently a lockdown.

## VII. CONCLUSION

The design for the Motion-Detecting Sentry exceeding the needs for our project specifications with a few adjustments. Members of the group put in enough time and effort to make the project a success. Invaluable skills were learned through troubleshooting and building. It was a team-building experience which improved professional demeanor and problem-solving skills.

## ACKNOWLEDGEMENT

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## BIOGRAPHY

Liderma Guerry will graduate in Spring 2022 with a Bachelor of Science in Computer Engineering. Her primary interests are homeland security and electronics.

Quintin Jimenez will graduate in Spring 2022 with a Bachelor of Science in Computer Engineering. His primary interests are not within the scope of his degree, though he plans to hold a temporary position in software development.

Michael MacAllister will graduate in Spring 2022 with a Bachelor of Science in Computer Engineering. His primary interests are in robotics and prosthetics.

Kaitlyn Martin will graduate in Spring 2022 with a Bachelor of Science in Electrical Engineering. Her primary interests are in circuit design and digital signal processing.

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