ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Project: High Noon Sheriff Robot

Team #03

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1 Introduction

1.1 Problem

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

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 wearing a red hat. 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 15 meters, so we suppose that the opponent stand about 10 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

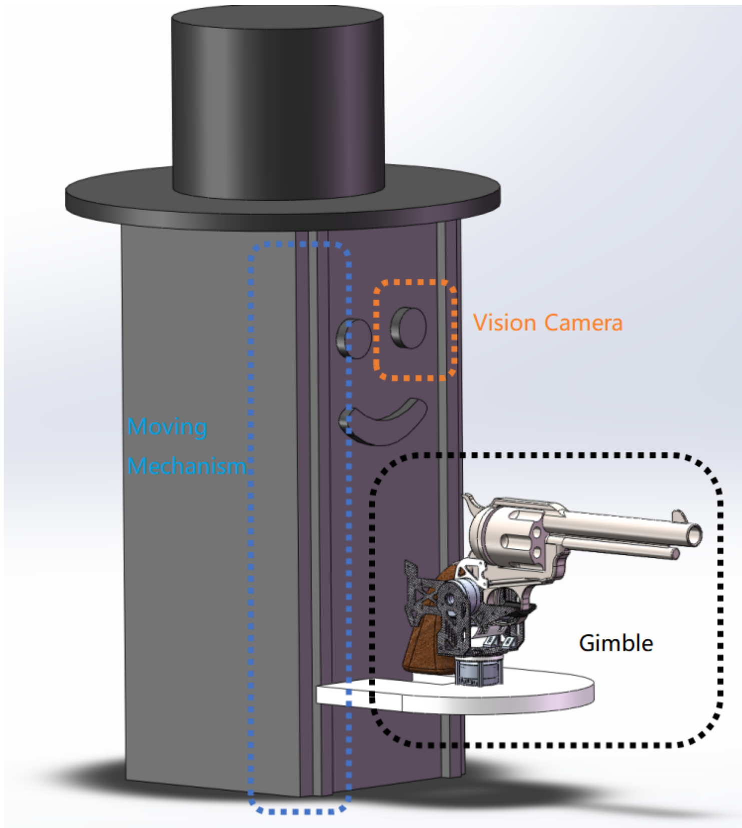

Figure 1: Block Diagram Overview

1.4 High-level requirements list

1. The robot should identify its opponent with a mark.
2. The robot could aim at the opponent and shoot on his chest.
3. The robot is able to complete the series of continuous actions of drawing, aiming and firing within 1.5 seconds.

2 Design

2.1 Physical Diagram

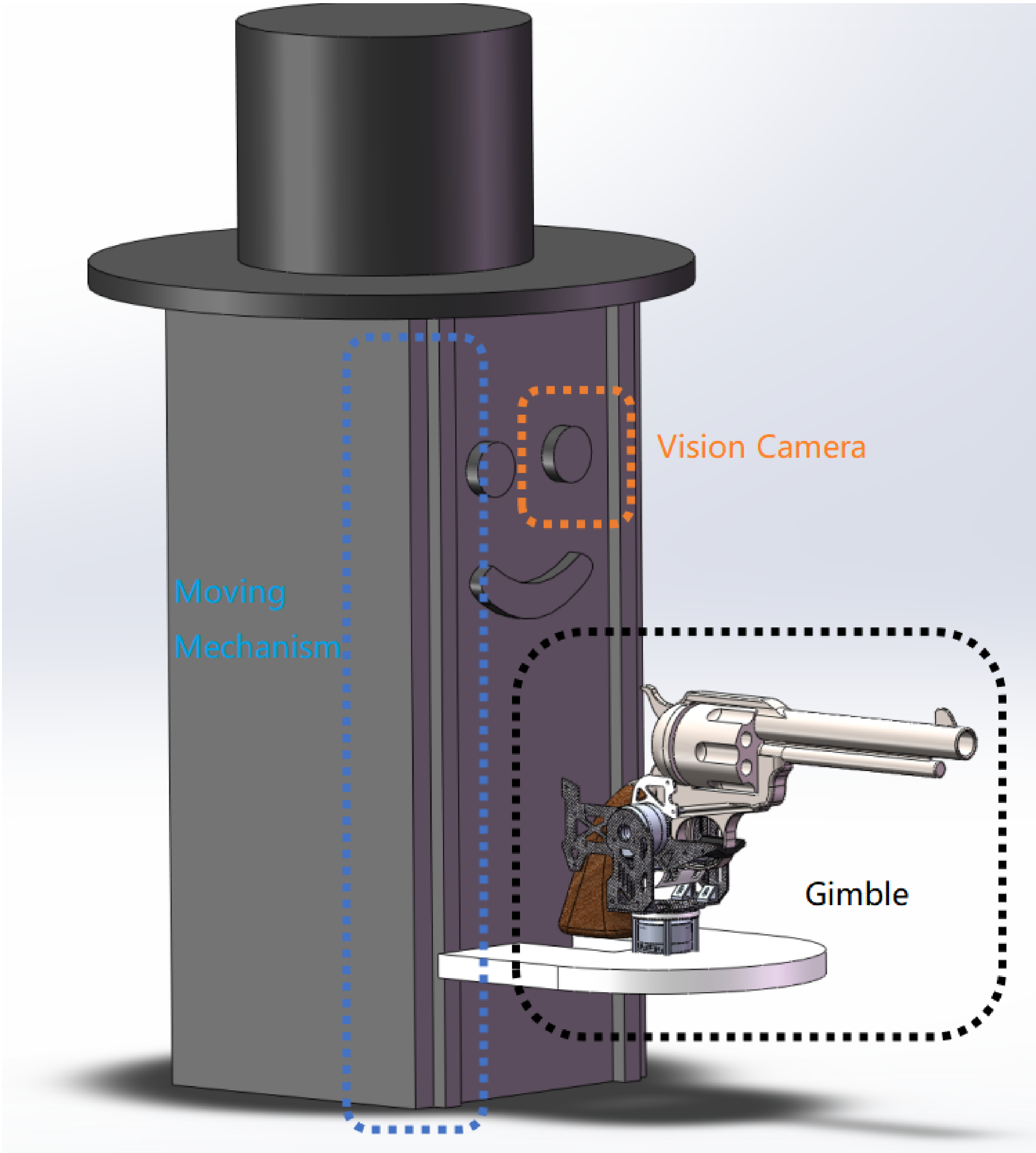

Figure 2: Block Diagram Overview

The draft design of our robot is shown in the figure. It consists of three parts, Gimble, moving mechanism and vision. in this week we mainly focus on two of the three parts to make the vision and electrical subsystem go on progressing and testing, so we use cartoon sketch to represent the moving mechanism.

2.2 Block Diagram

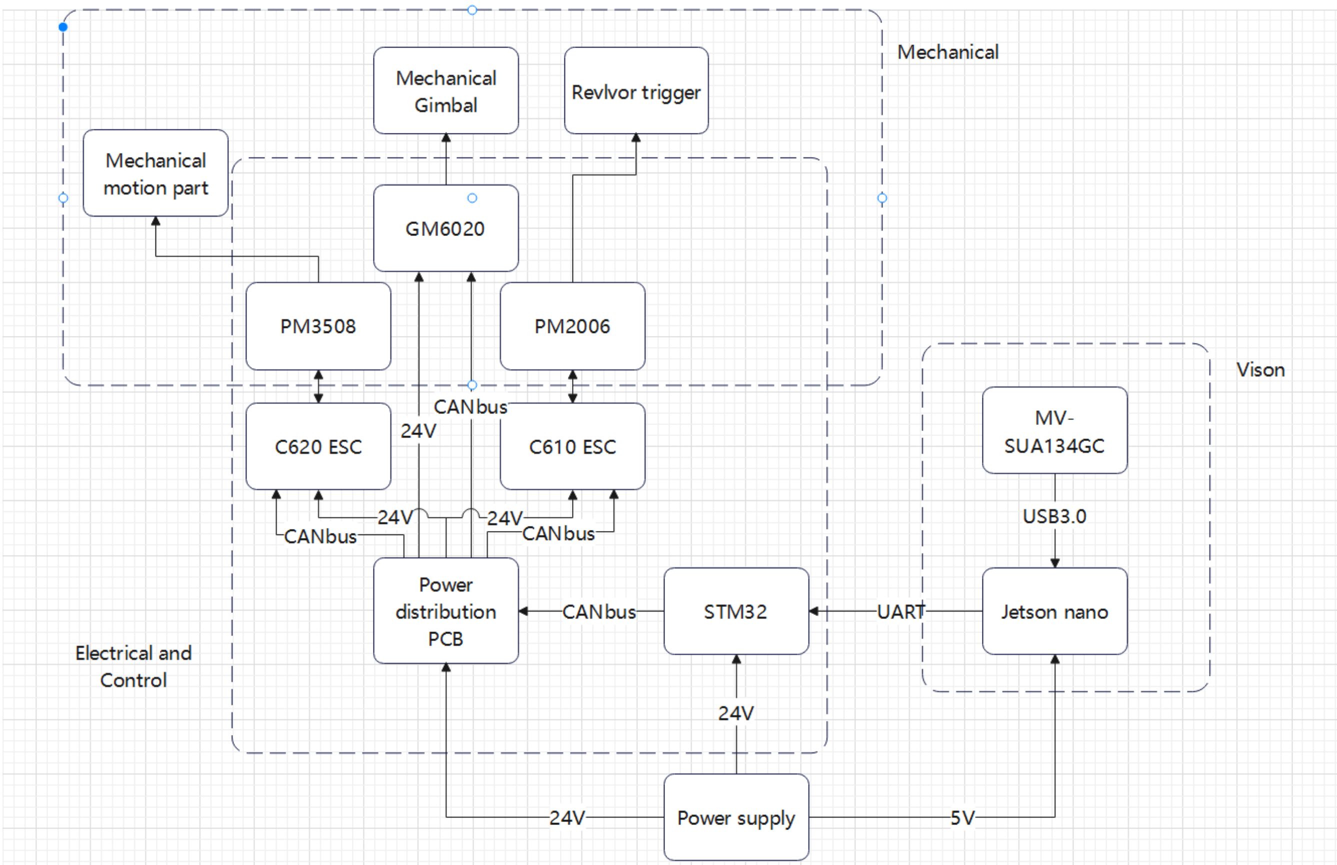

Figure 3: Block Diagram Overview

In figure 1 is our design block diagram overview. Our design have 4 subsystems including vision, electrical control mechanical design and power supply. We propose to use a high speed camera to capture target's movement and position information. 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.

2.3 Subsystem Description

2.3.1 Mechanical subsystem

Inside the black circle (fig.2) is the gimble. It includes two 6020 motors, revolver enrichment and firing mechanism. It has the function of fixing and firing the revolver and provides two degrees of freedom of rotation for aiming.

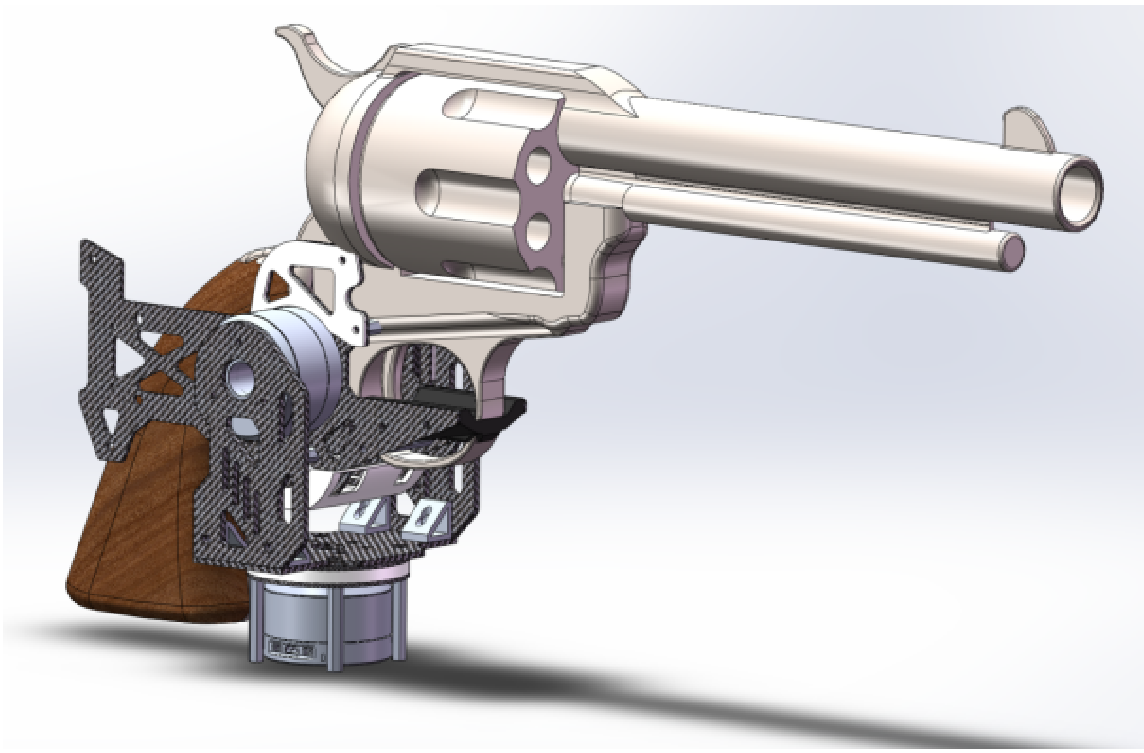

Figure 4: Gimbal

Inside the Orange circle (fig.2) is an image sensor, its function is to acquire the image of the surroundings and algorithmically mark the target person and derive his position, then send the coordinates to the gimbal motor for aiming.

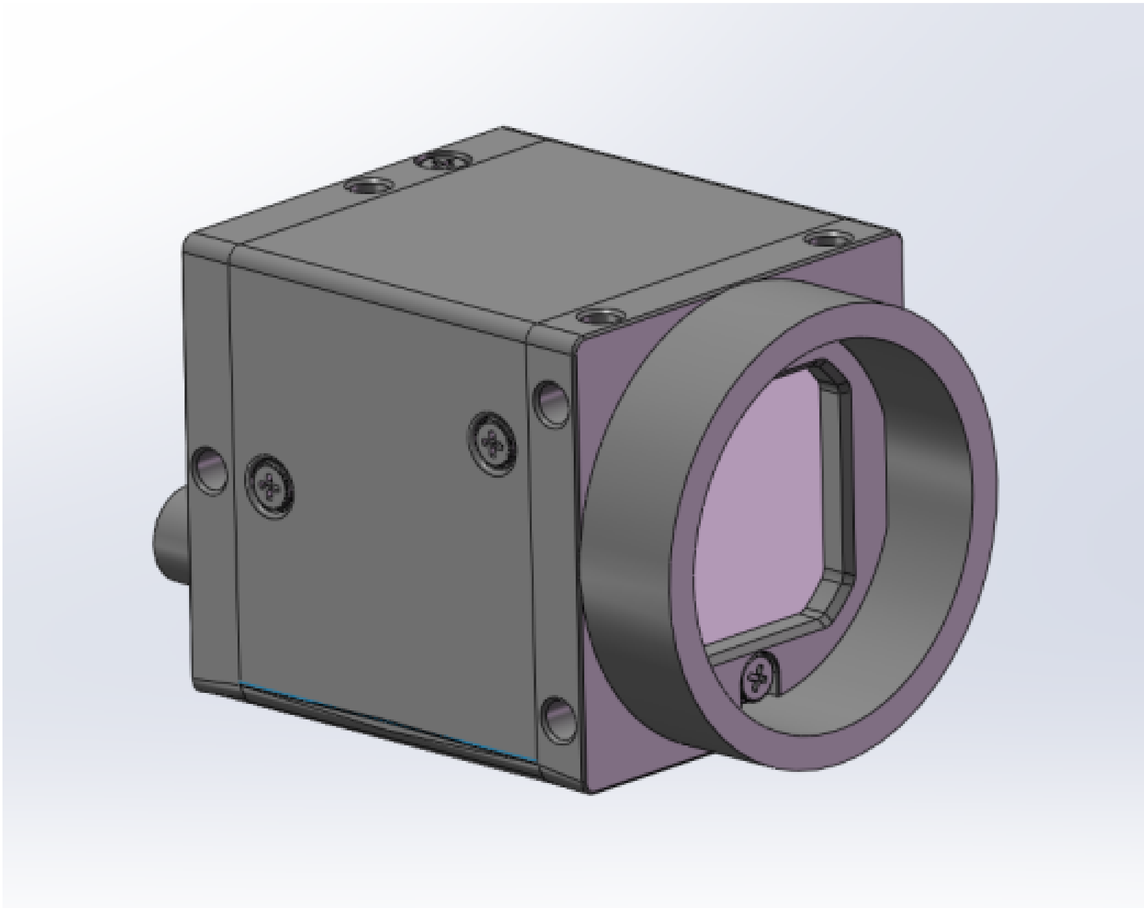

Figure 5: Camera

In the blue circle (fig.2) is the moving mechanism, which is used to pull the revolver from the safety position and transport it to a fixed position. It consists of a slidable platform. For the first version of the design, we mainly focused on the gimbal and the image sensor, because the vision and electrical control part needed the appropriate hardware platform to start progressing and testing, while the moving mechanism is composed entirely of mechanical parts relatively independent. After the initial version of the robot is built, we will design the mobile mechanism to resemble a human arm.

The basic force analysis on the chassis is shown in figure below. As the weight of the revolver around 1kg, and the 6020 motor is about 0.5kg, the mechanical structure is about 0.5kg, the vertical load is 20N, which is supported by the base of gimble. Setting the material of the sideboard as carbon fiber, the corresponding load simulation was operated through SolidWorks. The results of the stress and safety factor are shown as follows. As the safety factor is larger than 10, theoretically the chassis structure can hold the required weight.

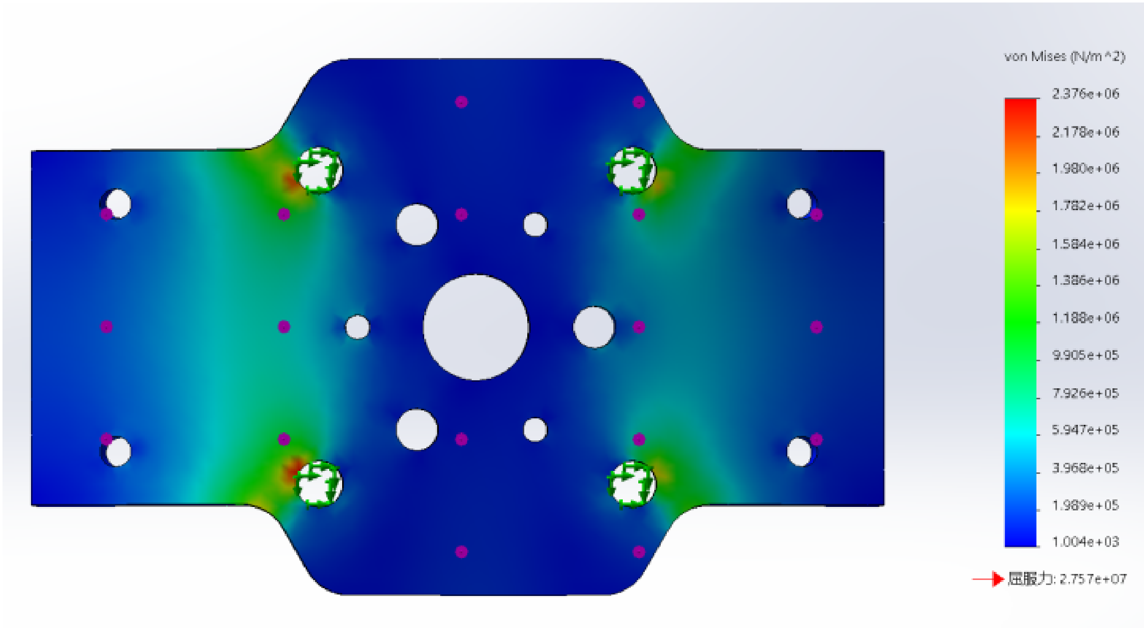

Figure 6: FEA

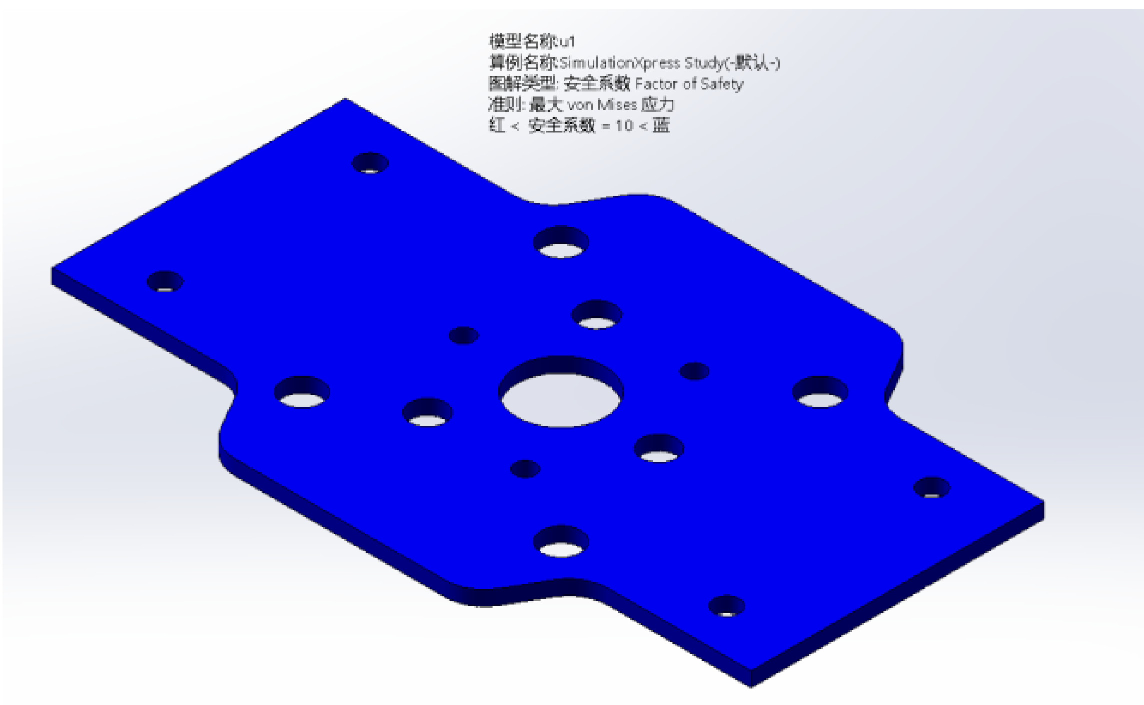

Figure 7: Red<safety factor=10<Blue

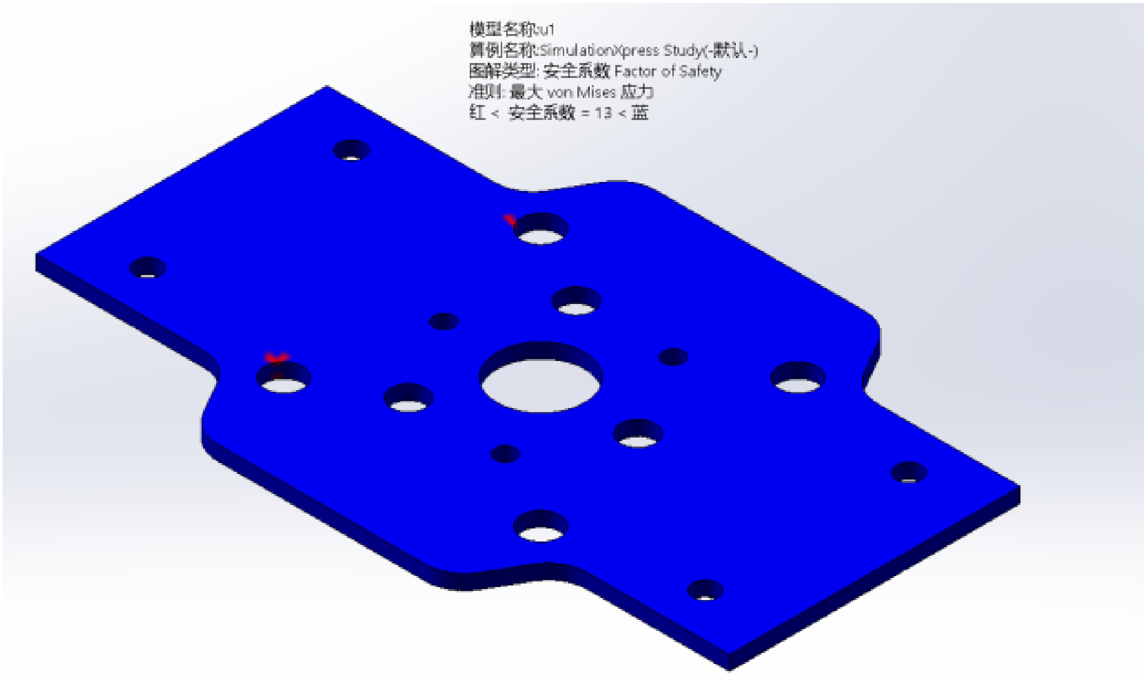

Figure 8: Red < safety factor=13<Blue

Requirements:

1. (Gimbal) Ability to aim at a given location within one second. Stable support that does not deform under high-speed rotation

2. (Camera) Camera weight can be reasonable

3. (Moving) Can drive the gimble to move from the lowest point to the highest point within 1 second, the distance is about 30cm

Verification:

1.
1.1 FEA analysis in CAD to verify theoretically the structural stability.

1.2 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.

1.3 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

2. Robots have a solid center of gravity after the camera is mounted on the robot.

3. 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.

Material:
1. Since the mass of the gimble will affect the movement of the motion mechanism, we choose the light weight and high strength carbon fiber material.

2. Fixed material is common 6061 aluminum hardware

3. The base of the motion mechanism needs to be strong enough and heavy enough, we use high fill rate 3D printed parts with counterweight blocks. The motion part adopts MGN standard sliders, which are commonly used in high precision and high speed machines and can meet our needs.

Analysis:
1. Analysis by SolidWorks built-in tolerance analysis and simulation function.

2. Verify that the mounting holes of the camera correspond to the connection mechanism by CAD software

3. Verification of the speed of the moving mechanism by using the speed of motor and the gear ratio.

2.3.2 Electrical and Control

The electrical and control module contains the STM32 development board, ESCs such as C620 and C610, motion motor PM3508, PM2006 and gimbal motor GM6020. The electrical and control part aim to build a system that can handle incoming position message from vision part and respond with in 1 seconds to make the motors react to the target position. The STM32 is the control center for the system and the motors are the output part for the system.

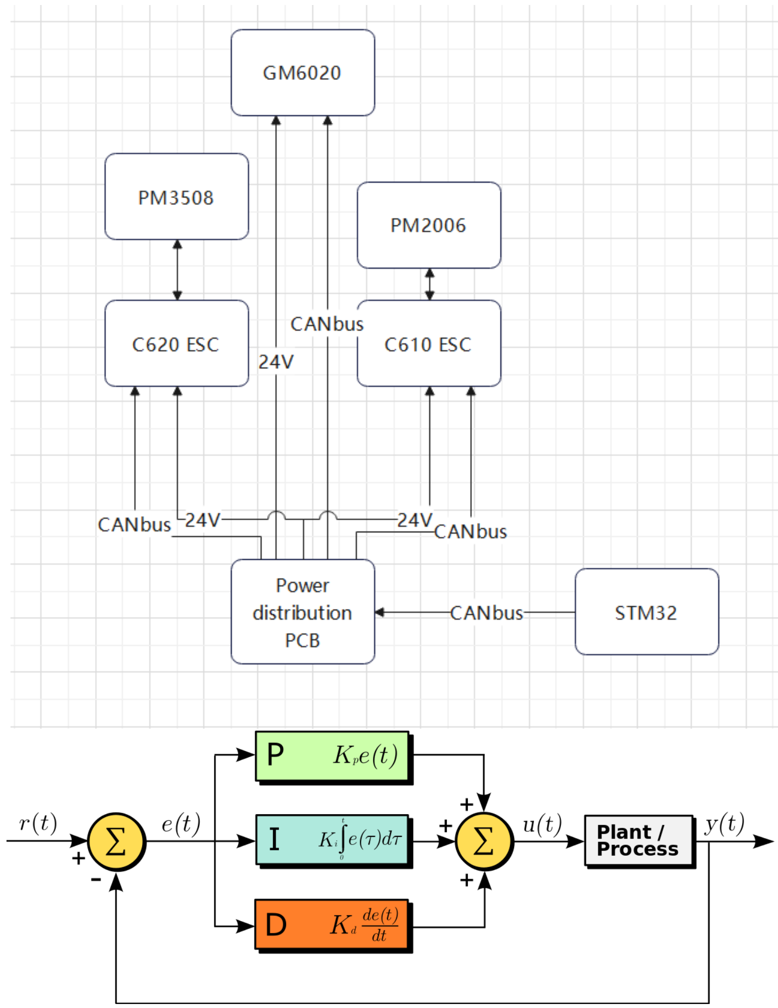

Figure 9: Electrical and Control Block Diagram

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.

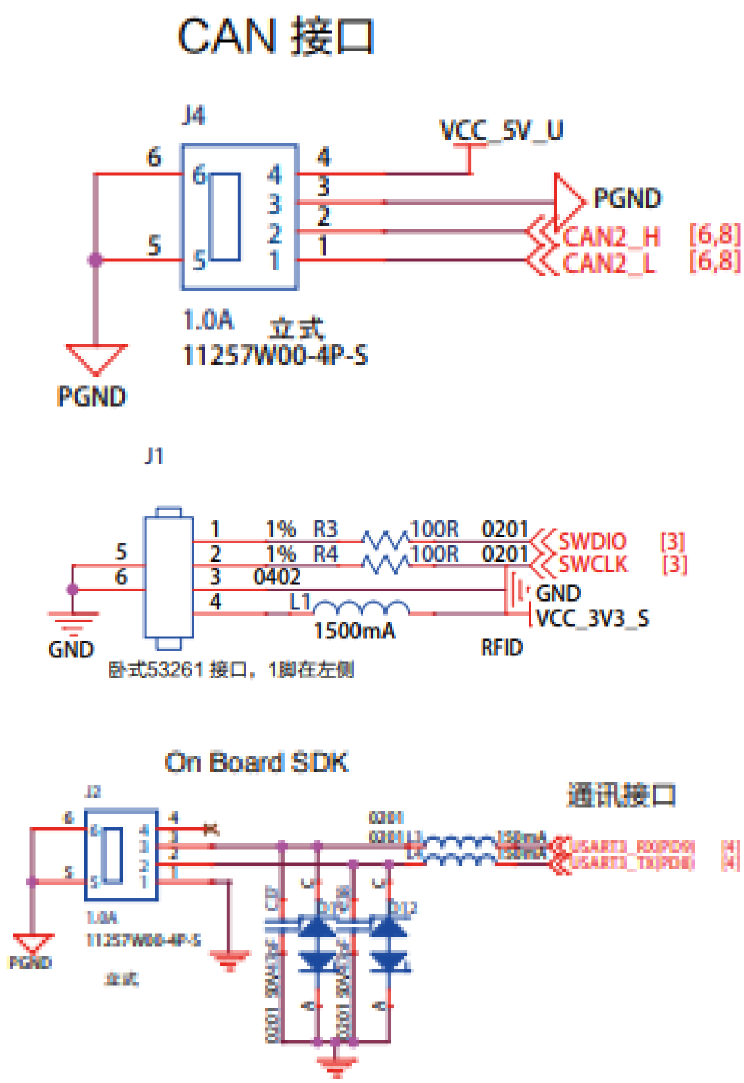

Figure 10: Hardware for the STM32 board

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.

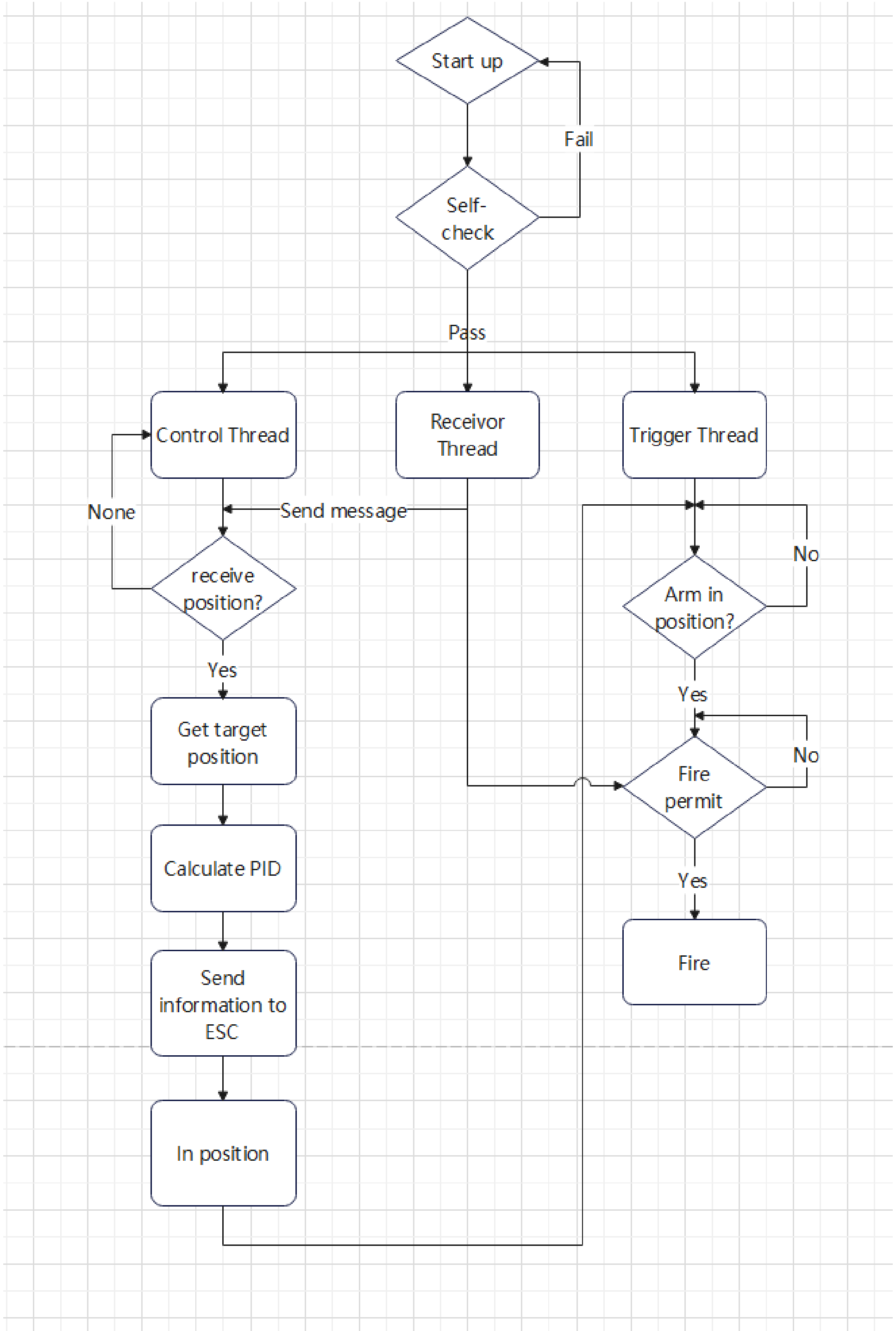

Figure 11: System logic block diagram

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.

PID control: A proportional–integral–derivative controller (PID controller or three-term controller) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value e(t) as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively)

Requirements:

1. The time delay for the control system from receiving message to motor respond in position should be less than 1 second

2. The position error for the gimbal motor should be less than 0.5 degree.

Verification:

1. 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.

2. 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.

2.3.3 Vision part

The vision subsystem of our robotic system consists of two primary components, namely a camera and a Jetson Nano board, 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, transmitting the images to the Jetson Nano board via USB. The object detection algorithm deployed on the Jetson Nano board is designed to identify firearms, 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. We have devised two different detection algorithms for the vision subsystem, which will be discussed in detail later. To ensure compliance with the latency restrictions, we may utilize our own laptop to run the object detection algorithm.

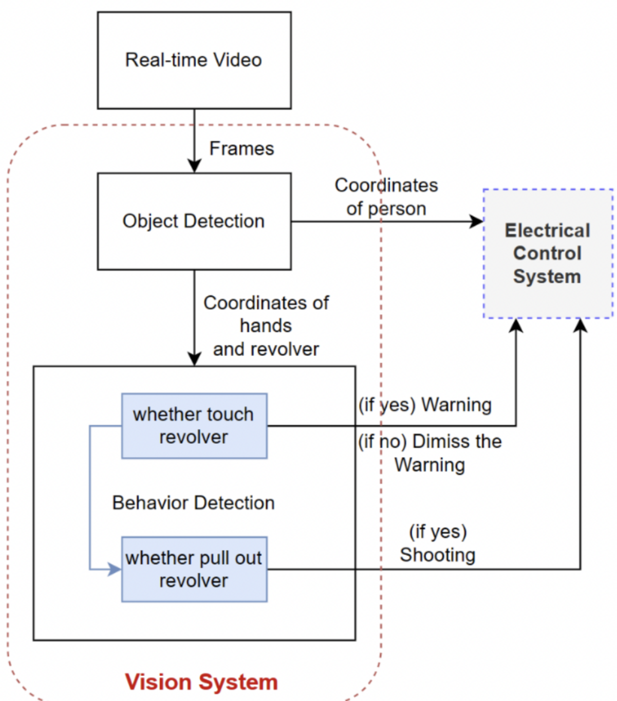

Figure 12: vision logic diagram

plain computer vision algorithms: While deep learning-based algorithms, such as neural networks, have achieved state-of-the-art results in object detection, they often require significant computational resources and extensive training data. An alternative approach is to use plain computer vision (CV) algorithms, which are simpler and more lightweight than neural networks. Additionally, CV algorithms do not require a training process, making them more easy to use. In this project, we will employ the OpenCV library to process images and obtain bounding boxes, following is a pipeline for object detection using CV algorithms:

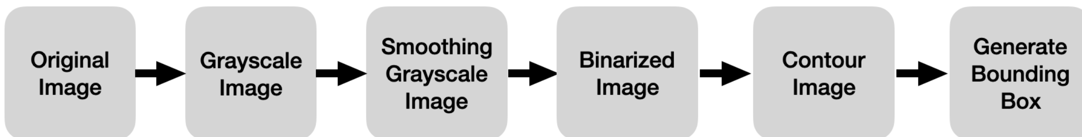

Figure 13: CV algorithm diagram

YOLO v5 algorithm: YOLO models are infamous for being highly performant yet incredibly small – making them ideal candidates for realtime conditions and on-device deployment environments. Yolo v5 is the leader in realtime object detection. This is the first native release of models in the YOLO family to be written in PyTorch first. Thus, it benefits from the established PyTorch ecosystem: support is simpler, and deployment is easier. Moreover, as a more widely known research framework, iterating on YOLOv5 may be easier for the broader research community. This also makes deploying to mobile devices simpler as the model can be compiled to ONNX and CoreML with ease. Second, YOLO v5 is fast. In a YOLOv5 Colab notebook, running a Tesla P100, we saw inference times up to 0.007 seconds per image, meaning 140 frames per second (FPS). This can be a good way to meet our needs, the robot needs to detect the position of the hand and gun in real time to judge the opponent's behavior. Third, YOLOv5 is accurate. In the tests on the blood cell count and detection (BCCD) dataset, the model achieved roughly 0.895 mean average precision (mAP) after training for just 100 epochs. Our robot needs high accuracy to aim at the opponent. Finally, YOLOv5 is nearly 90 percent smaller than YOLOv4. This means YOLOv5 can be deployed to embedded devices much more easily[4]. The advantages mentioned above satisfy all the requirements for object detection and behavior detection on the sheriff robot.

Upon obtaining the bounding box, determining the real-world location becomes a feasible task. The OpenCV software 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. (However, the plain CV algorithms is weaker than the neural network algorithms, so we may simplify the detection by putting some light on object, or mark the object with light color).

Figure 14: camera: MV-SUA134GC

Camera: The MV-SUA134GC camera unit[5] serves the purpose of providing a continuous stream of image input to our laptop or Nano board for the identification of human targets who may be carrying a gun and are about to engage in shooting. The camera has the ability to deliver a video stream at a resolution of 1280*1024 and a frame rate of 211 frames per second (fps). However, the usage of such a high resolution is contingent upon the available processing power, as it may be inadequate for processing the image data. The camera is designed to operate at a voltage of 5V and has a maximum power draw of 3W, as indicated by the specifications outlined in the MV-SUA134GC specification sheet. The accompanying image provides a visual representation of the camera unit.

Requirements:
1. Detect all hands, firearms and human body at the frame rate of at least 10 FPS.

2. Generate human behavior prediction at the frame rate of at least 10 FPS

Verification
1. The camera we use have a maximums 211 fps, which is much larger than 10 fps. The CV algorithms is light-weighted and our Jetson Nano have enough computation power to process the image in real time. Obviously, the rate is larger 10 fps.

2. The algorithms for human behavior detection is simple, we just keep track of the movement of hands and firearms, which can process in real time.

2.4 Tolerance Analysis

2.4.1 Power Supply

The power supply is a critical part for our design since all motors and development board have to consume power. The Jetson nano mainly works at 15W mode. The PM3508's max power is 150W. The max power for GM6020 is 15W. The max power for PM2006 is 44W. The camera is powered by Jetson nano through USB.

So the final power of the power supply is

for 5V power supply:

$$15W(jetsonnano) * 1 = 15W$$

for 24V power supply:

$$150W(PM3508) * 1 + 15W(GM6020) * 2 + 44W(PM2006) * 1 = 224W$$

The power supply we choose is MEAN WELL LRS-350-24 and RS-25-5 which have output for 24V 29A and 5V 5A. It is enough to handle the power supply.

2.4.2 Electrical and Control

The delay requirement for the control system is less than 1.5s so that the motor selection is important in our project. We choose PM3508 for the motion control and GM6020 for the gimbal control.

The standard PM3508 spin speed is 469rpm for torque at 3Nm and the CANbus rate is 1,000Hz. Suppose we need to move the robot arm about 100mm using 2GT 40 tooth gear.

$$\frac{100mm}{\frac{469rpm}{60s/min} * 25mm(geardiameter)} = 0.5117s < 1.5s$$

The standard GM6020 spin speed is 132rpm for torque at 1.24Nm and the CANbus rate is 1,000Hz. Suppose we need to move the robot arm about 100mm using 2GT 40 tooth gear.

$$\frac{180deg}{\frac{132rpm}{60s/min} * 360deg} = 0.227s < 1.5s$$

Hence, it is within tolerance.

2.4.3 Time Delay Analysis

In our project, as we plan to make the sheriff robot take an action immediately, the time delay for running the project should be limited. It is undeniable that the time for detection, electrical control and driving the motors will be delayed. We need to pay spacial attention to the time delay of each complete operation. Our model requires the total time delay to be less than 1500 ms, which enable the sheriff robot to shoot faster than the opponent. The time delay for our project can be divided into three parts: time delay for detection, circuits and motor driving.

$$T_{delay} = T_{detection} + T_{circuit} + T_{motor}$$

Based on our test and modification, the total time delay is limited to 1500ms, which satisfy the corresponding requirement.

3 Cost

3.1 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 / 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 15: 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 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 firearms detection	Control system frame	Purchase the materials of the gimble, moving mechanism, and machining the required parts.
April. 3	Train the yolov5 for firearms and human body detection	PID control for the motor	Finish the assembling of gimble and moving mechanism
MIlestone 1	Finish the human behavior prediction	The system can control motor moving to given position arrcu	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	improve the latency for our model	Can reveive 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 verion for the control system	Final version with human-like robot arm

Figure 16: schedule

5 Ethics and Safety

When designing a system that involves physical components, it is essential to consider the potential harm it may cause to humans. The IEEE and ACM Code of Ethics emphasizes the importance of protecting human safety, and this applies to the design of such systems [6]. To ensure that the toy gun does not harm humans and the robot does not aim at fragile components like eyes, designers must implement safety features such as limiting the range of motion of the robot or adding sensors to detect nearby objects. Additionally, when conducting experiments involving such systems, it is crucial to wear appropriate safety clothing.

The mechanical system of the robot must also be designed with user safety in mind. The structure should be sturdy enough to handle unexpected ovements of the motors, and the control system should have a safety loop that can cut off power before any risk occurs. These safety measures are in line with the IEEE and ACM Code of Ethics' emphasis on preventing harm to users [6].

Another ethical consideration in designing such systems is privacy concerns. For example, a camera may be used to identify a human's position and behavior, but this may raise privacy concerns. The IEEE Code of Ethics emphasizes the importance of rotecting the privacy of others [6]. To address this issue, designers can isolate the vision subsystem from other subsystems and store the video in a secure location that can only be accessed with authorized certification. By doing so, the vision subsystem only sends coordinates and behavioral assumptions to the control system, and users are notified about the use of the camera and the information collected.

Since our design has both mechanical parts and Electrical parts, we should consider the safety issues related to mechanical and electrical parts. For the mechanical part, we should consider the safety for the moving parts, we should make sure that it will not hurt users and have an emergency stop in case of some situation to stop the moving system in a second. And for the Electrical part since we are dealing with 220V AC power supply, the electrical circuit should follow the principle of separating the high AC power and low control DC power into two individual systems and make sure they would not interfere with each other to prevent potential safety issues. In this case, we can make sure of the safety issue with both mechanical parts and electrical parts.

References

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