ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Project: High Noon Sheriff Robot

Team #03

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May 18, 2023

Abstract

This project focuses on designing a robotic system that emulates a Western-style duel. The robot is programmed to identify an opponent through specific marking gun, react to their actions, and engage in a simulated duel scenario. It maintains its gun point to the ground when the opponent is not in a drawn position. Once the opponent assumes a draw position, the robot draws its gun and aims without firing. If the opponent gives up, the robot holsters its gun, but if the opponent persists to draw the gun, the robot shoots at their chest. Only one shot is fired, and the robot disengages to re-identify. The simplified scenario involves a single opponent standing approximately 3 meters away. By replicating a duel, this project showcases the robot's capabilities in fast aim, stable control, visual recognition, real-time tracking, decision-making and fast response, with potential applications in robotics and entertainment.

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1 Introduction

Our project aims to build a sheriff robot that replicates the duel scenes of the Wild West. Inspired by the legendary cowboys and outlaws of American history, we seek to recreate the spirit of justice and honor associated with these figures. The robot's primary purpose is entertainment, offering a thrilling and immersive experience reminiscent of the Old West.

1.1 Background

The original cowboys and outlaws of the Wild West are some of the most fantastic figures in American history. They have inspired countless writers and filmmakers to preserve their stories for future generations. However romantic life on the Wild West might seem, these tough cowboys had to be strong and smart enough to thrive. Always ready with a gun on their hip, they soon became powerful leaders in the American frontier. The legendary deeds of these famous cowboys, some heroic and some villainous, shaped the history of the Old West. . . never to be forgotten[1].

In an old western named High Noon, a sheriff named Will Kane has to fight to save his town. The villain in the movie is to fight with the sheriff at 12:00 noon, the movie got its name[2]. Later westerns cowboys generally choose to fight at noon seems to have become an unwritten rule, so we can often see two cowboys before the duel will stand in the hot sun for half a day, wait until the shadow of two people in the sun are 180 ° before drawing a gun to start. Because at this time the sun does not directly shoot any party's eyes affect the draw aim, to ensure that the duel is fair and just. We want to build a sheriff robot to reproduce this classic scene in memory of Sheriff's justice and the Wild West. The robot is for entertainment.

1.2 Solution Overview

To reproduce the situation of a duel, the robot should satisfy the following behavioral logic: First, the villain has conspicuous special markings on his body, such as carrying a blue gun. The robot recognizes the markings and considers the person as an opponent. Second, when the opponent is not in a drawn position, the robot should remain its arm away from the gun but always facing towards the opponent who may walk around. Third, when the opponent is in a draw position (touch the gun and ready to draw it), the robot is triggered to draw the gun and aim it at the opponent without firing. Forth, if the opponent gives up drawing and move his hand away from the gun, the robot should put its gun back in place. However, if the opponent persists in drawing his gun, the robot will shoot at opponent's chest. Finally, the robot shoots only once. After completing a shot, the robot will give up the old opponent and re-identify.

To simplify this scenario, there is only one opponent, and he remains in a standing position while shooting. The revolver used by western gunfighters has a striking distance of

50m, in the western, they often stand away from each other for more than 10 meters. But the striking distance of the tool gun is often smaller than 5 meters, so we suppose that the opponent stand about 3 meters away from the sheriff. Besides, the best gunfighters shoot around .3 of a second, while for trained ordinary people, the time for draw a pistol from a holster is 1.19 seconds, the time to raise a pistol and fire is 0.59 seconds[3]. We assume that the opponent has an average level, then our goal is to make the robot to complete the series of actions of drawing a gun and aiming to shoot in 1.5 seconds.

1.3 Visual Aid

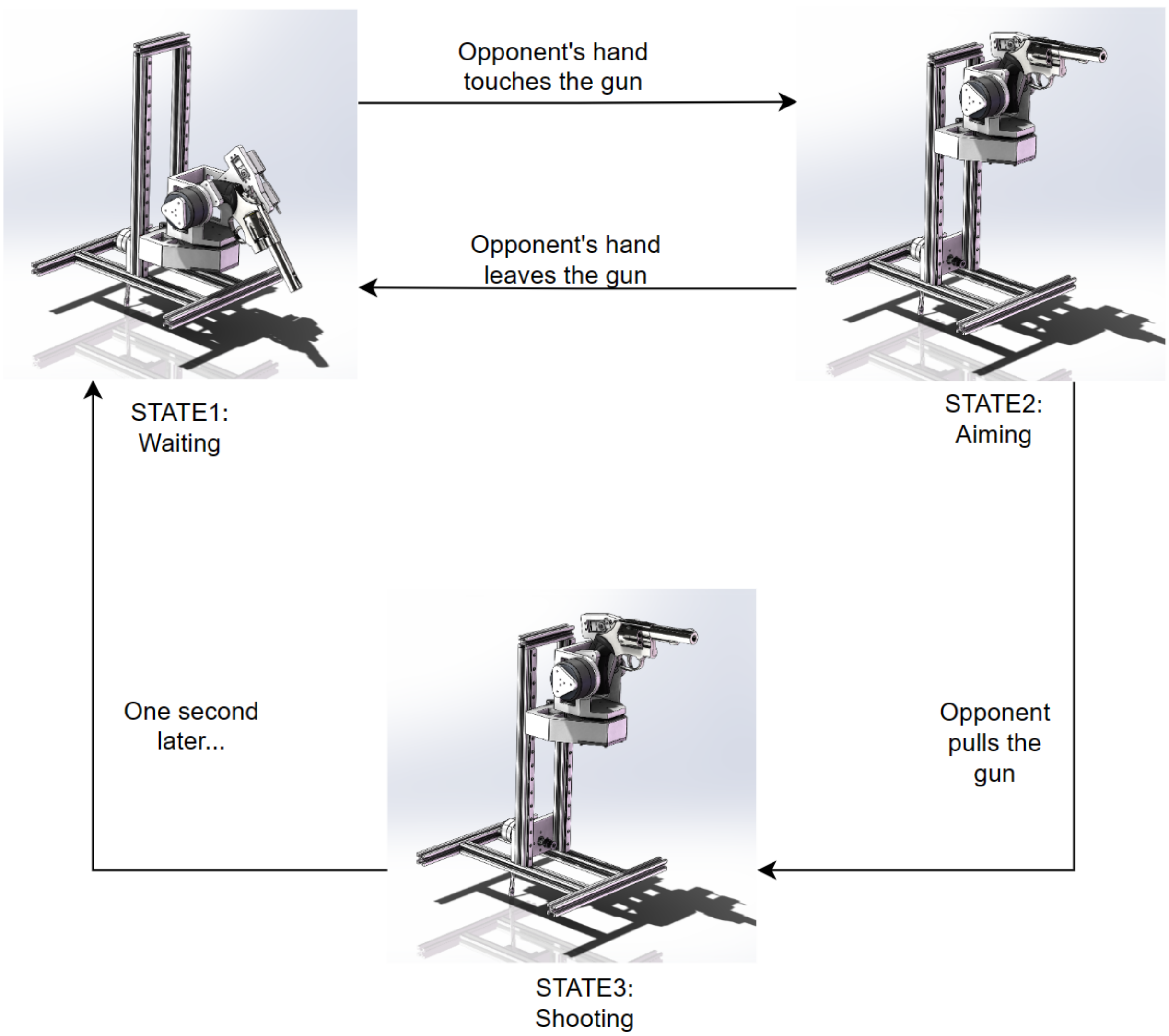

Figure 1: Visual Aid

1.4 Performance Requirements

The key factors influencing the performance of our project include the speed and accuracy of opponent identification, the stability of the robot's mechanical structure and the shooting mechanism's precision and reliability. These factors will contribute to creating an engaging and realistic duel experience for the audience.

The performance requirements for our sheriff robot are as follows:

1. Response Time: The robot's response time to the opponent assuming a draw position should be swift, ensuring the gun is drawn and aimed within 1.5s which is faster than most people in the world.
2. Opponent Identification: The robot should successfully identify the opponent based on conspicuous special markings, with a high degree of accuracy.
3. Tracking and Movement: The robot should be able to track the opponent's movements and maintain a prepared position, always facing the opponent.
4. Shooting Accuracy: The robot should accurately aim at the opponent's chest when they persist in drawing their gun, ensuring a fair and just duel experience.

1.5 Subsystem Overview

We divide our system into three parts: Mechanical subsystem, Electrical and Control subsystem, Vision subsystem. Vision subsystem detects and analyses the behavior of the opponent, and send the command signals to the Electrical and Control subsystem. It also detects the position of opponent and send the coordinates to the Electrical and Control subsystem for aiming. Electrical and Control subsystem deals with the command signals and coordinates sent from Vision subsystem, and control the motors and servos in the Mechanical subsystem to work as we want. It transfers the electrical signal into mechanical torque. Mechanical subsystem uses the motors and other moving mechanism to achieve the rising and rotation of gimble. It also use two larger-torque servo to complement the pulling of nerf gun's hammer and trigger.

2 Design

2.1 Block Diagram

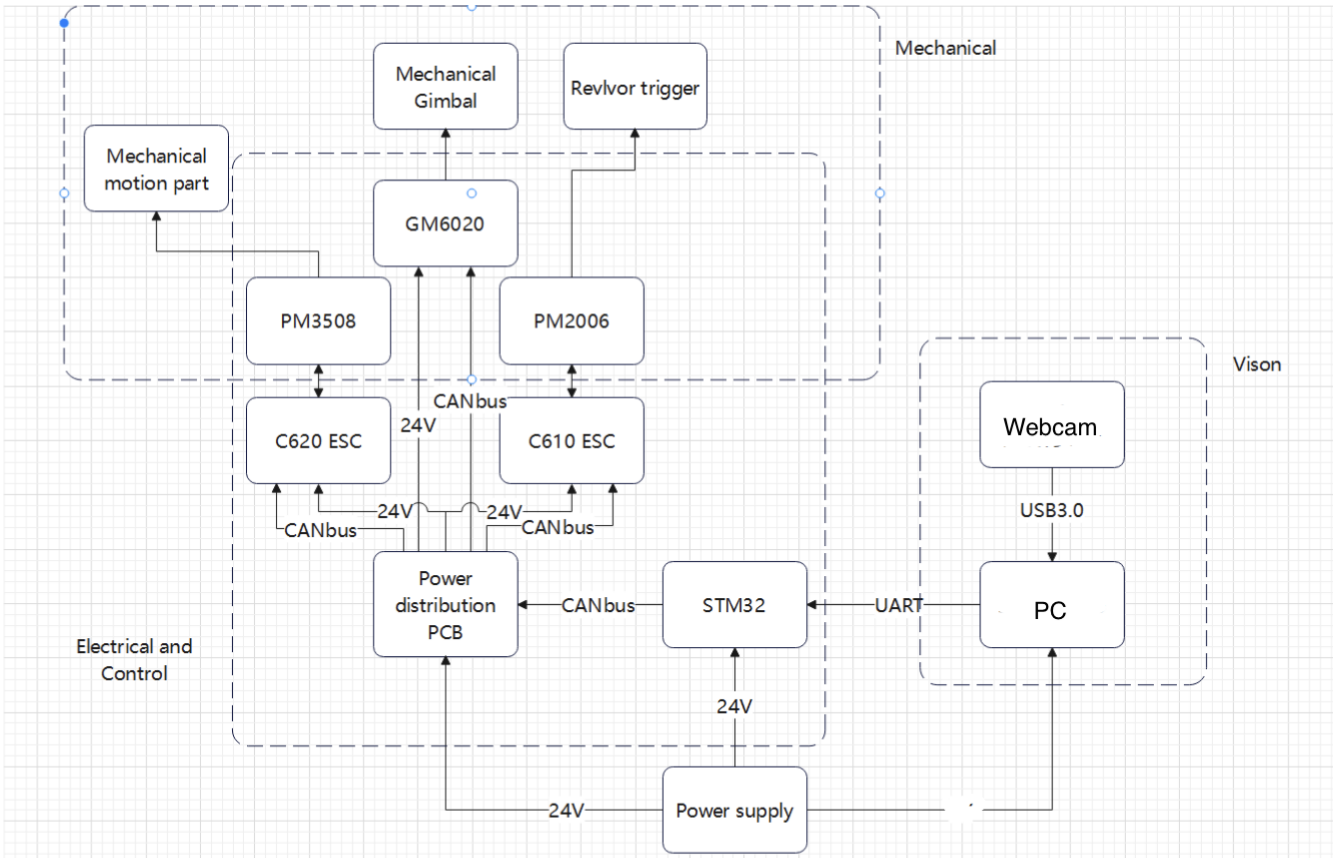

Figure 2: Block Diagram Overview

Figure 2 is our design block diagram overview. Our design have 4 subsystems including vision, electrical control mechanical design and power supply. The electrical control need to deal with the incoming message containing position information and control the motors through ESC to move accurately to the position. For the mechanical design, we need to come up a design that can handle high speed motion and can do the special movement such as pull out a toy revolver. And the following is our detail description about our design.

2.2 Mechanical subsystem

Mechanical part of the project mainly consists of three subsystems: Aiming Gimble, Strike Mechanism and Movement Mechanism. Figure 3 is a generate view of the Mechanical Subsystem.

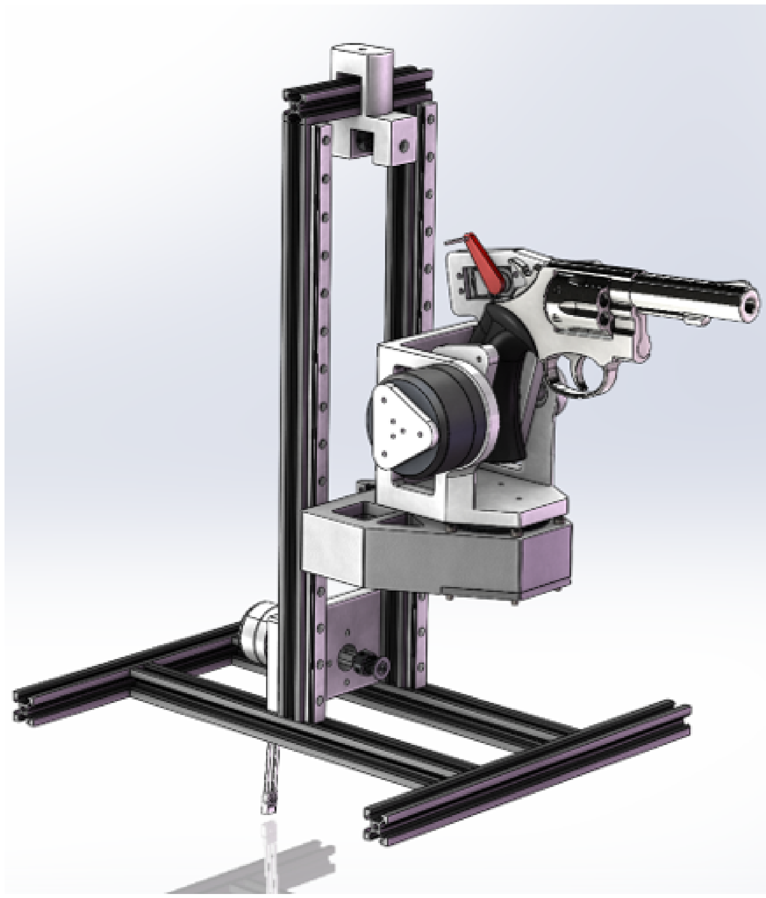

Figure 3: Generate View

2.2.1 Aiming Gimble

Aiming Gimble is the most important subsystem of the mechanical part . This subsystem is composed of two GM6020 Motors, Gimble Base and Rotation Mechanism above the base. This gimble offer a 2-degree-of-freedom to aim the revolver to the target, which can rotate around pitch and yaw axis. Figure 4 is the CAD model of the final generation.

The Aiming Gimble subsystem has undergone several iterations. As shown in figure 5, initially we designed to use carbon fiber as the main structural component, which is advanced on mechanical properties and small density. But we do not have the ability to process on carbon fiber and it would exceed the budget if we customization from factory. For the second edition we use FDM 3D printer to process abs components. The problem this time is that the gimble is not stable enough, cause the revolver shake terribly and the

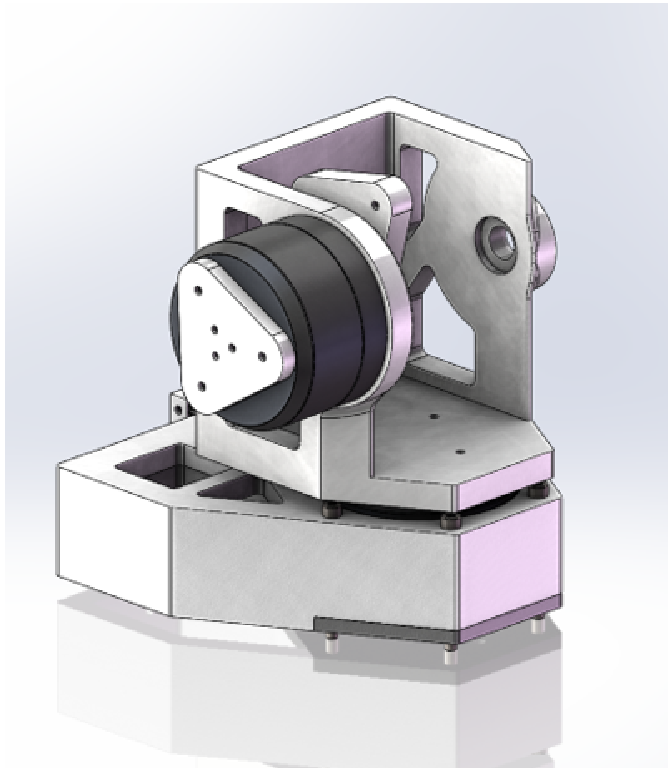

Figure 4: Gimble

vibration makes it very difficult for PID coding of the motor. we solved these problems in the final version of the design.

2.2.2 FEA, DFA and DFM

In the final design version, we performed a more rigorous FEA running by SolidWorks Simulation. The entire gimble is about 1.9 Kg and we set the load 5 times more than that. In the following diagram, the part with green arrows is the clamps, each group of red arrows represents 50 Newton of pressure, and 100 newton in total. In the simulation, almost every part of the turntable received von mises less than 1 million Pa and the displacement of the rotating axis is less than 0.1 mm. At the same time, through analysis I cut out several weight reduction holes in the turntable, these weight reduction holes can just reach through the screwdriver to tighten the three screws marked in green, while solving the assembly difficulties we encountered before.

Figure 5: Iteration of the Aiming Gimble

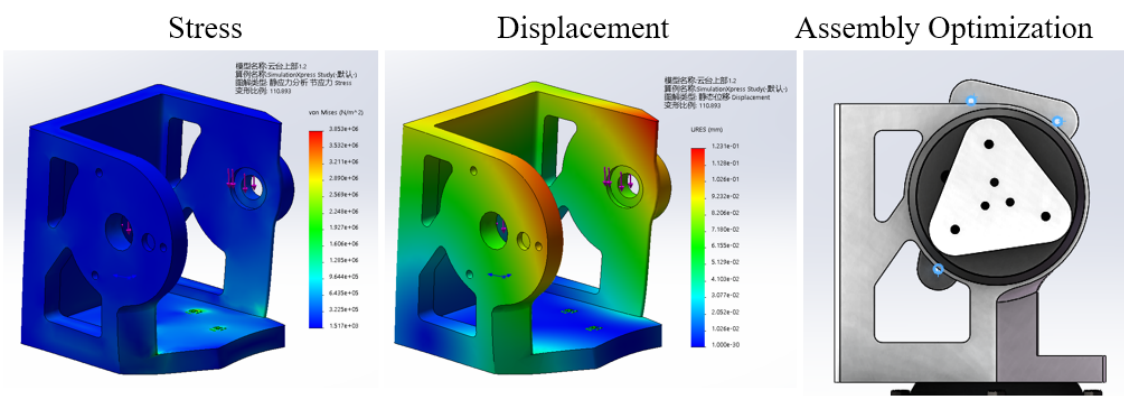

Figure 6: FEA of Aiming Gimble

Figure 7 is the FEA diagrams of the Gimble Base. Also almost every part of the base received von mises less than 1 million Pa and the displacement where the motor and rotating mechanism set is less than 1mm. The weight reduction holes here also take both FEA and assembly requirements into account, allowing the marked screws to be tightened through the weight reduction holes. This is our Design for Assembly (DFA). Additionally, on consider of our 3D printing process, we try to avoid overhanging surfaces in our design, that is our design of manufacture (DFM).

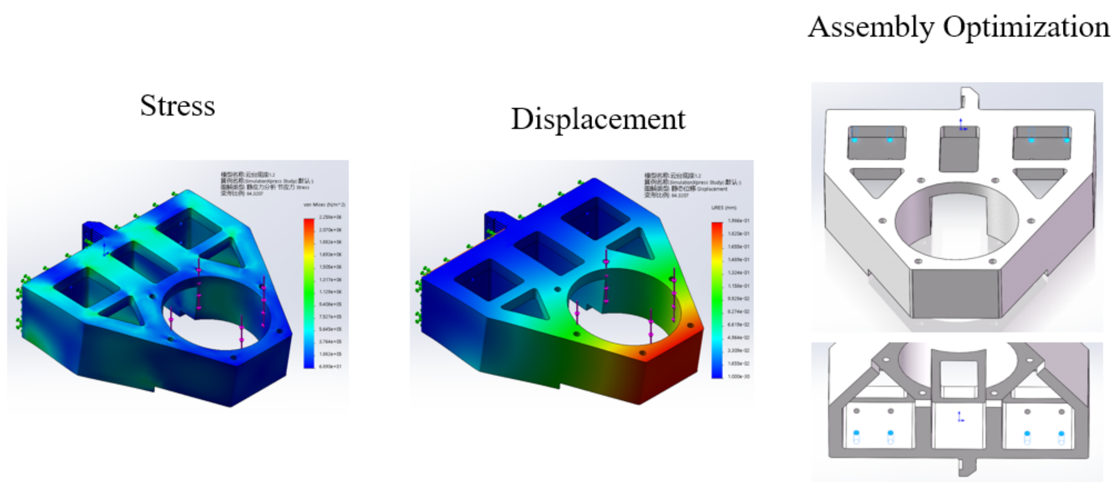

Figure 7: FEA of Gimble Base

Another problem we encountered was that the distance between the mounting holes on the bottom of the motor was too close to create a stable hold on the deformable ABS material. Therefore, we used fiberglass to make a plate for the motor to fixed on more stably, and then fixed this whole thing with 4mm*40mm bolts with a larger spacing on the ABS Gimble Base, and the motor was also clamped by the Gimble Base to make its installation further stable.

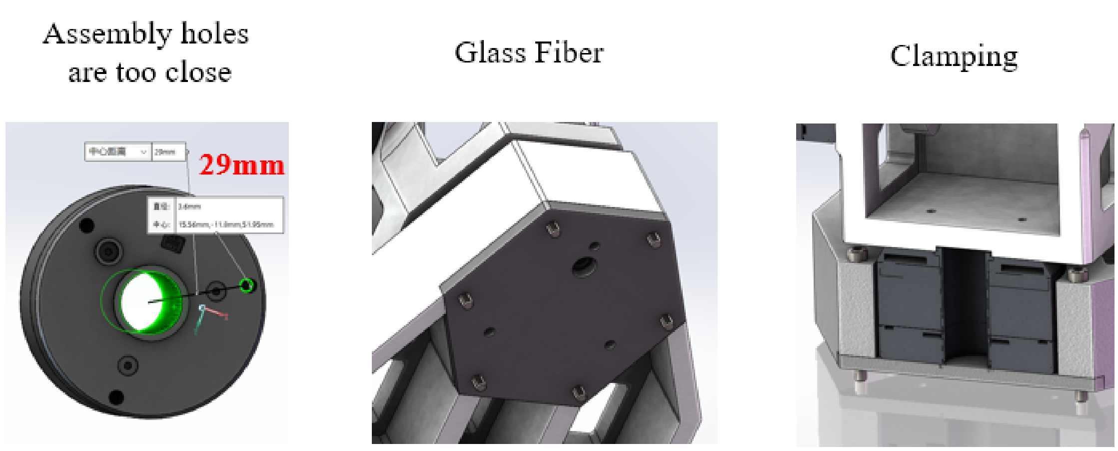

Figure 8: Motor Base

2.2.3 Tolerance

We have also encountered problems with tolerances in past designs. In the second version we used a triangular hole and a screw as the connecting structure of the pivot, but in the test, we found that due to the error of 3D printing and the limitation of ABS material, there was always a gap between the inner triangular column and the outer wall. So in the final design we use 3 screws as the fixing structure, which works well.

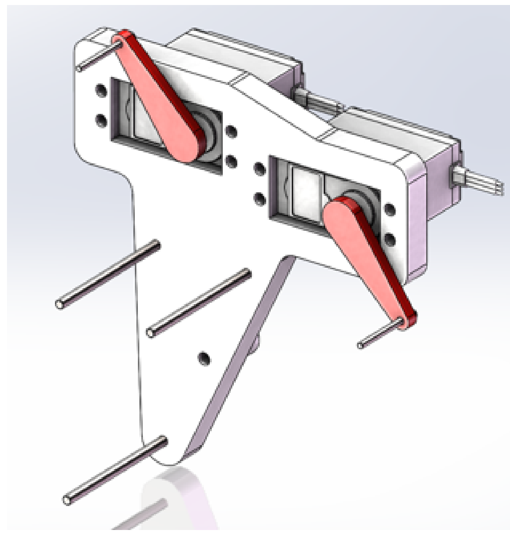

Figure 10: Strike Mechanism

Figure 9: Tolerance

2.2.4 Strike Mechanism

Figure 9 shows the striking mechanism. Since we use a single-action revolver, the robot need to move the hammer to a certain position before pulling the trigger to fire each time, we use two servos to do these two action. The torque required to pull the hammer and trigger is relatively large, so we use two 20 kg servos to do that.

2.2.5 Movement Mechanism

We use 2020 Aluminum extrusion as the structural material, it is a standard part with good mechanical properties, low cost and easy to assemble. To ensure the smooth and precise linear movement we use MGN12 linear guide and GT2 synchronous belt and M3508 motor. we have used all these parts in previous projects and DIY 3D printer, so we are sure that they will function perfectly. Actually, they works well.

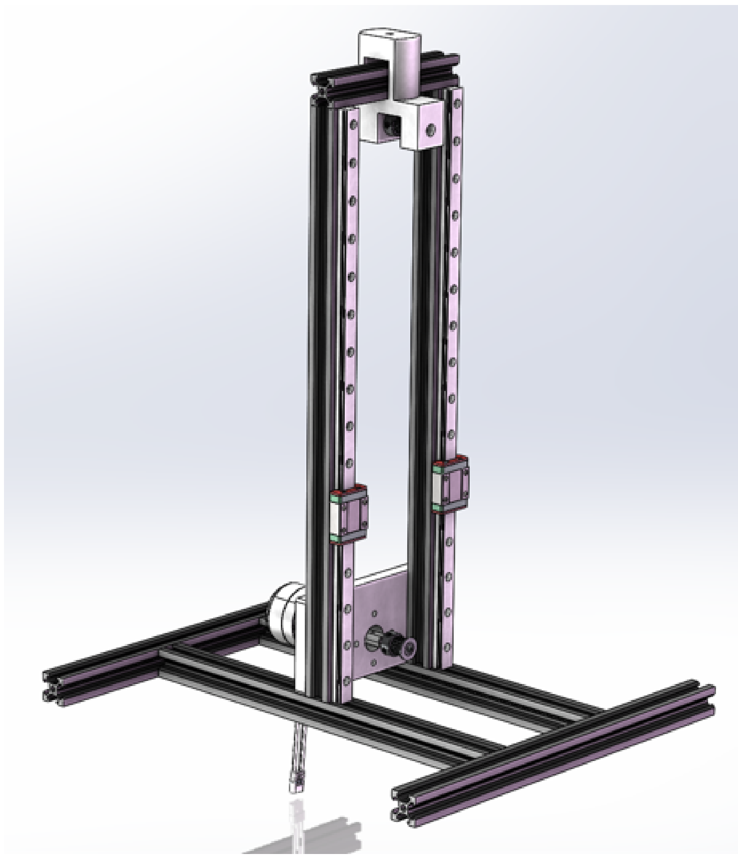

Figure 11: Movement Mechanism

2.3 Electrical and Control subsystem

The electrical and control subsystem is divided into the following systems.

2.3.1 Hardware

STM32 Development board: The STM32 Development Board Type A is a highly flexible controller board designed to be used in a wide range of robotics projects. It uses an STM32F427IIH6 as its main controller chip and features multiple extension and communication interfaces.It has CANbus, SWD, UART, PWM for user to use. It is powered at 4S to 6S LiPo.

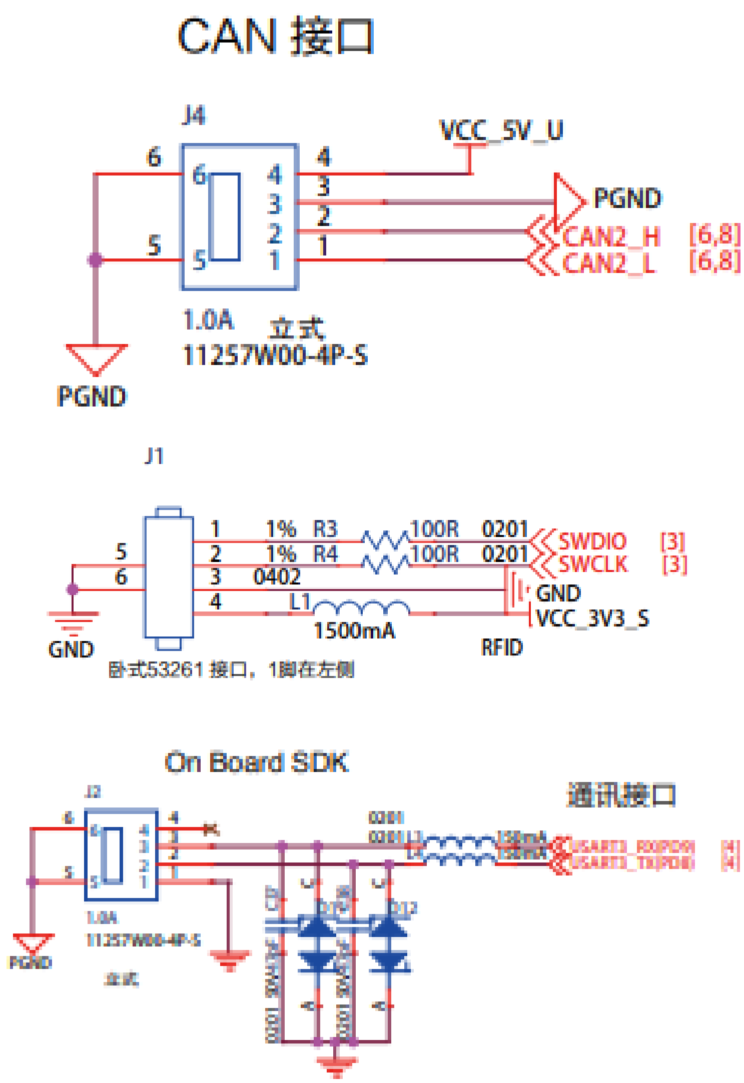

Figure 12: Hardware for the STM32 board

Control system: The control system for the ChibiOS which contian the hardware abstraction layer for the STM32 development board. The board use UART to communicate with Jetson nano to receive the message from vision subsystem. The board use CANbus to communicate and control the motor through ESCs. When start up, the system will open three threads. The first thread is the motor control thread, it will use PID algorithm to control the motor precisely. The second thread is the information receiving thread, it follow the rule of last-in-first-out rule to deal with the position information because of the time efficiency. The last thread is the trigger thread, when the robot arm is in position this thread would be unlocked and permitted to fire if the fire message is delivered by vision part. The board use SWD connector to program the system and also send feedback to the user.

PM3508: M3508 P19 Brushless DC Gear Motor is a high-performance servo motor, specially designed for small and medium-sized mobile platforms and robots. Compared with traditional square wave drive, the M3508 gear motor features sinusoidal drive used with C620 Brushless DC Motor Speed Controller, which boosts higher efficiency, flexibility, and stability. The gear motor's reduction ratio is approximately 19:1. The max power for the PM3508 is 150W.

PM2006: Using a 32-bit motor driver chip and field-oriented control (FOC), the C610 Brushless DC Motor Speed Controller enables precise control over motor torque. It is compatible can configure and update the speed controller firmware using Assistant.with the M2006 P36 Brushless DC Gear Motor to create a complete propulsion system.

GM6020: The GM6020 Brushless DC Motor is a high-performance motor with a built-in driver designed for use in fields such as educational research, automation, and robotic competition.The motor boasts a high pole number design, fractional slot concentrated windings, and rare earth magnets, making it an optimal solution for situations that require low rotational speed, direct driving and large torque.

The Field Oriented Control (FOC) algorithm of the built-in driver and the high-precision angle sensor allows for precision control of the motor's torque and position. If an error is detected, the motor issues warnings and automatically responds to protect itself. Multiple communication methods are supported that allow the user to control the motor and update firmware.

2.3.2 Control system

The control system's structure is showed as follow.

```
├──application
│  ├──High_noon_sheriff_robot
│  └──param_adjusts
│     └──pa_hn
├──board_pin
│  └──STM32F4
├──common
├──interface
│  ├──can
│  ├──can_motor
│  └──shell
├──logic
└──scheduler
```

Figure 13: Control system file structure

Application: the assemble module folder.

- High noon sheriff robot: the assemble module for our robot control system.
- param adjust: the module primary functionality test folder.

board pin: the board configuration file folder.

common: common constant storage folder.

interface: interaction function used for control system and hardware.

Logic: logic is the control system behavior logic. When receive the vision message, position, pull hammer instruction and pull trigger instruction, it will set the co-responding flag and move the gimbal into target position. The servos work in a finite state machine, when the co-responding condition is triggered, it will change the state.

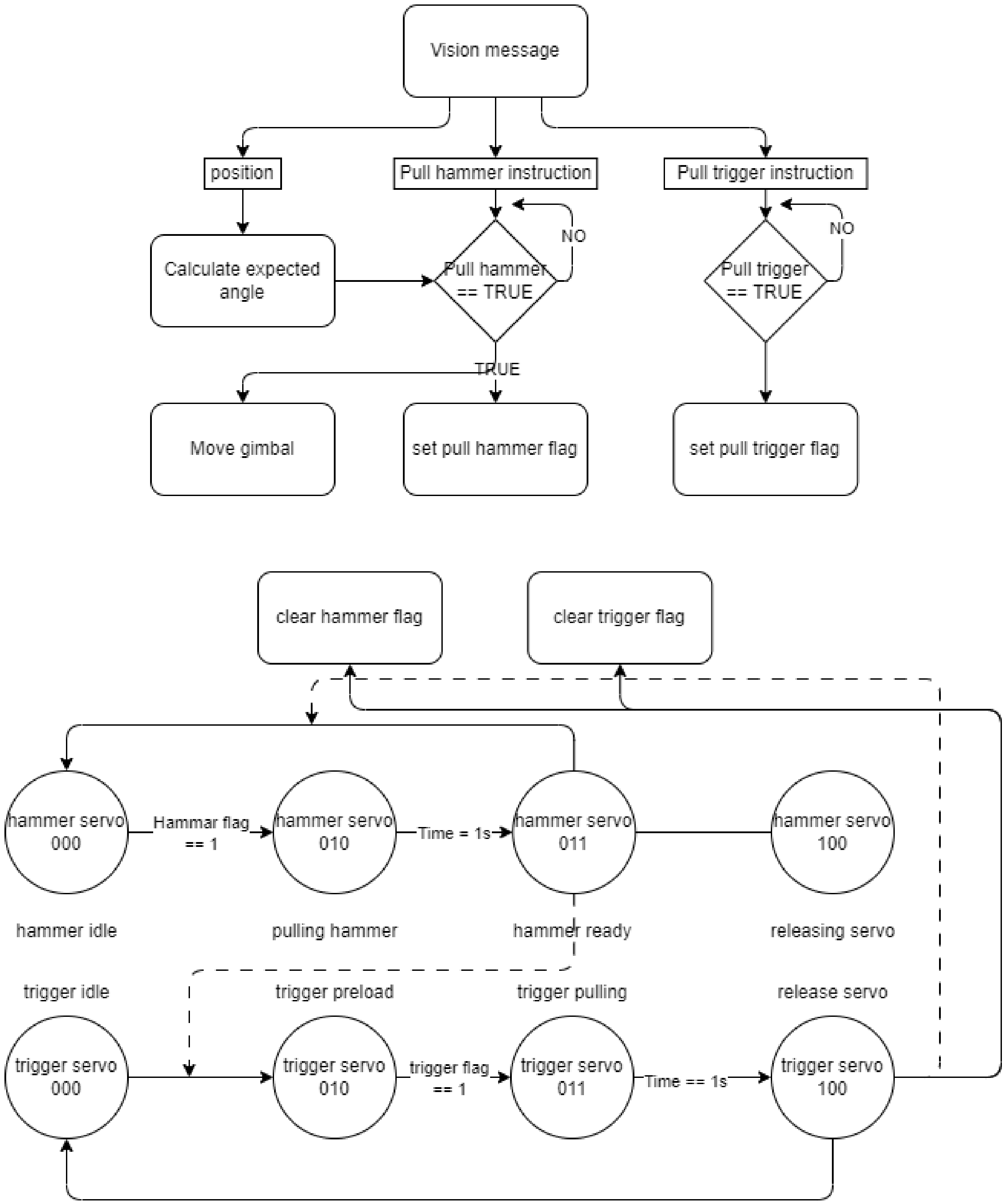

Figure 14: Control logic

- CAN: Basic can operation functions including sending and receiving functions based on hal.h
- CAN motor: Basic motor operation functions including set angle, velocity and current based on hal.h. PID calculation for angle to velocity loop and velocity to current loop.

- Shell: User interaction functions from Chibios and accept customize commands. logic: control behavior logic folder.

scheduler: it is a method for single process development board to achieve high speed parallel processing. The process will sleep after running for the given time. The sleep time is based on the process's needed respond time. The more it is important, the higher frequency it will have. Different process will have different priority to avoid conflict.

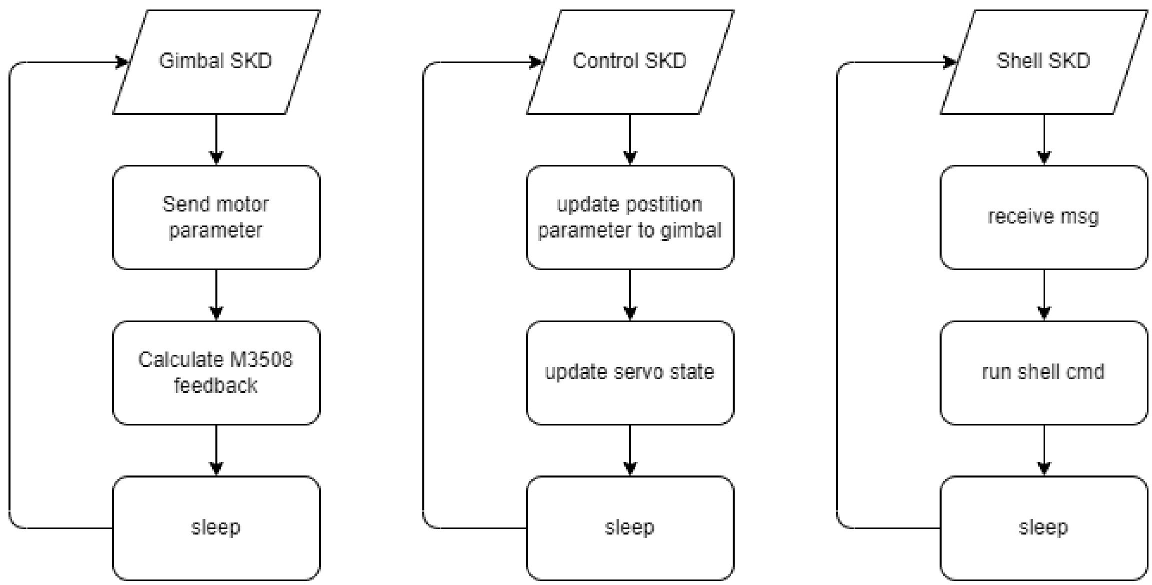

Figure 15: schedule example

2.4 Vision subsystem

The vision subsystem of our robotic system consists of two primary components, namely a webcam and a PC, which runs the object detection algorithm and human behavior detection algorithm. The camera is mounted in a fixed position and continuously captures the front view of the robot. The object detection algorithm deployed on the PC is designed to identify guns, human hands, and human bodies in the captured images. The vision subsystem generates 2D coordinates for each detected object, which are then transmitted to the central control unit. Based on these coordinates, the vision subsystem utilizes a set of pre-defined logical rules to predict human behavior and send warning signals to the central control system when necessary.

The vision subsystem get a bounding box by using object detect algorithm. Upon obtaining the bounding box, determining the real-world location becomes a feasible task. The object detection algorithm is capable of providing the center location for each bounding box present in the image. Assuming that the distances for both the human and the robot are already known, and that the image resolution, width, and height are also available, the camera being unmovable on the robot enables us to compute the real-world location via a similar triangle. Subsequently, the location information is transmitted to the central control unit.

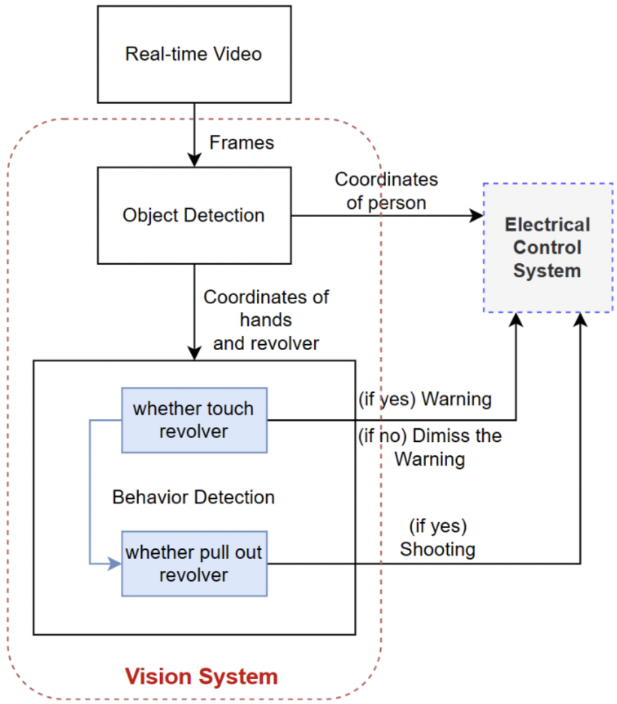

Figure 16: vision logic diagram

2.4.1 Object Detection Algorithm

Object detection is a critical task in the Vision subsystem that involves detecting and localizing objects in real-time stream. Yolov5 is a state-of-the-art object detection algorithm that has gained popularity due to its high accuracy, fast performance, and ease of use. The reasons why we choose Yolov5 as our object detection algorithm are as follows. Firstly, Yolov5 achieves high accuracy in detecting objects in various complex background. It has been benchmarked as one of the most accurate object detection algorithms available, making it suitable for applications where accurate object detection is critical. Secondly, Yolov5 is designed to be fast and efficient, making it ideal for real-time object detection. It can process images in real-time on a single GPU, enabling it to detect objects quickly and accurately. This makes it suitable for applications that require real-time object detection. Finally, Yolov5 is easy to use, with a user-friendly interface and open-source code. It is also customizable, allowing it to be tailored to specific detection requirements. It can be trained on custom datasets to detect specific objects and can be fine-tuned to improve its accuracy.

2.4.2 Datasets

In our project, we used the YOLOv5 object detection framework to develop a system that can accurately detect human body, hands, and guns in real-time. To train our model, we relied on a combination of open-source datasets for human body and hands, as well as our own dataset specifically created for guns.

At first, we only recorded the datasets in the laboratory with similar movements. After training, we find the model isn't robust enough to handle multiple environment and robot-human distance. Therefore, we record the datasets in different environments like laboratory, outside study room and classroom. We also add some background images without the objects in the datasets. These strategy enhance our model's robustness and generalization.

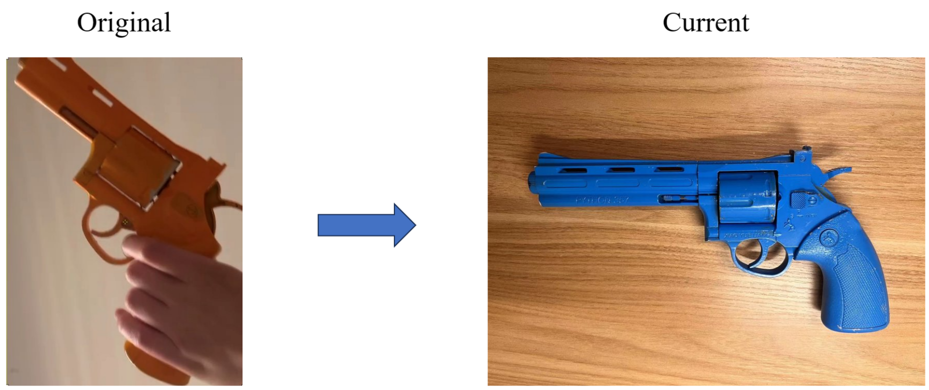

Figure 17: Color Change of the Gun

Besides, to reduce the difficulty of detection, we sprayed the nerf gun in the hands of the opponent with a paint that distinguished it from the background color. At first, we sprayed the gun orange. In the process of detection, we found that the hand was easily identified as a gun due to the close color of the hand to the gun and the lack of robustness of the dataset. So we sprayed the gun blue and then the detection accuracy became better. When doing certain action, the confidence of gun detection was lower than the effective value or even fail to be detected, so we added the image of this action to the dataset, then result is that the accuracy increase effectively.

The training results of our final custom dataset for gun detection are as follows. After 40-epoch training, mAP50 has reached 0.9 and mAP0.5:0.95 has reached 0.43.

epoch	train/box_loss	train/obj_loss	train/cls_loss	metrics/precision	metrics/recall	metrics/mAP_0.5	metrics/mAP_0.5:0.95	val/box_loss	val/obj_loss	val/cls_loss	x/lr0	x/lr1	x/lr2
0	0.12111	0.018493	0	8.8183E-05	0.027933	5.1508E-05	1.0615E-05	0.11196	0.009085	0	0.070667	0.0032593	0.0032593
1	0.10306	0.011405	0	0.0012875	0.40782	0.0011094	0.00027338	0.098861	0.0063601	0	0.040504	0.0064294	0.0064294
2	0.084947	0.010706	0	0.0022046	0.69832	0.014989	0.004085	0.078876	0.0069321	0	0.010175	0.0094346	0.0094346
3	0.071294	0.0098805	0	0.0028748	0.91061	0.10534	0.028609	0.069402	0.0066291	0	0.0092575	0.0092575	0.0092575
4	0.063232	0.0096597	0	0.28708	0.15084	0.12829	0.025523	0.06767	0.006068	0	0.0092575	0.0092575	0.0092575
5	0.062343	0.0085169	0	0.34586	0.49032	0.34429	0.08033	0.061071	0.0057309	0	0.00901	0.00901	0.00901
6	0.057369	0.0074277	0	0.46821	0.43017	0.40727	0.11547	0.061241	0.0056576	0	0.0087625	0.0087625	0.0087625
7	0.056386	0.0076031	0	0.64968	0.67598	0.67447	0.25898	0.050128	0.0054932	0	0.008515	0.008515	0.008515
8	0.054999	0.0070123	0	0.69118	0.69274	0.66925	0.20656	0.047949	0.0053525	0	0.0082675	0.0082675	0.0082675
9	0.052122	0.006846	0	0.78799	0.7095	0.77055	0.27633	0.04523	0.0052265	0	0.00802	0.00802	0.00802
10	0.052436	0.0063301	0	0.7206	0.7095	0.70908	0.24113	0.048245	0.005071	0	0.0077725	0.0077725	0.0077725
11	0.050712	0.006299	0	0.81752	0.67577	0.78248	0.32141	0.043991	0.0046872	0	0.007525	0.007525	0.007525
12	0.050069	0.0062454	0	0.61562	0.58659	0.57381	0.17413	0.050852	0.0046373	0	0.0072775	0.0072775	0.0072775
13	0.048784	0.0058458	0	0.859	0.68715	0.80954	0.32734	0.045248	0.004482	0	0.00703	0.00703	0.00703
14	0.046126	0.0059925	0	0.9103	0.7933	0.86798	0.38104	0.040782	0.0044426	0	0.0067825	0.0067825	0.0067825
15	0.047292	0.0057154	0	0.8108	0.69429	0.77822	0.29173	0.0443	0.0042295	0	0.006535	0.006535	0.006535
16	0.044739	0.0055674	0	0.81854	0.75601	0.79295	0.32303	0.041432	0.0043956	0	0.0062875	0.0062875	0.0062875
17	0.043975	0.0053377	0	0.88072	0.78372	0.85429	0.33866	0.043621	0.0039994	0	0.00604	0.00604	0.00604
18	0.045227	0.005254	0	0.90084	0.7933	0.86885	0.36448	0.039448	0.0038588	0	0.0057925	0.0057925	0.0057925
19	0.045018	0.0051295	0	0.86477	0.73743	0.83424	0.37142	0.040209	0.003759	0	0.005545	0.005545	0.005545
20	0.044882	0.0050236	0	0.88524	0.75419	0.85178	0.36015	0.040131	0.0037867	0	0.0052975	0.0052975	0.0052975
21	0.042203	0.0049202	0	0.90055	0.80946	0.8719	0.36148	0.03904	0.0036354	0	0.00505	0.00505	0.00505
22	0.041007	0.0049158	0	0.90405	0.81006	0.89277	0.38401	0.037949	0.0035659	0	0.0048025	0.0048025	0.0048025
23	0.041685	0.0048024	0	0.88924	0.85217	0.88545	0.3583	0.04053	0.0034711	0	0.004555	0.004555	0.004555
24	0.039533	0.0047839	0	0.91835	0.81684	0.89242	0.40336	0.039428	0.0034236	0	0.0043075	0.0043075	0.0043075
25	0.041839	0.0044772	0	0.86915	0.8324	0.89082	0.4023	0.036955	0.0034721	0	0.00406	0.00406	0.00406
26	0.040324	0.0045276	0	0.8676	0.79888	0.85928	0.33376	0.039709	0.0033954	0	0.0038125	0.0038125	0.0038125
27	0.039861	0.0045866	0	0.85876	0.78771	0.85445	0.40536	0.038012	0.0033336	0	0.003565	0.003565	0.003565
28	0.037918	0.0044549	0	0.89965	0.85149	0.89904	0.43918	0.036088	0.0032518	0	0.0033175	0.0033175	0.0033175
29	0.037187	0.0043186	0	0.89331	0.84916	0.89719	0.39902	0.035562	0.0032752	0	0.00307	0.00307	0.00307
30	0.036852	0.0042454	0	0.91055	0.84916	0.90689	0.42892	0.036508	0.003168	0	0.0028225	0.0028225	0.0028225
31	0.038073	0.0042124	0	0.94365	0.85475	0.90666	0.39548	0.037676	0.0031664	0	0.002575	0.002575	0.002575
32	0.038074	0.0040864	0	0.92428	0.81564	0.88499	0.3966	0.037504	0.0031325	0	0.0023275	0.0023275	0.0023275
33	0.03624	0.0040278	0	0.92976	0.8874	0.9197	0.42658	0.035225	0.0030567	0	0.00208	0.00208	0.00208
34	0.035441	0.0040912	0	0.9177	0.87211	0.9045	0.44464	0.033978	0.0030826	0	0.0018325	0.0018325	0.0018325
35	0.034535	0.0041229	0	0.91632	0.86034	0.91039	0.40839	0.035837	0.0030419	0	0.001585	0.001585	0.001585
36	0.034155	0.0042341	0	0.93966	0.87003	0.9226	0.42982	0.035008	0.0030554	0	0.0013375	0.0013375	0.0013375
37	0.034212	0.0038938	0	0.94657	0.89079	0.92826	0.44516	0.034099	0.0030392	0	0.00109	0.00109	0.00109
38	0.034036	0.0041226	0	0.92484	0.87709	0.91527	0.43255	0.033455	0.0030328	0	0.0008425	0.0008425	0.0008425
39	0.031652	0.0041091	0	0.90026	0.8572	0.89393	0.43665	0.033628	0.0030024	0	0.000595	0.000595	0.000595

Figure 18: Training Results

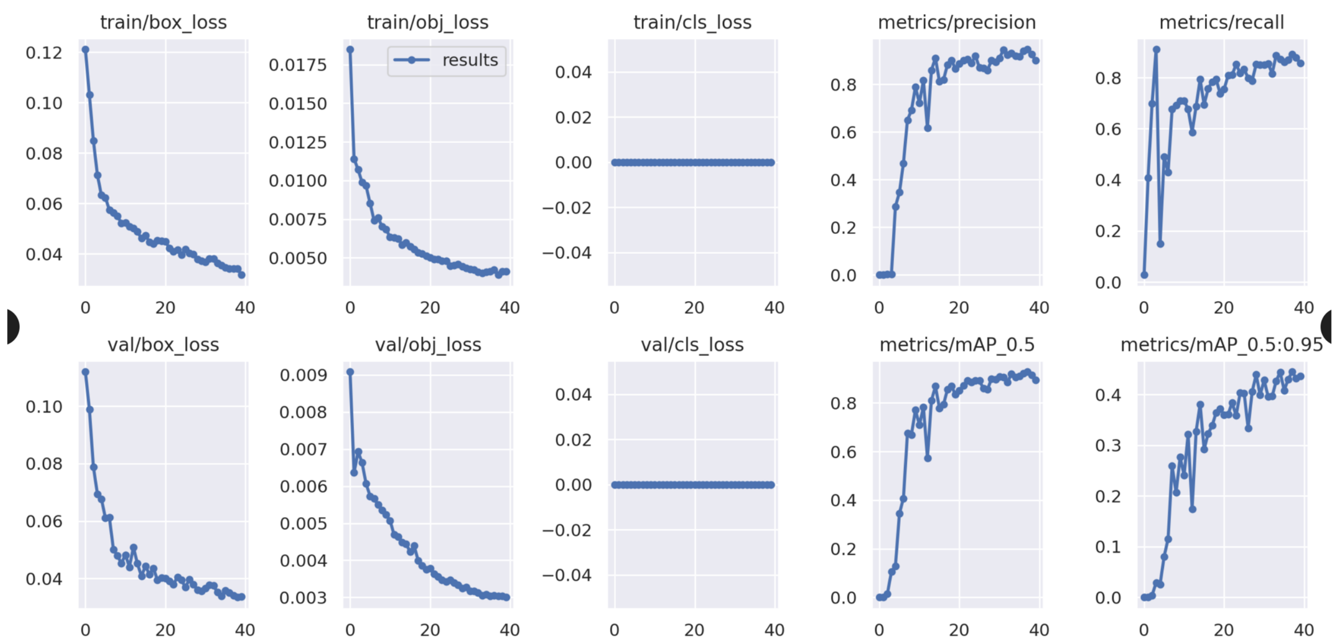

Figure 19: Training Results

2.4.3 Behaviour Analysis

Our task is to detect two types of behavior, touching the gun and drawing the gun. Detecting whether the opponent is touching the gun is easy. After we get the coordinates of the gun and the hand, we just need to determine if the distance between the gun and either hand is less than a threshold. If it is, then the opponent is considered to have touched the gun, we will send an aiming signal to the Electronic Control system.

To detect whether the opponent is drawing the gun, we need to compare the detection changes between several frames because Yolov5 detect separate frames with no connection in between. If the robot is in aiming state, at the same time, in two consecutive frames the coordinates of the gun move up and the distance exceeds the threshold, then the opponent will be considered to be drawing a gun. The shooting signal will then be sent to the Electrical Control system.

Both of the thresholds used to detect whether the gun is touched and pulled varies depending on the camera parameters and the distance from the robot to the opponent. Therefore, after determining the camera and the distance, we used a large number of practical tests to obtain a suitable thresholds. What's more, sometimes the detector detects the background as our target object with low confidence. We filtered these fake objects by setting a confidence threshold. We also displayed the coordinates of the target objects to verify the behaviour analysis logic and check the coordinates of human body that sent to the Electrical and Control system.

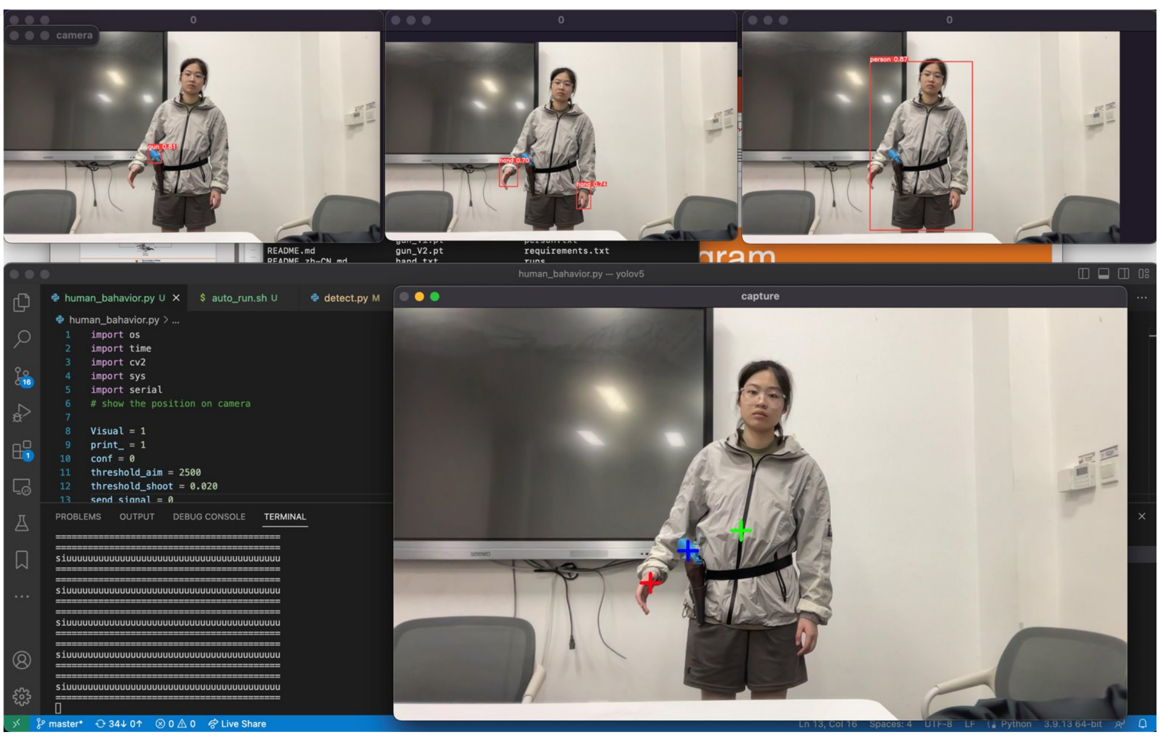

Figure 20: Visualization of the Detection

3 Verification

3.1 Mechanical subsystem

Requirement	Verification	state
1. The Aiming Gimble have the ability to aim at a given location within one second. Stable support that does not deform under high-speed rotation	1. FEA analysis in CAD to verify theoretically the structural stability. 2. After installation, apply 5 times the theoretical load on the Gimble and observe the deformation, if it is almost negligible, it proves that the safety factor is high and the structural strength meets the demand. 3. Power on test, considering the delay of the processor and serial port, if the gimble can aim at a specified position within 0.5 seconds, it is in line with the requirements.	Achieved
2. The Movement Mechanism can drive the gimble to move from the lowest point to the highest point within 1 second, the distance is about 30cm	Attach the head to the moving mechanism, power on the moving mechanism to measure the movement time from the bottom to the top, less than 1 second then access.	Achieved

3.2 Electrical and Control subsystem

Requirement	Verification	state
1. The time delay for the control system from receiving message to motor respond in position should be less than 1 second	The control system will give a time mark when receive the message from vision subsystem and when the motor was in position (error within 0.5 degree) the control system will give another time mark. When the process is finished, the serial will print the delay by the last time mark delete the first time mark to find the time delay.	Achieved
2. The position error for the gimbal motor should be less than 0.5 degree.	The GM6020 have a build in encoder for position. When the process is finished, the serial will print the position to compare with the expected position.	Achieved

3.2.1 Modular testing

The test for the electrical and control subsystem can be divided into 3 modules, the first module is CANbus system, the second module is the PID adjustment system and the last is the UART communication system.

For the CANbus module, the main function is to registrate the device on CANbus, the ability to send and receive data from CANbus to control the motor. The test purpose for the CANbus module is to check whether the CANbus can transmitte the message package and receive the package correctly. The validation can use the motor's build in sensor to see whether the infomation is correct or not.

For the PID module, I have developed a PID adjustment tool based on open source Swift project that can communicate with STM32 through Serial and receive real time message from the STM32 and change the PID value in real time. The validation of the PID parameter can use the feedback plot vs desired polt. When they are close, it means that we success.

For the UART communication with the Vision subsystem, the test purpose is to check whether the message is transmitted correctly through UART, it can be validate by check the infomation between Jetson nano and STM32.

3.2.2 Result

For the PID tool test:

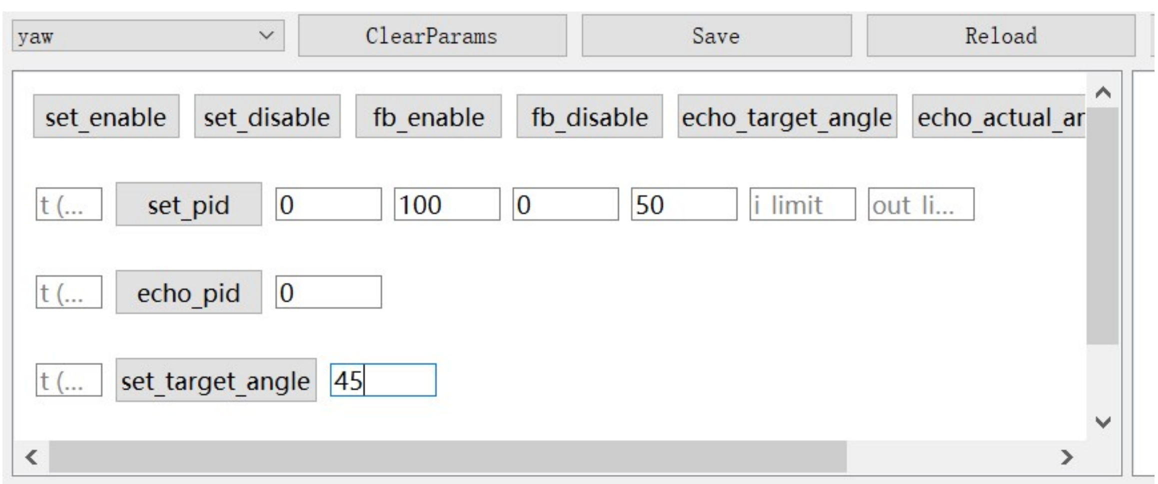

Figure 21: PID tool receive image

PID tool can now modify the parameter when the robot is running. It will help me to adjust the parameter more easily.

For the CANbus control test

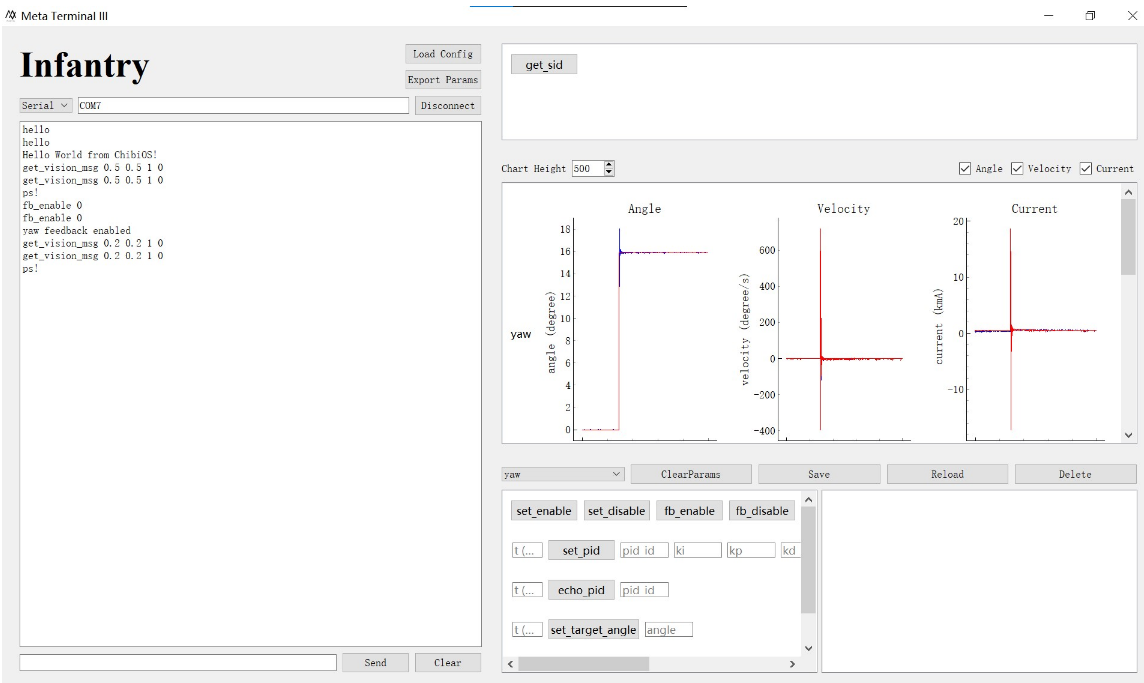

Figure 22: PID tool receive image

The serial plot shows that the motor can move as the package message sent to the motor through CANbus and receive the feedback. The plot is not smooth since the PID parameter is not implement.

For delay test and position error test

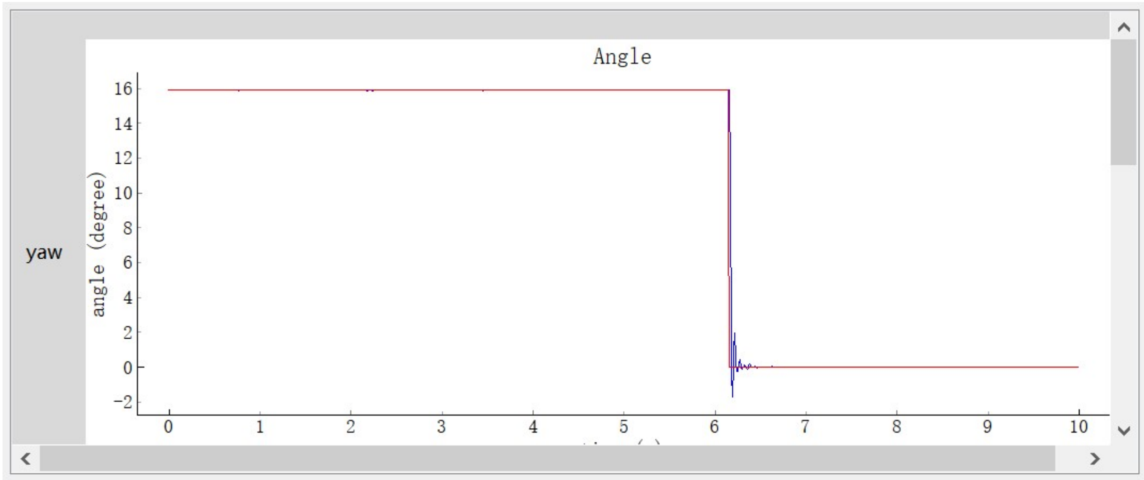

Figure 23: Yaw feedback

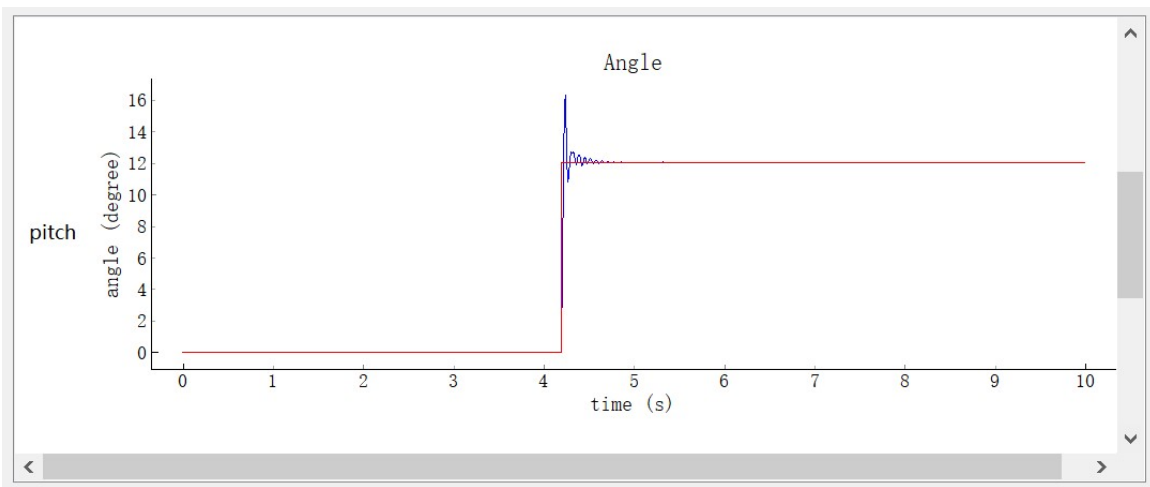

Figure 24: Pitch feedback

As the figure show, the yaw delay is about 330ms and the pitch delay is about 500ms. So that it is within the design requirement. Sine the blue line (actual posisiton) and red line (expect position) are almost in one line. The error can be ignored.

3.3 Contingency plans for failed tests

Currently, my test plan have not failed yet. But for the possible failed test in the future, The time between tests can be used as redundancy to deal with possible failed test. If the test failed again, I need to communicate with my teammate and solve this problem together.

3.4 Vision subsystem

Requirement	Verification	state
1. Accuracy: The vision subsystem should detect all the target objects including gun, hand and human body that appears in the camera's filed of view.	Visualize the bounding boxes of all the objects detected, and see if all the target objects has been framed by bounding box. All the objects should be recognized as the right classes. The confidence of these bounding boxes should be larger than 0.5.	Achieved
2. Real-time capability: The detection should be fast enough to implement real-time detection.	Print the time it takes to detect each frame. The time should be smaller than 100ms (10FPS).	Achieved
3. Behavior Analysis: The vision subsystem should identity touching the gun and pulling the gun actions correctly.	Print the aim signal and shoot signal for each frame. Let the opponent touch the gun, it should print 'aim=1, shoot=0'. Let the opponent pull the gun, it should print 'aim=1, shoot=1'. It should print 'aim=0, shoot=0' in other times.	Achieved

4 Costs

4.1 Cost Analysis

Labor cost: The labor cost is an important part for the senior design and the cost are estimated as below.The estimated salary for person is 100 Yuan/ hour (standard salary for Zhejiang University undergraduates). The normal work time per week is estimated for 20 hours according to our estimation for the senior design. We have 10 weeks to complete our senior design project.

$$4 * \frac{100}{hour} * \frac{20hours}{week} * 10week = 80,000$$

Material cost: the material cost contain all subsystems listed in the section II. The total cost of our senior project are

Part	MFT	Desc	Module	Price(￥)	Qty	Total
LRS-350-24	MEAN WELL	Power supply at 24V 29 A	Power supply	157	1	157
RS-25-5	MEAN WELL	Power supply at 5V 5 A	Power supply	49	1	49
C620	DJI	ESC for PM3508	Electrical and control	399	2	798
C610	DJI	ESC forPM2006	Electrical and control	159	1	159
PM3508	DJI	3Nm 150W	Electrical and control	499	2	998
PM2006	DJI	1Nm 44W	Electrical and control	275	1	275
CM6020	DJI	1.24Nm	Electrical and control	899	1	899
STM32	DJI	32-bit Dual ARM core	Electrical and control	429	1	429
Jetson nano	NVIDIA	4 GB 64-bit LPDDR4 1600MHz	Vision	799	1	799
MV-SUA134GC	Mind Vision	1280x1024 211FPS	Vision	1380	1	1380
M5x40 SHCS	Beart		Mechnical	0.05	50	2.5
M5x30 BHCS	Beart		Mechnical	0.05	50	2.5
M5x16 BHCS	Beart		Mechnical	0.05	50	2.5
M5x10 BHCS	Beart		Mechnical	0.05	50	2.5
M5 Post-install T-nut	Beart		Mechnical	0.05	50	2.5
M5 Hexnut	Beart		Mechnical	0.05	50	2.5
M5 1mm Shim	Beart		Mechnical	0.05	50	2.5
M4x6 BHCS	Beart		Mechnical	0.05	50	2.5
M4 Knurled Nut (DIN 466-B)	Beart		Mechnical	0.05	50	2.5
M3x8 SHCS	Beart		Mechnical	0.05	50	2.5
M3x6 FHCS	Beart		Mechnical	0.05	50	2.5
M3x6 BHCS	Beart		Mechnical	0.05	50	2.5
M3x40 SHCS	Beart		Mechnical	0.05	50	2.5
M3x30 SHCS	Beart		Mechnical	0.05	50	2.5
M3x20 SHCS	Beart		Mechnical	0.05	50	2.5
M3x16 SHCS	Beart		Mechnical	0.05	50	2.5
M3x12 SHCS	Beart		Mechnical	0.05	50	2.5
M3x10 FHCS	Beart		Mechnical	0.05	50	2.5
M3 Washer	Beart		Mechnical	0.05	50	2.5
M3 Threaded Insert (M3x5x4)	Beart		Mechnical	0.05	50	2.5
M3 Post-install T-nut	Beart		Mechnical	0.05	50	2.5
M3 Hexnut	Beart		Mechnical	0.05	50	2.5
M3 Hammer Head T-nuts	Beart		Mechnical	0.05	50	2.5
M2x10 Self-tapping Screw	Beart		Mechnical	0.05	50	2.5
					Total	6003

Figure 25: BOM estimation for Senior design

Actually we will not cost such huge amount of money for design since we can borrow many parts from RoboMaster Lab. But to be precise we need to take those parts into calculation.

4.2 Schedule

The schedule for our design is listed below. We need to finish our senior design within 10 weeks so that we need a detail plan for our progress and correct our steps according to the schedule. We divide us in to three groups, vision, electrical control and mechanical. Yuan Xu and Shuting Shao are responsible for the development of vision part to capture and detect potential threat and send message to the control system. Youcheng Zhang is responsible for the electrical control part to develop the control system for the motor with delay less than 1.5s and can receive message form vision subsystem. Yilue Pan is responsible fro the mechanical part to grab the revolver and have two axis Pitch and Yaw for aiming.

Week	Vision	Electrical and Control	Mechanical
Mar. 27	Train the yolov5 for gun detection	Control system frame	Purchase the materials for the gimble, moving machining the required parts
April 3	Train the yolov5 for gun and human body detection	PID control for the motor	Finish the assembling of gimble and moving mechanism
Milestone 1	Finish the human behaviour prediction	The system can control motor moving to given position accuracy	Sliding Mechanism version, finish CAD structure of human-like robot arm
April 10	Improve the accuracy for our model	Build for UART communication	Purchase the materials of human-like robot arm
April 17	Reduce the latency of our model	Can receive message from Vision and respond to it	Finish assembling of the final version
April 24	Finalize the vision system	Finalize the control system	Optimization improvements
Demo		Final version for the control system	Final version with robot arm

5 Conclusions

5.1 Accomplishment

Our efforts led to the development of a robotic system that can accurately recreate a duel scenario. The system's accomplishments can be encapsulated as follows:

Opponent Identification: The robot uses computer vision to recognize the opponent based on identifying markers, such as a blue gun, to distinguish one opponent from another.

Draw Position Detection: Using real-time object detection, the system can tell when the enemy is getting ready to draw their weapon. The robot retorts by removing its own cannon, pointing it in the direction of the foe, but not actually firing.

Responsive Actions: If the enemy gives up drawing and moves their hand away, the robot retracts its gun and returns to its starting position. The robot, however, will use known logic and fire at the opponent's breast if they insist on drawing.

Time Effectiveness: Taking into account the time limits, our method achieves the required reaction time of 1.5 seconds. This enables the robot to carry out the draw and aim process during the imaginary conflict fast and realistically.

These achievements show that our project successfully implements the behavioral logic needed for the robotic system to faithfully recreate a duel scenario. The robot recognizes the opponent with accuracy, keeps the defensive arm position, reacts to the opponent's movements, and completes the draw and aim sequence in the allotted amount of time.

5.2 Uncertainties

Environmental elements like lighting, occlusions, and background clutter can affect how well object detection systems function. Variations in these variables may affect the object detection process' accuracy and dependability, possibly producing false positives or false negatives.

The look and properties of the things that are being detected, such as the unique markings on the adversary's body or the weapon, can change. The object detection algorithm may encounter difficulties due to variations in object shape, size, or appearance, which could impair the system's capacity to recognize and track the relevant items.

The entire stability and dependability of the system can be impacted by the structural integrity of the robot, including the physical parts and connections. The robot's capacity to carry out the desired operations precisely and repeatedly may be impacted by mechanical problems, such as misalignments or component failures.

5.3 Ethics Consideration

It's crucial to think about any potential risks to people when building a system with physical components. The protection of human safety is emphasized in the IEEE and ACM Code of Ethics, and this holds true for the design of such systems [4]. Designers must incorporate safety features like limiting the robot's range of motion or adding sensors to detect surrounding objects in order to make sure that the toy gun does not damage people and the robot does not aim at delicate parts like the eyes. Additionally, it is essential to put on the proper safety gear when conducting studies utilizing such systems.

User safety must also be taken into consideration when designing the robot's mechanical system. The framework must be strong enough to withstand unforeseen motor movements, and the control system must contain a safety loop that may cut power before any danger arises. These safety precautions adhere to the IEEE and ACM Code of Ethics, which place a strong focus on guarding against harm to users [4].

Privacy issues are another ethical factor to take into account while creating such systems. For instance, a camera may be used to track a person's movement and activity, although this could cause privacy issues. The IEEE Code of Ethics highlights the significance of preserving other people's privacy. Designers can solve this problem by separating the vision subsystem from other subsystems and keeping the video in a safe place that can only be accessed by people with the proper credentials. As a result, users are informed about the use of the camera and the data gathered while the vision subsystem merely transmits coordinates and behavioral hypotheses to the control system.

We must take into account the safety concerns for both mechanical and electrical aspects because our design includes both. In terms of the mechanical component, we need think about the security of the moving parts, ensure that it won't harm people, and have an emergency stop in case of some situation to quickly stop the moving system. The electrical part should also follow the principle of separating the high AC power and low control DC power into two separate systems and make sure they would not interfere with each other to avoid potential safety issues since we are dealing with a 220V AC power supply. In this case, we can make sure of the safety issue with both mechanical parts and electrical parts.

5.4 Future Work

There are a number of areas where we can improve our project's simulation capabilities in the future. These include enlarging and diversifying the dataset for better object detection, optimizing the detection models for better accuracy, modifying the behavioral logic to simulate realistic duel scenarios, implementing real-time feedback mechanisms for adaptive responses, improving human-robot interaction through natural language processing and gesture recognition, ensuring safety measures through obstacle detection and emergency stop mechanisms, and developing a user-friendly interface. By putting participant safety and user pleasure first, these upcoming improvements will help create a more dynamic, realistic, and immersive dueling experience.

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