ECE 445 / ME 470

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Robotic T-shirt Launching System Mark III

Team #39

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1 Introduction

1.1 Problem and Solution Overview

The Mark II T-shirt launcher poses significant challenges due to its bulky and heavy design, making it difficult to transport and operate effectively. Its instability when carried by hand will also increases the risk of accidents. Consequently, it is imperative to implement measures aimed at minimizing its dimensions and weight to enhance portability and ensure safer handling.

Additionally, considering its predominant deployment in expansive stadiums, there exists a critical imperative to broaden the distribution of T-shirts to a larger audience. Therefore, enhancing the launcher's capacity for spare ammunition and refining both reloading and firing procedures are paramount to facilitate seamless operation in such settings.

Regrettably, the current version of the MARK II model faces a prolonged reloading process, significantly hindering the swift distribution of T-shirts. This issue requires immediate attention. During the system's design phase, it is crucial to anticipate and address any potential uncertainties that could disrupt its functionality. A thorough risk assessment is necessary to identify possible problems and evaluate their potential impact. For instance, issues such as air pressure leaks in the chamber or the risk of explosions leading to safety concerns must be carefully considered.

Furthermore, we must remain cognizant of the potential hazards posed by the high velocity of the T-shirt launcher, which could endanger spectators. To mitigate these risks effectively, we can integrate supplementary safety features, establish backup systems, and enforce stringent testing protocols. These measures are essential to guarantee seamless operations and prevent any untoward accidents.

While preserving the achievements of ROBOTIC's T-SHIRT launcher, the MARK II, our team will address its key shortcomings. For example, the MARK II was too large and heavy for its function; we will reduce the overall weight of the launcher, where the air chamber can be reduced in size, by switching to a larger volume bottle to inflate the chamber and reduce the weight in the user's hand. Secondly, the design of the launcher can be simplified to reduce weight. To address the slow firing rate of the MARK II, we will abandon the revolver loading method and adopt a machine-gun style of loading, with top-down loading to enable continuous firing of the launcher, and use a quick exhaust valve to provide sufficient air pressure to increase the efficiency of firing the rounds. At the same time the use of fast filling valve, and high pressure cylinders for the transmitter gas chamber filling energy, to realize the rapid filling of gasIn addition, in terms of system automation, we will strive to achieve the unfinished business of MARK II by using a new control system that ensures smooth operation and allows for the controlled release of gas to ensure the safety of the experiment. An automated system to control the gimbal, including a computer vision module that automatically recognizes spectator behavior for fully automated firing. All in all, we are delivering a new version of MARK III that is more reliable and efficient.

1.2 Visual Aid

Figure 1: Manual Mode

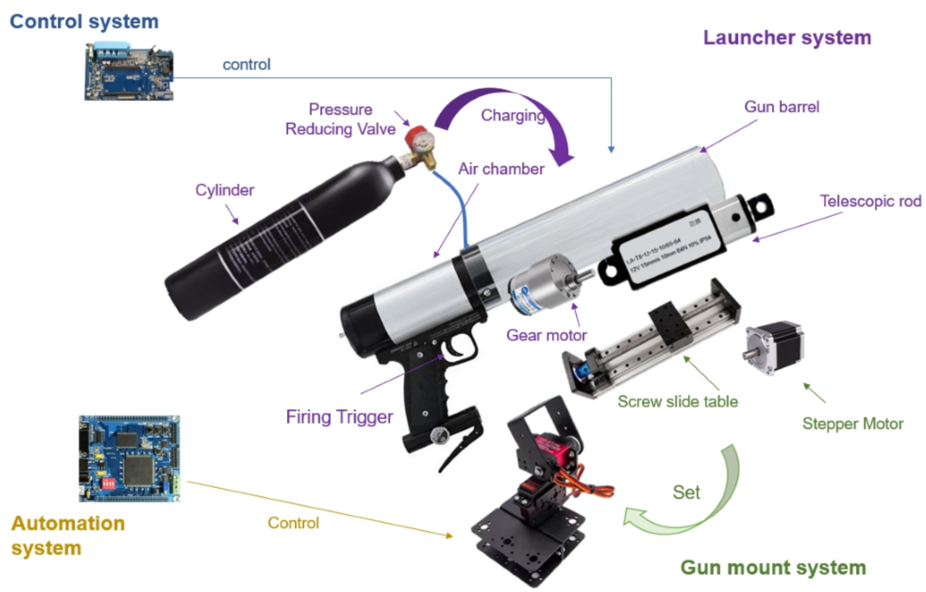


Figure 2: Automatic Mode

1.3 High-level requirements list

1. Pressurized Chamber Pressure Range: The pressurized chamber should be capable of maintaining a safe operating pressure ranging from 1 atmosphere to 20 atmospheres. The system should allow for precise adjustment of pressure levels within this range to accommodate different launching scenarios.

2. Maximum Projectile Range: The T-shirt launcher must be capable of propelling T-shirts to a maximum distance of 80 meters.This range ensures effective distribution of T-shirts within large sports arenas or stadiums.

3. Gun Mount System Adjustability: The gun mount system should provide two degrees of freedom for precise targeting.

3.1 Pitch Angle:

The pitch angle should be able to be adjusted from 30-60 degrees.

3.2 Horizontal Rotation Angle:

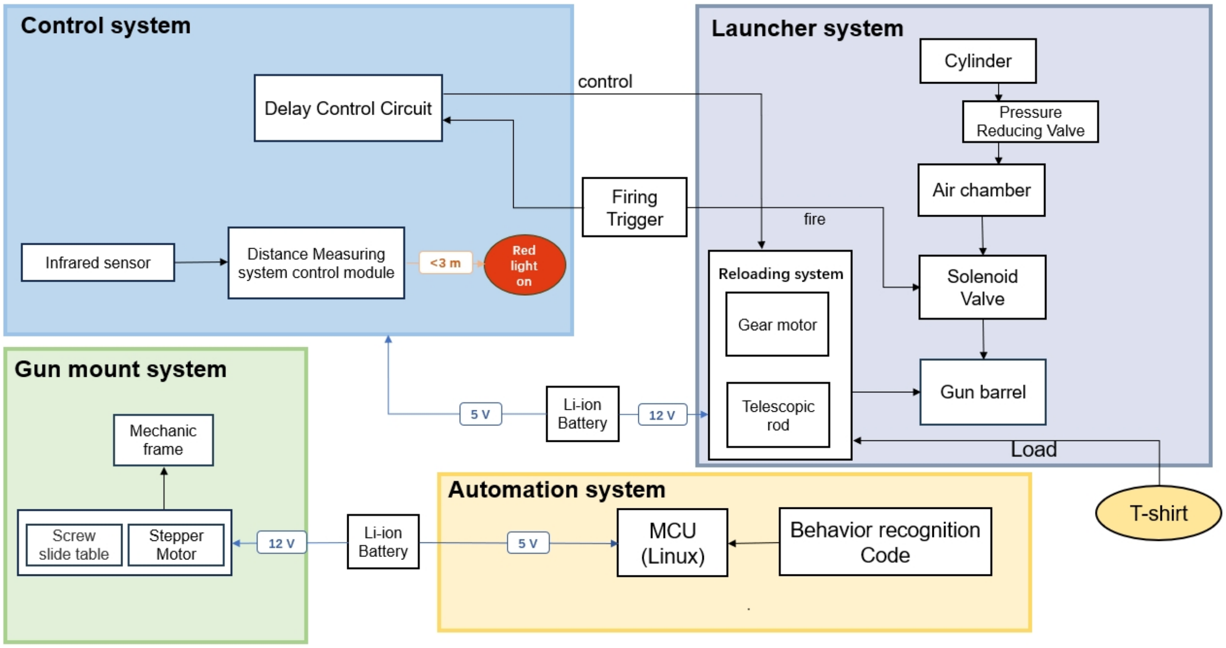
The system should be able to rotate horizontally through a full 360 degrees.

4. launch cycle:

The launcher system should respond to the trigger trigger by firing the projectile and be able to complete the reloading and inflation process for the next cycle within 30s, so the firing cycle of the launcher system should be within 30s.

2 Design

2.1 Block Diagram



2.2 Launcher system

The launcher system consists of two cylinders, a pressure reducing valve, a solenoid valve, gear motor, telescopic rod and gun barrel. The air chamber to store compressed air so that there is enough air pressure to fire the bullet when the gas is released. The cylinder fills the air chamber with air through the pressure reducing valve in time for rapid firing. The telescopic rod is connected to the barrel to ensure gas-tightness during firing and to facilitate bullet change by means of telescoping. The reduction motor is used to push out the shells to realize the change of shells All the components are connected together to form a firing system capable of rapid firing. The firing system is directly connected to the gun mount system for 360 degree firing. The control and automation system allows electronic control of the trigger and remote operation.

2.2.1 Cylinder

Cylinders are used as high-pressure storage tanks to hold high-pressure gases, rapidly inflate the air chamber, and always maintain chamber air pressure for rapid continuous firing. We are going to use a 0.5-liter volume, aluminum alloy gas cylinder as the high-pressure storage tank.

Requirements	Verification
1.Storage of 0.45 liters of high-pressure gas, internal gas pressure adjustable between 0 and 30 atmospheres	A. Use water to fill an empty gas cylinder and pour the water out of the cylinder into a measuring cylinder to measure the volume of water should be 0.45L. B. Use an air pump to continuously inflate a closed cylinder, use a barometer at the mouth of the bottle to check the air pressure inside the bottle, and check whether there is any leakage during the process until 30 atmospheres.

2.2.2 Pressure reducing valve

A pressure reducing valve is used to connect the cylinder to the air chamber. The pressure reducing valve includes an inlet port, an outlet port, a low pressure chamber, a regulating knob, a bleeder knob, and a barometer. By adjusting the regulating knob to set the air pressure in the air chamber, the cylinder can be quickly inflated to the gas chamber when the air pressure is lower than the set value.

Requirements	Verification
1.The pressure reducing valve allows the gas pressure in the gas chamber to be adjusted within the range of 8-12 atmospheres, 2. The gas pressure in the gas chamber can be returned to the set value within 30s after the gas chamber is deflated	1.A. Use a barometer at the mouth of the gas chamber to detect the air pressure in the chamber in real time, and after turning the regulating knob, observe the barometer reading covering 8-12 atmospheres. 2.A. Start timing after deflating the air chamber until the barometer shows that the air pressure reaches the set value and stabilizes, then stop timing and check whether the timing time is within 30s. B. Use an air pump to continuously inflate a closed cylinder, use a barometer at the mouth of the bottle to check the air pressure inside the bottle, and check whether there is any leakage during the process until 30 atmospheres.

2.2.3 Air chamber

The air chamber stores the air and is connected to a solenoid valve that releases the gas to power the launching t-shirt. We will use a 0.25L gas cylinder made of aluminum alloy as the air chamber.

Requirements	Verification
1. Storage of 0.25 liters of high-pressure gas, internal gas pressure adjustable between 0 and 15 atmospheres	A. Use water to fill an empty chamber and pour the water out of the chamber into a measuring chamber to measure the volume of water should be 0.25L. B. Use an air pump to continuously inflate a closed chamber, use a barometer at the mouth of the bottle to check the air pressure inside the bottle, and check whether there is any leakage during the process until 15 atmospheres.

2.2.4 Gear motor

A gear motor is connected to the drive gear set to increase torque and power the reloading subsystem to push out empty cartridges from the chamber. The gear motor operates at a rated voltage of 6 volts and realizes a torque of 0.3 $N{\cdot}m$.

Requirements	Verification
1. The speed can be adjusted according to different voltages, 30 rpm under 3V and 60 rpm under 6V. 2. It can reach 0.1N.m torque.	1. A. Using a DC power supply and voltmeter, observe whether the motor can rotate normally at 3v and 6v. B. Timed for one minute, counting the number of motor revolutions and whether it can reach 30rpm at 3V and 60rpm at 6V. 2.A. Use a torque tester to measure whether a motor can deliver 0.1N.m of torque at 3v and 6v respectively.

2.2.5 Telescopic rod

The telescopic rod is attached to the barrel and, when contracted, causes the barrel to compress the cartridge case, providing a gas-tight environment. When extended, it loosens the cartridge case to allow the gear motor to push out the cartridge case and realize cartridge change. The telescopic rod is capable of providing a force of 32N and has a travel of 50mm.

Requirements	Verification
1.It has a 50mm telescopic stroke and a telescopic speed of up to 30mm / sec at 12V, providing 30N of force.	A. Use a DC power supply and voltmeter to see if it can work properly at 12v. B. Use a ruler to measure whether a cycle of motion travels up to 50mm. C. Use a stopwatch to measure the time required for one cycle of movement and check if the movement speed can reach 30mm per second according to the calculation. D. Use a dynamometer to test whether the pulling force provided can reach 30N.

2.2.6 Solenoid valve

The solenoid valve is connected to the air chamber and serves as the air outlet of the air chamber, which can control the air chamber on and off. Capable of operating at 6 volts and 10 atmospheres of pressure.

Requirements	Verification
1.Fast response to control valve opening and closing at 6 volts and 10 atmospheres.	A. Using a DC power supply, a voltmeter, and a development board, observe the fast response of the magnetorheological valve to realize the bleed function at 6V and 10 atmospheres of pressure.

2.2.7 Gun barrel

The main function of the barrel is to guide the flight of the T-shirt, to improve the stability and range of the warhead in flight, after testing, we plan to use the PVC transparent tube with an inner diameter of 75mm, a thickness of 4mm and a length of 200mm as a barrel.

2.3 Gun mount system

The gun mount system plays a pivotal role in adjusting the firing angle, ensuring firing accuracy and stability during the operation of the t - launcher. It can be thought of as a

Requirements	Verification
1.The barrel is made of transparent PVC with a length of 200mm, an inner diameter of 75mm and a thickness of 4mm.	A.Use a ruler to measure the length of the barrel to be 200mm, the inner diameter to be 75mm and the thickness to be 4mm.

Requirements	Verification
1.Able to withstand a pressure of 50N and freely adjustable pitch and horizontal rotation angle.	A. Place a metal block weighing 50N on the Frame to see if it can be stabilized, and then manually adjust the pitch angle and horizontal rotation angle to see if it can be stabilized again.

targeting head with two degrees of freedom, incorporating advanced components such as stepper motors, precision reduction gear sets and durable aluminum frame construction. The gun mount system should have the ability to quickly and accurately help the launcher reach the set position by rotating it horizontally in less than 10 seconds and the aluminum frame can stably withstand at least 50N pressure. Stepper motors can receive electrical signals transmitted from the control system in real time and realize accurate 0-360 degree rotation angle adjustment.

2.3.1 Mechanic frame

The mechanical frame is used to mount the entire transmitter system, which can be freely rotated in pitch angle, and horizontal angle. It is made of H-type aluminum alloy and is able to bear a pressure of at least 50N.

2.3.2 Screw slide table

Screw slide table is used to adjust the pitch angle of the mechanical frame by moving the slider horizontally on the slide rail. It can be adjusted from 30 degrees to 60 degrees of pitch.

2.3.3 Stepper motor

Stepper motors are electric motors capable of precisely controlling the angle and speed of rotation according to a program, driving the horizontal movement of the slider in the slide and regulating the horizontal rotation angle of the mechanical frame. It is capable of operating at 12 volts and provides a torque of 0.2N*m.

Requirements	Verification
1. Effective stroke up to 400mm and can be positioned.	A. Use a ruler to measure whether the length of the movement axis is 400mm. B. Observe whether the slider can stay and be fixed in the current position when the motor stops C.Using a protractor to measure whether the Frame pitch angle can be adjusted within 30-60 angles when the slider moves between 0-400mm travel.

Requirements	Verification
1.Can operate normally at 12V to provide 0.2N.m of torque.	A.Use a DC power supply and voltmeter to test whether the stepper motor can operate normally at 12V. B. Use a torque meter to check if the maximum torque that the stepper motor can provide under 12V is 0.2N*m.

2.4 Control System

The function of the control system is to control components such as the solenoid valve of the launcher system to achieve the functions of the launcher through the trigger. The control system also acts as an interface between the launcher system and the automation system, enabling the launcher to connect to the automation system. In addition, the control system should be equipped with a sensor to measure the distance of the launcher's front end from the nearest object and light a red LED to alert the operator when the distance is too close, which can allow the operator to avoid some dangerous operations.

The control system uses a PCB board to achieve these functions. A delay circuit should be included to correctly implement the launcher's combination of features. An infrared sensor measures the distance of the object in front of the launcher and transmits it to the circuit of the PCB board to light the LED on it. A trigger emits a specific electrical signal that causes the launcher to fire. We need some chips to perform specific functions to achieve these circuit designs.

The control system is implemented by a PCB board equipped with a circuit. In order for the control system to work properly, we need to provide a voltage of +5 V to the circuit. The voltage range should be between + 4.5V to + 5.5V, in this voltage range, the circuit and its required chip can work normally. In addition, for unpackaged PCB boards, we need to do waterproof treatment, or avoid working in an environment with water, such as rainy days. Temperatures above 100 degrees Celsius should also be avoided.

Requirements	Verification
1. It has a delay circuit built into the PCB board, driven by a 4.5 V to 5.5 V power supply, and to provide the telescopic rod module with a +- 12V signal to drive it, and the interval between the two signals is at least 5second.	1.A. Using a DC power supply and voltmeter to see if it can work properly at 4.5V to 5.5V and provide 12 V signal. B. Using a stopwatch to measure the delay time of the delay circuit several times to ensure that it is greater than 5 seconds.
2. It has an infrared ranging system controlled by a 5 V power supply that ensures an alarm when there are obstacles within 3 meters, including people and human limbs as well as larger obstacles.	2.A.Using a square obstacle around 1 decimeter side length and a tape measure to ensure that the obstacle can be identified within 3 meters of the transmitter.

2.5 Automation System

For the case of use on the gun mount, we want the launcher to be able to fire automatically. Therefore, the system should have a suitable function to automatically adjust the direction and force of the launch according to the situation. In addition, for safety reasons, the system will include a computer vision module to conduct spectator behaviour recognition to avoid potential accidents, such as stampedes. The Automation System is responsible for implementing the function of behaviour recognition, which can recognize the abnormal behavior of the audience and avoid firing the T-shirt into these areas to avoid the occurrence of dangerous incidents.

The Automation System needs to control the movement of the gun mount system and the launch function of the launcher. These functions are realized through the MCU output electrical signals and control the voltage of the corresponding parts of the gun mount and launcher.

In addition, the Automation System also needs algorithms to implement the automatic launch function. The Automation System algorithm code will be installed on an MCU with a Linux system installed. On the subsystem, a camera takes image information from the audience and transmits it to the MCU. Algorithms in the MCU will process the image information from the camera to identify crowd behavior in the audience, such as stillness, cheering, commotion, etc. The recognition of these images will be used to decide where the Automation System controls the launcher launch.

2.5.1 Algorithm selection

First we need to clarify what principles we need to select algorithms based on in order to achieve our goals. The problem of identifying crowd behavior in the audience belongs to crowd behavior analysis under computer vision.[1] Therefore, in the selection of algorithms, we will focus on selecting the algorithm of crowd behavior analysis, and optimize it based on the existing SOTA algorithm and combined with our actual problem, that is, audience crowd behavior recognition.

In addition, we also have certain requirements for the computing power required by the algorithm. Our design is based on outdoor use scenarios and requires real-time computing, so using cloud computing and high-performance computing equipment is not in line with our use scenario. We will give more consideration to computing power when selecting algorithms. In short, we need to choose an algorithm with good recognition and relatively low computational power. The choice of algorithm will be a trade-off between performance and the required computing power.

2.5.2 Data set

There are a variety of databases on crowd behavior analysis, but there are few databases for audience. At present, we have not found a dataset that focuses on audience crowd behavior recognition. Therefore, we will take a pre-training - fine-tuning model training approach. That is, we need to select a pre-trained model, or train a model on a dataset with enough data, this process is called pre-training; Then, we need to fine-tune our pre-trained model for the problem we care about, which is audience crowd behavior recognition.

Fine-tuning requires the use of a smaller but higher quality data set. So, we use existing audience videos from some concerts or sporting events to build our own fine-tuned data sets.

2.5.3 Hardware selection

Because of the above needs, we want to choose the most powerful MCU as possible within the budget. So, we chose an MCU with the RK3568 chip and equipped it with 4 GB of RAM and 32 GB of ROM. The rk3568 chip has an NPU computing unit that provides the chip with up to 1 TOPS of computing power. This makes it possible to deploy deep learning algorithms on the MCU. RAM ensures the parameter storage requirements in the inference process of deep learning models; ROM is more than required, which helps us reduce some of the tedious steps in the development process. In mature, mass-produced products, the size of the ROM can be drastically reduced.

In addition, we also selected the camera component that comes with this MCU to enable image capture.

2.5.4 Working environment

The behavior recognition that carries the code runs on the MCU of the control system, so we need to provide a voltage that meets the MCU. The MCU requires a + 5v power supply. In the worst case, the voltage should be between + 4.5V and + 5.5V to ensure its normal operation.

The cameras required by the automation system cannot operate in excessively humid environments to ensure the clarity of the images. Like the control system, the automation system should avoid working in an environment with water, such as rainy days.

2.6 Tolerance Analysis

The level of air pressure poses a risk to the successful completion of the MARK III, i.e. it is important to ensure that the entire unit is airtight. Air leakage due to poor gas tightness causes the air pressure generated when releasing the gas to be too low for the bullet to gain enough momentum to reach the desired distance. Therefore, we will perform a tolerance analysis, mathematical analysis, and simulate the effects of different air pressures, and other variables on the distance the T-shirt is fired.

The first thing we need to know is the energy released by the compressed air in the air chamber.

$$W_1 = (P_1V_1 - P_2V_2)/(\gamma - 1)$$

Where W_1 is the energy that can be released by the compressed gas, i.e. the kinetic energy provided by the T-shirt. P_1 and V_1 are the pressure and volume of the gas in the initial state, and P_2 and V_2 are the pressure and volume of the gas in the final state. γ is the adiabatic index of air, which is usually 1.4.

V_1 is the volume of the gas chamber which is about 0.25 L and P_1 is the pressure of the gas chamber which is about 1 MPa. When the solenoid valve is opened, the compressed air is released and fills up the whole barrel, and the end state volume of the gas,

$$V_2 = V_1 + \pi L(d/2)^2$$

where $\pi L(d/2)^2$ is the volume of gun barrel, L=200 mm, d=75 mm.

After the compressed air is released, the gas fills the entire barrel at a pressure.

$$P_2 = P_1(V_1/V_2)^\gamma$$

We then get the kinetic energy gained when the t-shirt is fired, but the t-shirt is subject to air resistance in flight and atmospheric pressure doing work in the barrel. The work done by air resistance as the T-shirt moves through the barrel is negligible because of the short length of the barrel.

$$\delta W = W_1 - P_a \pi L(d/2)^2 = 1/2mv^2$$

Where P_a is the atmosphere, v is the initial velocity of the T-shirt at the end of the gun barrel. In the ideal state, we can get the initial velocity of launch v,

$$v \approx 40m/s$$

If poor airtightness occurs, the pressure released from the air chamber will be much less than 1Mpa, and the T-shirt will not be able to gain enough kinetic energy and have enough initial velocity to reach the set distance. Therefore, airtightness is crucial to the success of the program.

3 Cost and Schedule

3.1 Cost Analysis

Our fixed development costs are estimated to be $30.00 per hour. 9 hours/week for 4 people. We consider approximately 60% of our final design in this semester (16 weeks):

$$2 * \$30/hr * 9hr/wk * 16wks/0.6 * 4 = \$57600$$

Part	Cost(Prototype)	Cost(Bulk)
pressure reducing valve(OEMG,1)	265RMB	265RMB
PU Tube, 10m(People,1)	29rmb	15rmb
0.45L Gas Clinder(Jinjiang,1)	149RMB	149RMB
0.25L Air-Chamber(Jinjiang,1)	129RMB	129RMB
pneumatic joints(Zhuoji, for all required sizes)	100RMB	18RMB
Gas cylinder fittings(Xianjuan, for all required styles)	50RMB	25RMB
Screw slide table(Olida,1)	287RMB	287RMB
Gear motor(MUD,1)	28RMB	28RMB
Stepper motor(ZDYZ,2)	190RMB	190RMB
Development Boards and Camera Kits(Yehuo,1)	529RMB	529RMB
PVC Tube(Hongqu,for all required sizes)	50RMB	30RMB
Aluminum Alloy (Zexin,for all required sizes)	120RMB	80RMB
Total	1926RMB	1745

All this yields a total development cost of $57866.

3.2 Schedule

Week number	M-Team	E-Team
6	Finish the 3D model design of all parts	Improve PCB design; Implementation algorithm
7	Establish gas pressure room of cylinder and chamber for test	Improve PCB design; Implementation algorithm
8	Design the reloading system	Wait for PCB production; Finetune the algorithm based on the data set
9	Build the reloading system and launcher system.	Solder components to PCB; Trying to deploy algorithms to the MCU
10	Building the gun mount system.	Compression algorithm
11	Integrate all the system together.	Integrate all the system together.
12	Debug and decorate.	Debug and decorate.
13	Debug and decorate.	Debug and decorate.

4 Discussion of Ethics and Safety

4.1 Ethics

We looked up the relevant laws, and under the Gun Control Act of 1968, a projectile fired with compressed gas does not constitute a firearm. Currently, the law is enforced by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) under the United States' Department of Justice.[2]

However, Illinois excludes non-powder guns of.18 caliber or smaller and non-powder guns with muzzle velocities of less than 700 feet per second from the definition of firearms. Apparently, the muzzle speed of our launcher T-shirt is less than 700 feet per second. Therefore, under Illinois law, a T-shirt Launching System is not a firearm. However, there are areas that define all non-powder guns as firearms and therefore may consider our T-shirt Launching System to be firearms, such as New Jersey and Rhode Island. Therefore, we need to pay attention to the design of the appearance of the Launching System of a T-shirt to avoid its appearance being similar to that of a real gun.[3]

However, in conclusion, according to relevant laws, we can safely use T-shirt Launching System on UIUC campus without worrying about legal risks.

4.2 Safety

The dangers of using pressure vessels are well known. Therefore, in order to avoid dangers during manufacturing and use, we and all team members conducted safety training, discussed several dangerous situations we may encounter and the corresponding handling methods. According to the IEEE Code of Ethics, we will also pay attention to and remind the potential risks of the products we design, and disclose all possible dangers in a timely manner.[4] In addition, pressure vessel maintenance and pressure detection will also be part of the design.

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