ECE 445 / ME 470

SENIOR DESIGN LABORATORY

FINAL REPORT

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

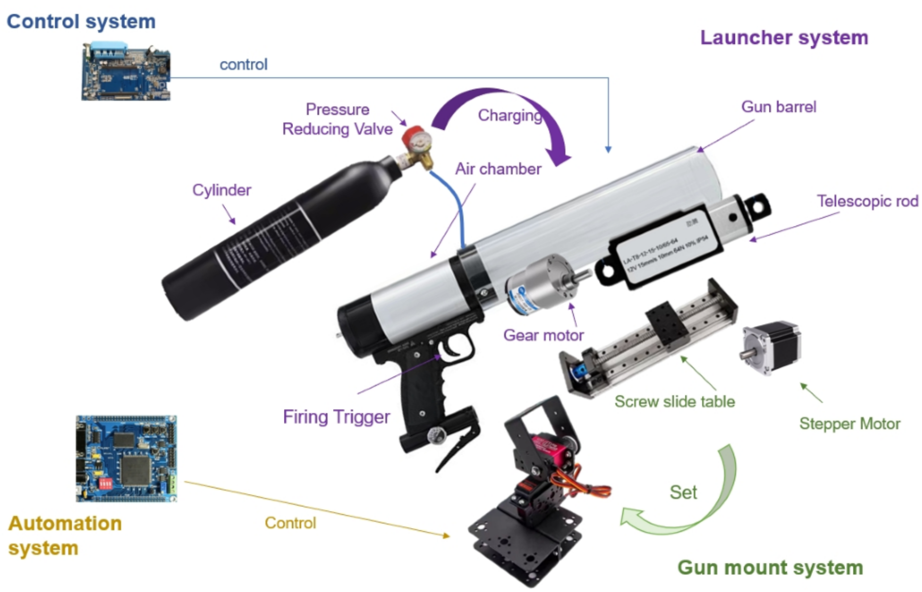
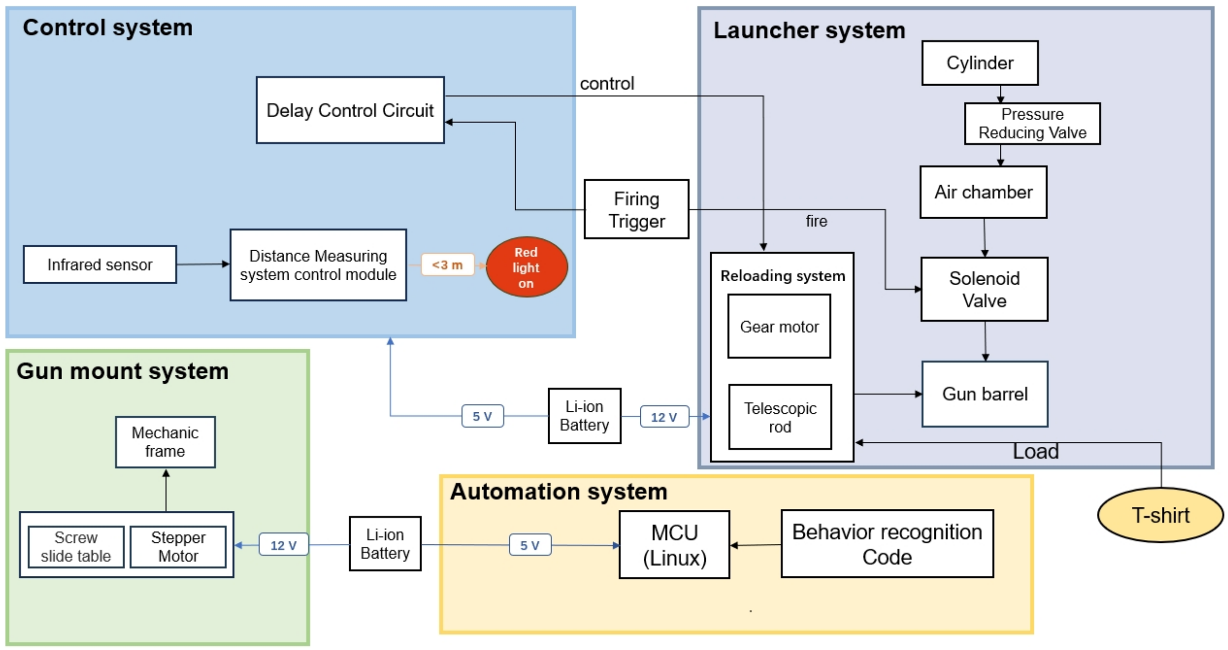


Figure 2: Automatic Mode

2 Design

2.1 Block Diagram



2.2 Launcher system

2.2.1 Design procedure

In this design process, we can choose the same bullet change design as the MARK II, like the revolver-style rotary bullet change. But in the end, we chose to use a similar method of changing bullets in a sniper rifle, where the bullets are inserted into the chamber. The advantage is that due to the uncertainty of the accuracy of the 3D printed parts, the rotating wheel can cause jamming and unsmooth changing of the bullets, which makes it impossible to realize continuous firing. The sniper rifle style loading method, on the other hand, is more silky smooth and effectively solves this problem. Next is the choice of gas chamber problem, the capacity of large volume gas cylinder can provide enough kinetic energy for the launch of the T-shirt, but the disadvantage is also obvious, the weight is too large, resulting in not easy to hold. Therefore, our final choice is a small 0.25 liter cylinder as the air chamber.

2.2.2 Design details

The launcher system consists of two cylinders, a pressure-reducing valve, a solenoid valve, gear motor, telescopic rod and barrel. The air chamber is used to store compressed air so that there is sufficient air pressure to fire the bullet when the air is released. The cylinders inflate the air chamber through the pressure reducing valve in time for rapid firing. We set the air pressure of the gas chamber to 1Mpa. When the cylinder inflates the gas chamber to 1Mpa, the pressure is balanced and the inflation stops automatically. The telescopic rod is connected to the barrel to ensure airtightness during firing and to facilitate bullet replacement through telescoping. The movement distance of the telescopic rod is 5cm. When the cartridge case falls into the chamber from the magazine, the telescopic rod drives the barrel to contract, making the barrel and the cartridge case form a whole. The gear motor is used to change bullets. When the firing is completed, the gear motor drives the gear set to push out the cartridge case from the slot on the left. All components are connected together to form a launching system capable of rapid firing. The launcher system is directly connected to the gun mount system, allowing for 360-degree firing. The control and automation system allows electronic control and remote operation of the trigger.

2.3 Gun mount system

2.3.1 Design procedure

During the design process of our gun mount system, we have designed many versions according to the different ways of height, footprint and rotation. For example, in the dimension of height, we originally wanted to use a support arm with a length of 10cm to connect the launcher's mount to the slider on the Screw slide table, but according to our calculation, in order to achieve a better T-shirt shooting effect, we chose to use a 30cm long support arm and designed suitable connectors to make the overall length of the support arm reach about 40cm, which is more in line with our calculation. However, according to the calculation, in order to achieve a better T-shirt shooting effect, we chose to use a 30cm long arm, and designed a suitable connector so that the overall length of the arm reaches about 40cm, which is more in line with our calculation results. In the dimension of floor space, after considering the size of the launcher as well as the overall coordination and aesthetics, we chose to change the size from 100cm*100cm to 60cm*30cm. the rotation method is a very important factor in our design concept, we originally chose to use a flat turntable as our rotating axis, but subsequently found that the turntable is difficult to assemble to the We originally chose to use a flat turntable as our rotary axis, but later found that it was difficult to fit the turntable into the structure of the gun mount and the adjustability of the flat turntable in the z-axis was very poor. Therefore, we chose to use a combination of flat bearings and a 10mm diameter hardened optical shaft as our rotary mode, and successfully assembled a nylon-printed worm gear and a worm with the same module to form a transmission structure that smoothly cooperated with the stepping motor to realize the horizontal rotary function of the gun mount.

2.3.2 Design details

The gun mount system plays a key role in adjusting the firing angle, ensuring firing accuracy and stability when the launcher is in operation. It can be thought of as a targeting head with two degrees of freedom, integrating advanced components such as stepper motors, precision reduction gear sets and durable aluminum frame construction. The entire gun mount can be divided into three main planar structures with different heights and functions. The top planar structure is called the launcher placing frame, which consists of two 50cm aluminum profiles and two 15cm aluminum profiles, which together with various connectors for 3D printing can stably support the launcher placed on the top, and the middle structure mainly consists of a screw, which is made of aluminum. consists of a screw slide and worm gear, the screw slide is connected to the upper and lower planes through the support arm and 3D printing parts respectively, the worm gear is mounted under the screw slide, which can rotate the screw slide and the launcher placing frame through transmission, the lower planar structure is the foundation of the whole gun mount, which consists of two 60cm aluminum profiles and four 30cm aluminum profiles, four universal wheels and the stepper motors and some connectors, which can keep the gun mount stable and can rotate and move freely. The gun carriage system should be able to accurately help the launcher to reach the set position within 30 seconds through horizontal rotation, and the aluminum frame can stably withstand a pressure of at least 50N. The stepper motor receives electrical signals from the control system in real time, and realizes precise rotation angle adjustment from 0-360 degrees. At the same time, the screw slide can realize 15-55 degrees of pitch angle adjustment of the launcher placing frame.

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.

2.5 Automation system

For use in gun mounts, the launcher needs to be able to fire automatically. Therefore, the system should have corresponding functions to automatically adjust the direction and force of launch according to the situation. In addition, for safety reasons, the system will include a computer vision module for spectator behavior recognition to avoid potential accidents such as stampedes. The automated system is responsible for implementing the behavior recognition function, which can identify the abnormal behavior of the audience, avoid launching the T-shirt into these areas, and 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 output electrical signal of the MCU(slave computer) to control the voltage of the corresponding part of the gun mount and launcher.

In addition, the automation system also needs algorithms to implement the automatic launch function. The automation system's algorithm code will be installed on an MCU(master computer) 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 Design procedure

The basic idea for designing the automation system came from a number of mature commercial products that performed similar functions, for example, large blowers that were used to distribute souvenirs. In their use scenarios, portability is not the most important technical indicator, but more attention is paid to the convenience of device use. Therefore, the idea of designing an automation system is reasonable.

In the design process of automation system, we chose to use a combination of master computer and slave computer, because according to our comprehensive consideration of MCU with rich computing resources, Using an additional MCU(slave computer) that focuses on the control task can greatly reduce our costs.

We also 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, automation system adopts the pre-training - fine-tuning model training method. That is, selecting a pre-trained model or training a model on a dataset with enough data is called pre-training; Then, the pre-trained model is fine-tuned for the concerned problem, namely audience crowd behavior recognition.

2.5.3 Hardware selection

Because of the above needs, we want to choose the most powerful MCU(master computer) 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. we also selected the camera component that comes with this MCU to enable image capture.

In addition, arduino acts as the slave computer of the automation system. arduino is easy to develop and meets the task requirements of this project.

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 Verification

3.1 Launcher system

3.1.1 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.

3.1.2 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	State
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.	Achieved

Requirements	Verification	State
1. The speed can be adjusted according to different voltages, 30 rpm under 3V and 60 rpm under 6V.	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. It can reach 0.1N.m torque.	Achieved

3.1.3 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	State
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.	Achieved

3.1.4 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	State
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.	Achieved

3.2 Gun mount system

3.2.1 Mechanic frame

The mechanical frame is used to mount the entire launcher 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.

Requirements	Verification	State
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.	achieved

3.2.2 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.

Requirements	Verification	State
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.	achieved

3.2.3 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	State
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.	achieved

3.3 Control system

TBD.

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. 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.	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.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.

3.4 Automation system

3.4.1 Algorithms and MUC computing resources

Considering the availability and timeliness of vision module, the scale of computing resources and computational complexity of MUC algorithm are required. That is, the MCU needs to complete the corresponding calculation task within the specified time.

Requirements	Verification	State
1. The model can complete the image processing on the MCU in a specified time (ideally 1 frames per second). 2. Furthermore, in terms of accuracy, we require the model to be at least usable (our standard is set to the worst-performing baseline algorithm used in the literature we cite).	Load the model into the MCU, connect the camera, and connect the MCU to the computer. Set in the code of the model, every time the MCU completes the calculation of a picture (that is, 1 frame), it records the running time of the program and returns it to the computer. Run for 10 minutes, view and calculate the returned data, and calculate the average time per frame. Possible problems and solutions: 1. If the number of images processed per second is greater than 1 frames, it is considered successful. Otherwise, we will try to compress the model again, or use another model. 2. If the performance obtained on the test set is below a certain threshold (e.g. MAE and MSE are higher than the 2016 method [2] we referenced), it is considered a failure. If that happens, we'll look at other models first, and if we still can't improve performance, we'll look at more powerful MCU.	achieved

4 Costs

4.1 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.

5 Conclusions

5.1 Accomplishments

Designed and assembled the mechanics of both the launcher and gun mount systems, successfully achieving the desired goals.

5.2 Uncertainties

TBD. We need more testing to complete this part, and we will make it up in the final version.

5.3 Ethics Consideration

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.[3]

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.[4]

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

It is important to note that due to our manufacturing process in China, we have recently re-examined the legal risks of our project in China and have come to the conclusion that one of the parts used in our manufacturing process, the constant pressure valve, may legally be considered a firearm part.[5] However, according to the latest jurisprudence, buying the parts we need from the formal way can largely avoid such legal risks. [6]

5.4 Safety Consideration

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.[7] In addition, pressure vessel maintenance and pressure detection will also be part of the design.

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