ECE 445 / ME 470

SENIOR DESIGN LABORATORY

FINAL REPORT

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# Robotic T-shirt Launching System Mark III

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# Abstract

The Mark III T-shirt Dispenser improves upon its predecessor, the Mark II, by addressing key issues of portability, safety and efficiency. Our design focus was to reduce the size and weight of the device, enhance stability, and increase the range and speed of T-shirt dispensing. The Mark III features an optimized pneumatic system for faster loading, a more stable frame, and integrated safety mechanisms to prevent accidents. Extensive testing has shown that the Mark III offers significant improvements in operability and reliability. These improvements ensure safer and more efficient operation and meet the original objectives

Key words: T-shirt launcher, Pressure, Safety, Rapid firing, Crowd counting

# Contents

# 1 Introduction

## 1.1 Background

The utilization of T-shirt launchers as a means of enhancing live event experiences emerged in the late 1980s. One notable instance occurred during Tim Derk's tenure as the San Antonio Spurs mascot, known as "Coyote," from 1983 to 2004. Derk [1], constantly striving to elevate fan engagement, explored innovative ways to augment the game-day atmosphere. Among his repertoire of antics, the distribution of free merchandise stood out. However, this gesture was constrained by the limitations of a mascot's throwing range, leaving fans in the upper bleachers feeling overlooked. In the 1990s, Derk and fellow mascots embarked on a mission to transcend these spatial barriers. Inspired by wartime innovations, particularly the Holman Projector used by British sailors in World War II, they sought to develop a more efficient means of distributing T-shirts. This led to the creation of a colossal cast-iron pipe, utilizing pneumatic principles to propel shirts to distant sections of the audience. Simultaneously, the history of T-shirt launching technology reveals a lineage rooted in wartime exigencies. The Holman Projector, initially devised to defend commercial freighter ships, employed steam from the vessel's boilers to discharge projectiles. In contemporary contexts, the evolution of "shell launchers" employs compressed gases, typically carbon dioxide, to propel various items, ranging from potatoes to paintballs and rolled-up T-shirt.

## 1.2 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 gas. In 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.

Figure 1: The ultimate T-shirt launcher

## 1.3 Visual Aid


Figure 2: Manual Mode

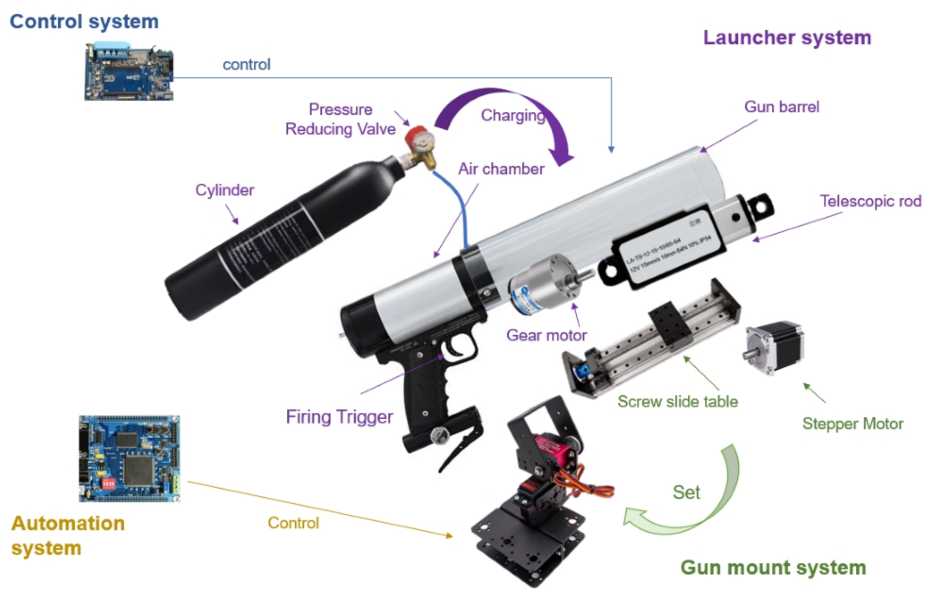
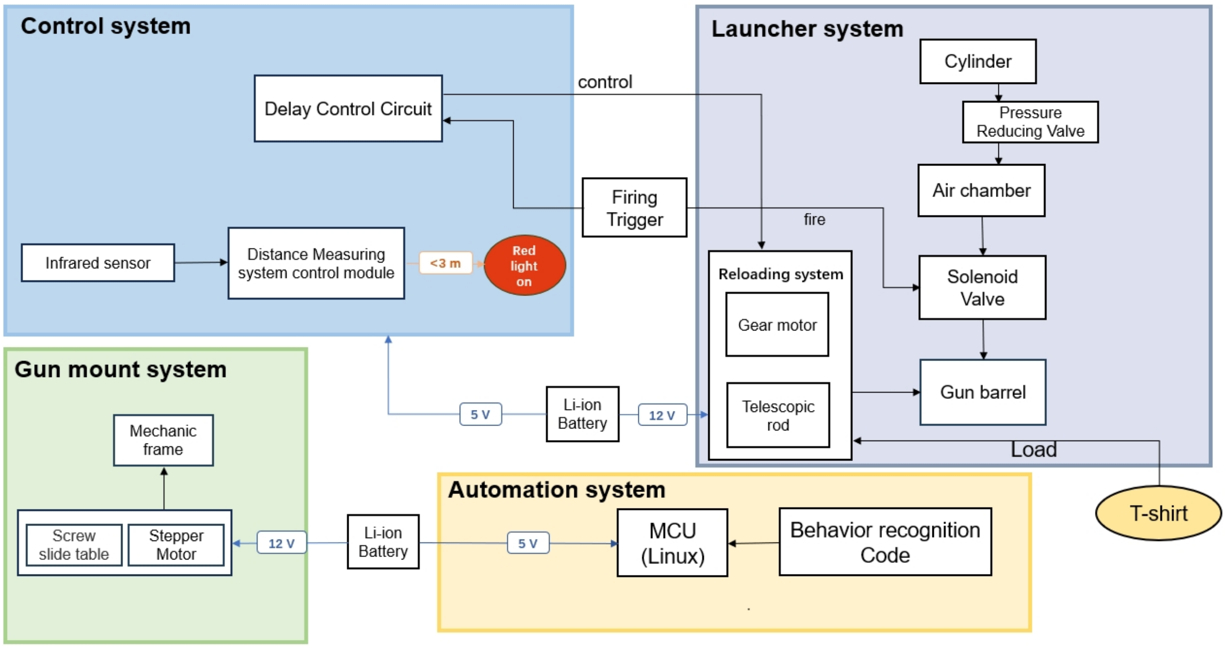



Figure 3: Automatic Mode

# 2 Design

## 2.1 Block Diagram




## 2.2 Launcher system

### 2.2.1 Design procedure

The launch system has undergone a total of three upgrades, resulting in four generations of launchers. The role of the first generation was to validate the design concept and explore its feasibility with team members. However, certain key components were missing from the first-generation model, such as the structural design of the power system and loading mechanism.

Based on its predecessor, the design of the second-generation launcher focused on validating the design concept through computer-aided design modeling. The design of the second-generation launcher focuses on the verification of the design concept through computer-aided design modeling, as well as the design of the various mechanical transmissions of the various reloading systems. Additional include reduction gears, telescoping rods, and other important components. In addition, improvements were made to the power system with the introduction of two gas cylinders and associated gas lines and constant pressure valves.

The main purpose of the development of the third-generation launcher was to fit accurately dimensioned magazine, chamber, and barrel assemblies into the modeling software, however, it did not take into account pneumatic components such as 0.25L cylinders or the fixed structure of the barometer.

Therefore, based on the third-generation design framework, we designed our final iteration, the fourth-generation launcher, through fine-grained dimensional verification. This definitive version consists of 13 3D printed parts and four acrylic cut parts. There are also a number of outsourced parts, including a PC tube metal handle. All these parts can be assembled into a fully functional launcher system using only a 10mm diameter acrylic rod with M4 size screws and nuts.

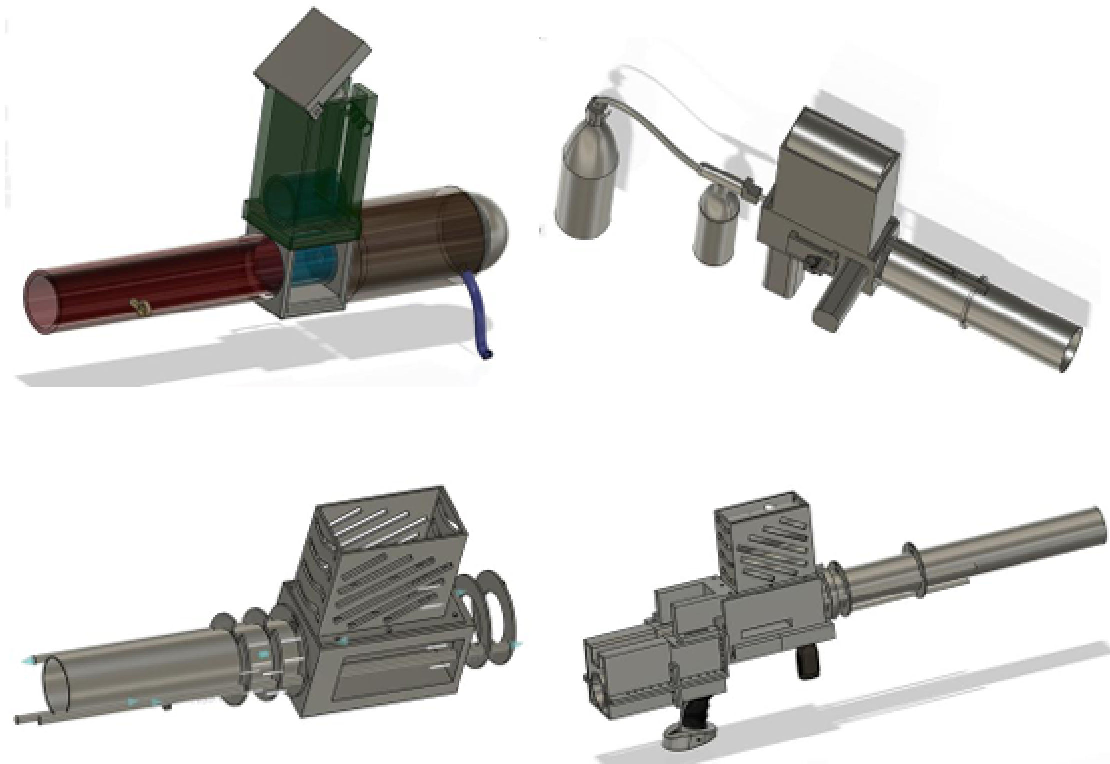


Figure 4: Iteration of launcher design

#### 2.2.2 Design details

The launcher system can be divided into three subsystems: reloading system, power system and main body structure.

#### 2.2.3 Reloading system

In the design of the reloading system, we considered whether to use the same loading mechanism as the MARK II (revolver-like rotation) or a bolt-action method like that of a sniper rifle. In the end, we chose the latter because we were concerned about the possibility of jamming, and the smoothness of loading with a rotary mechanism given the uncertainty of the accuracy of 3D printed parts.

The reloading system consists mainly of a geared motor and a telescopic rod combined with specific mechanics. The "bullet" consists of a rolled t-shirt stuffed into a cartridge case, hereafter collectively referred to as a bullet. First, one bullet is placed in the chamber and then two bullets are placed in the magazine. When the solenoid valve is opened, the T-shirt in the chamber is pushed forward by a high-speed airflow. At the same time, the gear motor on the right side of the chamber engages and rotates the gear connected to the rack and pinion mechanism. The rack and pinion mechanism pushes the empty cartridge case to the left, completing the ejection process.

At the same time, the telescopic rod extends forward, pushing the barrel out of the chamber. This prevents the T-shirt in the magazine from getting caught in the rear end of the barrel and not falling into the chamber. Once the barrel is fully extended out of the chamber, the T-shirt in the magazine falls into the chamber by gravity. Subsequently, the gear motor reverses, the rack and pinion mechanism retract, and the telescopic rod pulls back on the barrel, pushing the bullet that has fallen at the front end of the chamber to the rear end until it is completely attached to the wall, ensuring that the barrel is tightly adhered to the bullet and the chamber wall to ensure a gas-tight seal for increased firing range. This cycle is repeated for subsequent shots.

This loading system design ensures smooth and reliable T-shirt loading and ejection, enhancing the overall functionality and user experience of the robotic T-shirt firing system Mark III.

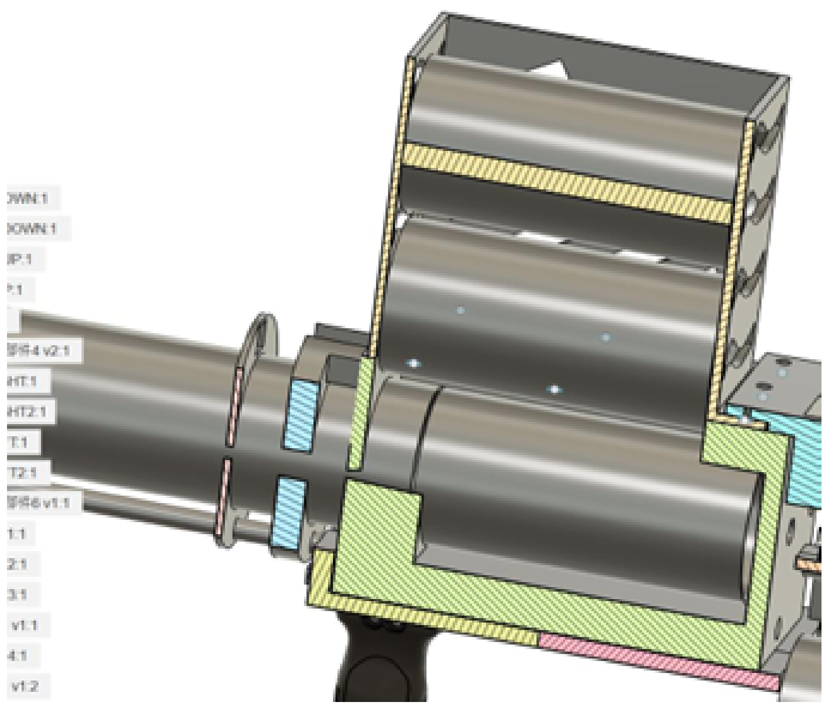


Figure 5: Reloading system design details

### 2.2.4 Power system

The power system primarily comprises a 0.45L high-pressure air cylinder, a 0.25L high-pressure air cylinder, and a pressure relief valve, cooperate with some pneumatic components.

The 0.45L high-pressure air cylinder serves as the primary storage unit for high-pressure air, which is then transferred to the 0.25L cylinder. It can withstand a maximum pressure of up to 200 atmospheres. Positioned at the rear of the gun body, the 0.25L cylinder functions as an air chamber. However, considering the characteristics of various pneumatic components, the maximum pressure it can store internally is limited to 11 atmospheres. Upon opening the electromagnetic valve, the high-pressure air inside the 0.25L cylinder is released, propelling the T-shirt for launch.

The pressure relief valve, also known as a constant pressure valve, plays a vital role in maintaining the pressure within the 0.25L cylinder. Installed at the mouth of the 0.45L high-pressure air cylinder, it regulates the pressure within the system. Connected to the 0.25L cylinder via pneumatic tubing and various pneumatic connectors, the pressure relief valve allows for precise adjustment of the pressure within the 0.25L cylinder, ranging from 0 to 11 atmospheres. The power system ensures the efficient and controlled release of compressed air, facilitating the propulsion of T-shirts during launch operations.

### 2.2.5 Main body structure

The main body structure, as depicted in the figures above, consists of the barrel, gun chamber, magazine, grip, vertical grip, and some 3D-printed fixtures and connectors. Additionally, it includes a 0.25L air cylinder inside the 3D printed parts.

The barrel serves as the conduit through which T-shirts are launched, ensuring proper trajectory and directionality. The gun chamber provides housing for the T-shirt cartridges and facilitates smooth loading and ejection processes. The magazine stores multiple T-shirt cartridges, enabling rapid and continuous firing capabilities. The grip and vertical grip offer ergonomic handling and stability during operation, enhancing user comfort and control.

3D-printed fixtures and connectors play a crucial role in securing and integrating various components within the main body structure, ensuring structural integrity and compatibility. These fixtures provide mounting points for pneumatic components, electrical connections, and accessory attachments.

The 0.25L air cylinder is positioned within the main body structure, serving as the primary air chamber for launching operations. Its compact size and high-pressure capacity contribute to the overall efficiency and performance of the launching system.

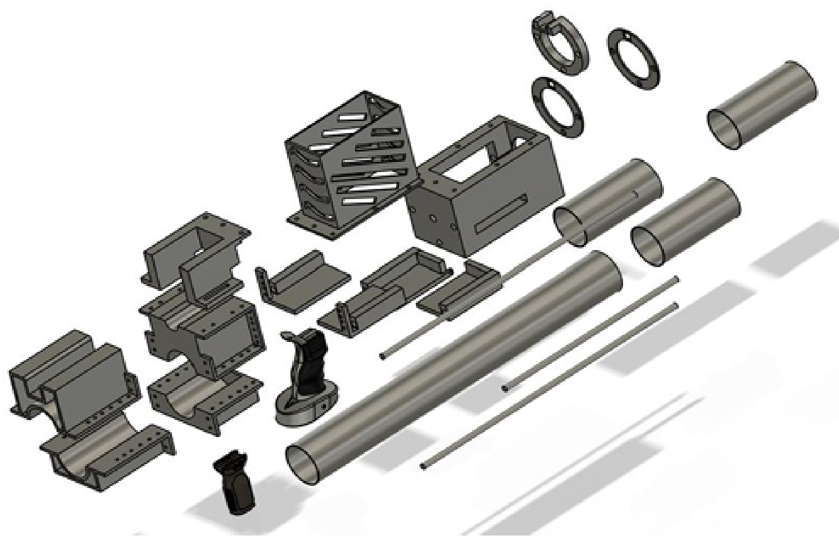


Figure 6: CAD design of the main structural components of the launcher system

## 2.3 Gun mount system

### 2.3.1 Design procedure

During the design process of our gun mount system, we explored various versions to optimize for height, footprint, and rotation, which were critical in ensuring the effectiveness and functionality of the T-shirt launcher. Initially, we considered using a 10cm support arm to connect the launcher's mount to the slider on the screw slide table. However, calculations indicated that a longer arm would improve the T-shirt shooting effect. Therefore, we opted for a 30cm long support arm and designed suitable connectors to extend the total length to about 40cm. This adjustment better aligns with our calculations and enhances the launcher's performance by providing the necessary height and stability.

In terms of footprint, we reassessed the original 100 cm x 100 cm dimensions. Taking into account the size of the transmitter, its overall harmonization and aesthetics, we reduced the footprint to 60 cm x 30 cm.

Rotation was a key element in our design concept. Initially, we chose a flat turntable as the axis of rotation. However, we found that the turntable was difficult to integrate into the gun mount structure and had poor adjustability along the Z-axis. To solve these problems, we switched to a combination of a flat bearing and a hardened optical shaft with a diameter of 10 mm for rotation. This setup allowed us to assemble a nylon-printed worm gear and worm shaft with the same module, creating a drive structure that works smoothly with the stepper motor. This configuration ensures that the gun carriage can rotate horizontally with precision and stability.

#### 2.3.2 Design details

The gun mount system is pivotal in adjusting the firing angle, ensuring firing accuracy, and maintaining stability during launcher operation. Functioning as a targeting head with two degrees of freedom, it integrates advanced components like stepper motors, precision reduction gear sets, and a durable aluminum frame construction.

This system comprises three main planar structures, each with distinct heights and functions. The top planar structure, termed the launcher placing frame, is composed of two 50cm aluminum profiles and two 15cm aluminum profiles, along with various 3D-printed connectors. Together, they provide stable support for the launcher placed on top. The middle structure features an aluminum screw slide and worm gear. The screw slide connects to the upper and lower planes via support arms and 3D-printed parts, while the worm gear, situated beneath the screw slide, facilitates rotation of both the screw slide and the launcher placing frame. Acting as the foundation, the lower planar structure consists of two 60cm aluminum profiles, four 30cm aluminum profiles, four universal wheels, stepper motors, and assorted connectors. This foundation ensures stability while allowing the gun mount to rotate and move freely.

Designed to precisely position the launcher within 30 seconds through horizontal rotation, the system's aluminum frame can withstand pressures of at least 50N. The stepper motor receives real-time electrical signals from the control system, enabling precise rotation angle adjustments from 0 to 360 degrees. Additionally, the screw slide facilitates pitch angle adjustments of the launcher placing frame from 15 to 55 degrees.

#### 2.3.3 Horizontal angle adjustment

The main function of the stepper motor is to drive the worm gear, which in turn drives the turbine. The turbine is attached to a steel rod with a diameter of 10 millimeters. Through this mechanism, the stepper motor effectively powers the entire gun mount, allowing it to rotate 360 degrees. By utilizing the power of the stepper motor, we ensure precise and reliable control over the orientation of the gun mount. This rotational capability enhances the versatility and maneuverability of the launcher.

#### 2.3.4 Pitching angle adjustment

The screw slide is a vital component used for adjusting the launcher's pitch angle. Integrated with connecting pieces, it enables precise adjustments within a range of approximately 30 to 60 degrees. This capability enhances the launcher's versatility and accuracy, ensuring optimal performance in various shooting scenarios.

### 2.4 Control system

#### 2.4.1 Function Overview

The central control system is the core control unit of the T-shirt launcher, responsible for receiving user input signals and controlling the operations of the solenoid valve and motors according to preset logical sequences. The entire system is driven by an Arduino development board and is triggered by pressing a button. The system first activates the solenoid valve to launch the T-shirt, then sequentially drives three motors with set delays to eject the shell after the T-shirt is launched. Each motor's operation time and sequence are precisely controlled to ensure the system's stability and efficiency.

#### 2.4.2 Circuit Design

In terms of circuit design, we use the Arduino development board as the main controller, connecting multiple input and output devices to realize system functions. The specific hardware connections are as follows:

Button:

The button is connected to the Arduino's digital input pin (Pin 2) and is used to initiate the launch process. The button pin is configured in INPUT PULLUP mode to avoid floating states. Solenoid Valve:

The solenoid valve is connected to the Arduino's digital output pin through a relay module, with specific pins chosen in the actual circuit. When the button press signal is received, the Arduino controls the solenoid valve to open, releasing compressed air to launch the T-shirt. Motor Control:

Motor 1:Motor 1 is connected to Arduino's Pin 11 and Pin 12, controlled via an L298N motor driver module, with speed controlled by the PWM signal from Pin 13.

Motor 2:Motor 2 is connected to Arduino's Pin 4 and Pin 5, controlled via an L298N motor driver module, with speed controlled by the PWM signal from Pin 6.

Motor 3:Motor 3 is connected to Arduino's Pin 9 and Pin 10, with power supplied by Pin 7, and speed controlled via the PWM signal from Pin 8.The power pin (Pin 7) is set to HIGH to ensure continuous power supply, guaranteeing stable voltage for Motor 3.

Power Module:Provides stable power to the Arduino, relay module, solenoid valve, and motors. The power design ensures the supply requirements of each component are met, maintaining system stability.

Relay Module:Used to drive the solenoid valve and motors. It is connected to the Arduino's digital output pins and uses relays to switch high-voltage devices. With the above hardware design and connections, the central control system can reliably receive user input and control the solenoid valve and motors according to the set logical sequences, achieving the T-shirt launch and shell ejection functions.

#### 2.4.3 Software Design

Initialization In the system initialization part, we set the modes for each pin and use interrupts to handle button press events. The main initialization steps include:

Set the button pin to input mode using INPUT PULLUP to prevent floating states. Configure the solenoid valve and motor control pins to output mode to ensure the Arduino can correctly control these external devices. Initialize the relay module to ensure the solenoid valve and motors can be correctly driven. Use interrupt functions to detect button press events, ensuring quick response. Main Program Logic The main program primarily detects the button status in a loop and triggers the T-shirt launch process when the button is pressed. The entire process is as follows:

Button Press Detection: Use the interrupt function buttonPressed to record the current time and start the motor control process when the button is pressed. Solenoid Valve Control: After the button is pressed, the solenoid valve is first activated to launch the T-shirt. Motor Control: Control the motors' start and stop based on the set delays, including: Motor 1 (Solenoid Valve): Runs forward for 0.5 seconds, then stops. Motor 2 (Telescopic Rod): Waits for 1 second, then runs forward for 2 seconds, stops for 3 seconds, and then runs in reverse for 2 seconds. Motor 3 (Gear Motor): Waits for 1 second, then runs forward for 2015 milliseconds, stops for 500 milliseconds, and then runs in reverse for 1990 milliseconds. Motor Control Functions To achieve the above logic, controlMotor2 and controlMotor3 functions are designed to specifically control the motors' forward, stop, and reverse operations, ensuring execution according to the preset time and sequence.

#### 2.4.4 Debugging and Optimization

During debugging, button bouncing caused multiple triggers. To solve this problem, the following methods were adopted:

1. Use INPUT PULLUP mode to configure the button pin, utilizing the internal pull-up resistor to reduce floating states.

2. Implement software debouncing in the code to ensure each button press triggers the event only once.

To ensure the accuracy of the delay function, the following adjustments were made:

1. Use the millis() function to record time, avoiding the delay() function that blocks the main program operation.

2. Adjust the motors' start and stop times, ensuring accurate delay operations through multiple debugging sessions.

Several Arduino code errors were encountered during development, including pin conflicts and function call errors. To resolve these issues, the following measures were taken:

1. Use the Arduino IDE's built-in debugging tools to debug the code, step by step troubleshooting and resolving errors.

2. Refer to the Arduino official documentation and community resources to understand the usage of various functions and libraries deeply.

#### 2.4.5 Summary

Through the above debugging and optimization measures, a stable and reliable central control system was ultimately realized, capable of accurately controlling the solenoid valve and motors to complete the T-shirt launch and shell ejection tasks. Detailed code implementation will be provided in the attachment for reference.

### 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. The recognition of these images will be used to decide where the automation system controls the launcher to 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.

### 2.5.2 Algorithm and model

In order to achieve the design goal, the automation system needs to be able to recognize the crowd behavior of the audience, which belongs to the crowd behavior analysis under computer vision.[1] However, the crowd behavior analysis currently available tends to target smaller numbers of people and generally requires the entire human body to appear in the picture. This is not realistic for the actual scenarios that the T-shirt launcher faces. Therefore, we convert the task to detect the number and density of the audience, that is, crowd counting tasks.

In crowd counting tasks, the mainstream practice is to use a deep learning algorithm to process the original picture into a density map, and then integrate the density map to calculate the number of people in the picture.[2] The density map generated by the deep learning algorithm used in crowd counting meets the needs of automation system to detect the crowd density of the audience.

Figure 7: Image of moderate crowd density

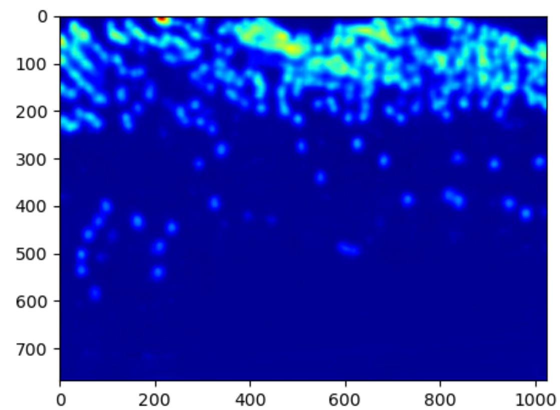



Figure 8: Corresponding density map


Figure 9: Image of high crowd density

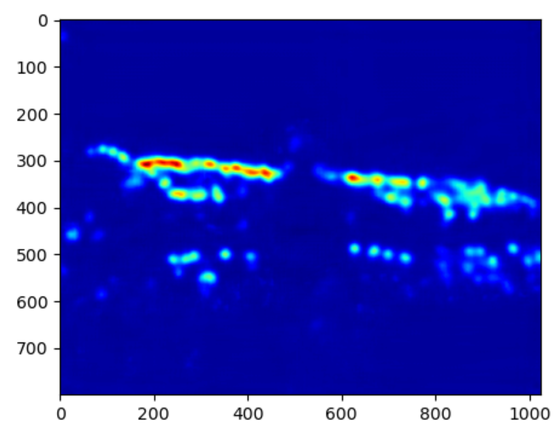



Figure 10: Corresponding density map

As shown in the above series of images, the density map generated by crowd counting


Figure 11: Meaning of density map

algorithm shows the crowd density of a certain area in the image. This information is useful as a reference for the device's launch T-shirt.

In addition, the realization of the functions of automation system has strict requirements on the computing power required by the algorithm. The design of the T-shirt launcher is based on the outdoor use scenario. Considering the actual use scenario, the automation system needs to be able to calculate in real time. Therefore, the use of cloud computing and high-performance computing equipment is inconsistent with the use scenario of the device. In the selection of algorithms and models, more consideration should be given to computing power. In short, the automation system needs to choose an algorithm with good recognition effect and relatively low computational power. The choice of algorithm will be a trade-off between performance and the required computing power.

However, some of the current SOTA models are so large relative to the computing resources of the MCU that they run too long on the MCU to even run.[3] [4] Therefore, automation system finally chose the AutoScale model[5] as the method for crowd density estimation.

The idea of image processing in this model is that when making annotations, human beings will directly mark sparse heads, while they will first enlarge and then mark heads in dense areas, and regions with different density should have different scaling coefficients. Taking into account some challenges of crowd counting, it is more beneficial for the model to learn accurately when the crowd density in a picture is similar.

Therefore, this model first predicts the image once to get the initial density map, and then binarizes the density map and analyzes the connected domain to get the dense region. For each dense region, it transmits the corresponding features of the region to the L2S module to learn a scale factor$r_d$. This scale factor is used to scale the region and then forecast it again. Finally, the density map of the secondary prediction is fused with the density map of the initial prediction to obtain the final density map.

#### 2.5.3 Data set

There are a variety of databases available for crowd behavior analysis, and some very popular databases are UCF_CC_50[6], ShanghaiTech[7], NWPU-crowd[8], and GCC[9]. However, there is no major database specifically for audience seats. Therefore, automa-


Figure 12: This image illustrates the situation discussed in AutoScale's paper: the density of crowd in different areas can vary greatly within the same image.[5]

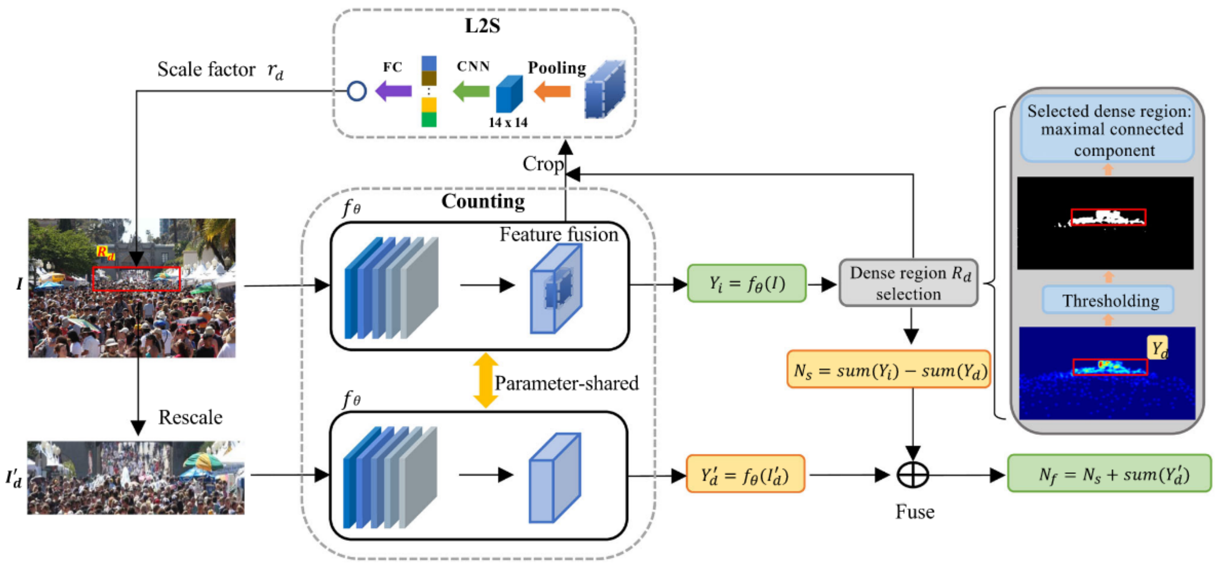



Figure 13: structure of the AutoScale model.[5]

tion system adopts the model training method of pre-training - fine-tuning. 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.

Based on the above ideas, automation system uses a model trained on the NWPU-crowd dataset. The NWPU-Crowd dataset[8] contains 5,109 common crowd images and 2,133,238 labeled entities. The sheer size makes this data integration one of the largest actual datasets. These images come from Google, Baidu, Bing, Sougou and other common search engines and pixbay, pxhere, wallhere and other image material websites. Researchers searched the sites using a series of Chinese and English keywords to find the images. In addition, this dataset also contains some negative samples, which helps to enhance the robustness of the model.

### 2.5.4 Hardware selection

In order to meet the design requirements, it is necessary to select an MCU(master computer) with as many computing resources as possible within the budget. Therefore, the design uses an MCU with an RK3568 chip and is equipped 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, the design uses arduino as the slave computer of the automation system. The development of arduino is simple and can meet the needs of this project for electromechanical control.

### 2.5.5 Algorithm deployment

In order to realize the functions of the automation system, it is necessary to deploy the model trained on the x86 architecture system (personal computer or server) to the Luban Cat 2 MCU of the ARM architecture system. The PC environment used is WSL2, the system is ubuntu20.04, and the MCU system is ubuntu20.04 (ARM). The tool used is RKNN-Toolkit2, which provides a python interface to simplify the deployment and running of the model.

The algorithm deployment process is as follows: The trained model was exported to ONNX model, and the ONNX model was converted to RKNN model using RKNN-Toolkit2 on PC. (RKNN model is the exclusive model of RK series chips). The NPU platform using the MCU chip provides the Python programming interface RKNN Toolkit Lite2 to deploy the RKNN model to the MCU.[10]

### 2.5.6 Working environment

In the automation system, we need to power the two MCU separately. The master computer requires a +5 v power supply, and in the worst case, the voltage should be between +4.5 V and +5.5 V. The slave computer requires a +9 V power supply, but in practice, it can also work using a +5 V power supply. In the worst case, the voltage should be between +5 V and +9.5 V

The automation system's power supply equipment is not waterproof, and the cameras in the system can not work in too wet an environment, because this will affect the clarity of the picture. In short, the automation system needs to work in a waterless and relatively dry environment.

## 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.

$$W_1 = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

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. $\gamma$ 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,

$$V_2 = V_1 + \pi L (\frac{d}{2})^2$$

where $\pi L(\frac{d}{2})^2$ 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.

$$P_2 = P_1 (\frac{V_1}{V_2})^\gamma$$

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.

$$\delta W = W_1 - P_a \pi L (\frac{d}{2})^2 = \frac{1}{2} m v^2$$

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,

$$v \approx 40 m/s$$

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.

The pressure regulation system ensures gas pressure within the chamber falls within 8-12 atmospheres, verified by real-time monitoring using a barometer. Pressure adjustments are made via a regulating knob until the desired range is achieved. Additionally, the system confirms that pressure returns to the set value within 30 seconds post-chamber deflation, verified by timing the stabilization of pressure at the designated level. Furthermore, system performance is assessed by inflating a sealed cylinder until reaching 30 atmospheres, with simultaneous pressure monitoring and leak checks. All requirements have been successfully met, affirming the system's functionality.

### 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 $N{\cdot}m$.

The motor's functionality is assessed based on two requirements detailed in the table. Firstly, it must adjust its speed accordingly to different voltages: 30 rpm under 3V and 60 rpm under 6V. This is confirmed by observing normal rotation using a DC power supply and voltmeter, coupled with a timed assessment ensuring the motor attains the specified speeds. Secondly, it must achieve a torque of 0.1N.m, a requirement that has been successfully met. These verifications affirm the motor's compliance with the specified criteria.

### 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.

The performance of the telescopic device is evaluated based on a single requirement outlined in the table. It must possess a 50mm telescopic stroke and achieve a telescopic speed of up to 30mm/sec at 12V, providing 30N of force. Verification involves multiple steps: confirming proper operation at 12V using a DC power supply and voltmeter, measuring the telescopic stroke with a ruler, timing a cycle of movement to ensure the speed meets specifications, and using a dynamometer to verify the provided pulling force reaches 30N. These tests confirm that the device successfully meets the specified criteria.

#### 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.

he performance requirement for the control valve is to exhibit a fast response to opening and closing at 6 volts and 10 atmospheres. This is confirmed by observing the valve's rapid response using a DC power supply, voltmeter, and development board to activate the bleed function at the specified voltage and pressure. The verification process confirms that the magnetorheological valve successfully achieves the desired fast response, meeting the specified criteria.

### 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.

The requirement for the frame is to withstand a pressure of 50N and allow for freely adjustable pitch and horizontal rotation angles. Verification involves placing a 50N metal block on the frame to check its stability, followed by manually adjusting the pitch and horizontal rotation angles to ensure stability is maintained. This test confirms that the frame successfully meets the specified criteria.

#### 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.

The requirement for the device is to have an effective stroke of up to 400mm and be positionable. Verification includes several steps: measuring the movement axis's length with a ruler to confirm it reaches 400mm, checking if the slider can be fixed in its position when the motor stops, and using a protractor to ensure the frame's pitch angle can be adjusted within 30-60 degrees as the slider moves between 0-400mm. These tests confirm that the device successfully meets the specified criteria.

#### 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.

The requirement for the stepper motor is to operate normally at 12V and provide 0.2N.m of torque. Verification involves using a DC power supply and voltmeter to confirm normal operation at 12V and using a torque meter to ensure that the motor can provide a maximum torque of 0.2N*m under this voltage. These tests confirm that the stepper motor successfully meets the specified criteria.

## 3.3 Control system

The control system was completed with the integration of the deceleration motor, solenoid valve, and telescopic rod. This advancement improved the precision and efficiency of the system's operations, ensuring smoother mechanical movements and enhanced functionality.

The device is required to meet specific criteria outlined in the table. Firstly, it must feature a delay circuit within the PCB board, driven by a 4.5V to 5.5V power supply, providing a +-12V signal to drive the telescopic rod module, with a minimum interval between the signals of at least 5 seconds. Secondly, it should incorporate an infrared ranging system, powered by a 5V supply, triggering an alarm when obstacles, including people, human limbs, or larger objects, are detected within 3 meters.

Verification entails several steps: ensuring proper operation within the specified voltage range and signal provision, confirming the delay circuit's timing exceeds 5 seconds, and validating the infrared system's functionality by detecting obstacles within the prescribed range.

These tests confirm that the device successfully meets the specified criteria for both requirements.

## 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.

The model must fulfill two key requirements: completing image processing on the MCU within a specified time (ideally 1 frame per second), and achieving accuracy at least on par with our baseline algorithm, as set by the worst-performing baseline algorithm cited in our literature.

Verification involves loading the model into the MCU, connecting the camera, and linking the MCU to a computer. In the model's code, each time the MCU finishes processing an image (i.e., 1 frame), it records the program's runtime and sends it to the computer. Over a 10-minute period, data is collected, and the average time per frame is calculated.

For assessing speed, if the processing rate exceeds 1 frame per second, it is deemed successful; otherwise, options include model compression or using an alternate model. Regarding accuracy, if performance falls below a predefined threshold (e.g., higher MAE and MSE compared to the 2016 method cited), it's considered a failure. In such cases, alternative models are explored initially, followed by consideration of more powerful MCUs if performance fails to improve.

These tests confirm that the model successfully meets both speed and accuracy requirements.

# 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 | 1745RMB |

All this yields a total development cost of $57866.

# 5 Conclusions

## 5.1 Accomplishments

To summarize our accomplishment, the Robotic T-shirt Launching System Mark III project has achieved most of its stated goals. Our primary goal was to enhance the functionality and usability of the previous model. The system now meets the expected standards: it can fire three T-shirts in a row at 60-second intervals, meeting the requirements of the project when it was originally built.In addition, with the 0.45-liter tank pressurized to 50 atmospheres, we can achieve up to eight launches, while the tank's maximum pressurization capacity of 200 atmospheres allows for more than 20 consecutive launches under ideal conditions.

Additionally, the size and weight of the device have been significantly reduced, with a weight of about 5 kg and a size of about 1 meter. The optimization of weight and size facilitates one-handed operation and improves ease of use and portability.

One of the most important achievements is the simplification of the operating system. The entire launch sequence can be initiated autonomously by simply pulling the trigger. This includes the processes of firing, ejecting, loading, chambering and re-pressurizing, enabling the user to easily perform operational use.

In addition, while the frame system currently relies on human judgment of orientation for control adjustments due to limitations of the sensor and camera suite, it is capable of precise control through computer-aided operation. Utilizing this feature, the operator can manipulate the gun mount system to adjust the elevation and horizontal rotation angles for aiming and orientation by inputting commands to the computer, thus ensuring flexibility and applicability in real-world usage scenarios.

## 5.2 Uncertainties

Acknowledging the potential uncertainties in our design is crucial for ensuring its accuracy and reliability. One important factor is the variable character of the 3D printing process, which can lead to small deviations in part dimensions. While we strive for accuracy in our designs, these deviations can affect the fit and function of the assembled part. Another factor is the strength of the PLA material, especially if the fill level is not high, this may result in lower performance of the printed structure, especially for components serving as connectors or fixtures on the gun mount. Under significant external forces, such as recoil or impact, these printed parts may be prone to damage, compromising stability and functionality.

Beyond the challenges posed by 3D printing, the reliability of electrical components, including motors and sensors, presents another area of concern. For instance, within the telescopic rod, a gear motor drives the extension and retraction mechanism. At the top of the gear motor is a set of small gears arranged to form a reduction gear assembly. Under high-intensity operation, these gears may experience wear and tear, leading to issues such as gear jamming and motor stalling. Such malfunctions could impact the overall performance and functionality of the system.

The reloading system also has a critical issue that the absence of a baffle in the gun chamber causes bullets to slide down when the launcher is tilted, hindering the basic function of launching T-shirts effectively.Moreover, the operation of sensors integrated into the design could also be susceptible to environmental factors and wear over time. Dust accumulation, exposure to moisture, or mechanical stresses could affect sensor accuracy and responsiveness, potentially compromising the system's reliability.

## 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.[11]

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.[12]

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.[13] However, according to the latest jurisprudence, buying the parts we need from the formal way can largely avoid such legal risks. [14]

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

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# Appendix A Verification form

| 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.<br><br>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.<br><br>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.<br><br>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.<br>B. Timed for one minute, counting the number of motor revolutions and whether it can reach 30rpm at 3V and 60rpm at 6V.<br>2. It can reach 0.1N.m torque. | Achieved |

| 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.<br>B. Use a ruler to measure whether a cycle of motion travels up to 50mm.<br>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.<br>D. Use a dynamometer to test whether the pulling force provided can reach 30N. | Achieved |

| 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 |

| 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 |

| 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.<br><br>B. Observe whether the slider can stay and be fixed in the current position when the motor stops<br><br>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 |

| 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.<br><br>B. Use a torque meter to check if the maximum torque that the stepper motor can provide under 12V is 0.2N*m. | achieved |

| Requirements | Verification | State |
|---|---|---|
| 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.<br><br>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.<br><br>B. Using a stopwatch to measure the delay time of the delay circuit several times to ensure that it is greater than 5 seconds.<br><br>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. | 1.achieved |

| Requirements | Verification | State |
|---|---|---|
| 1. The model can complete the image processing on the MCU in a specified time (ideally 1 frames per second).<br>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.<br>Possible problems and solutions:<br>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.<br>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 **dataset** 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 |

# Appendix B Code

Replace val.py in AutoScale_regression with the following code to output the density plot

```
def validate_test(Pre_data, model, rate_model, args):
    print ('begin test')
    test_loader = torch.utils.data.DataLoader(
        dataset.listDataset(Pre_data, args.task_id,
                            shuffle=False,
                            transform=transforms.Compose([
                            transforms.ToTensor(), transforms.Normalize(mean
                                =[0.485, 0.456, 0.406],
                             std=[0.229, 0.224, 0.225]),
                            ]), train=False),
        batch_size=args.batch_size)

    model.eval()

    mae = 0
    mse = 0
    original_mae = 0
    visi = []

    for i, (img,target,kpoint,fname,sigma_map) in enumerate(test_loader):

        img = img.cuda()
        target = target.cuda()

        d2, d3, d4, d5, d6, fs = model(img, target, refine_flag=True)

        density_map = d6.data.cpu().numpy()
        original_count = density_map.sum()
        original_density = d6
        [x, y, w, h] = findmaxcontours(density_map, fname, args)


        # density_map is a four-dimensional array of shapes (1, 1, 768, 1024)
        # We select the data for the first batch element and the first channel
        density_map_to_visualize = density_map[0, 0]
        print(density_map_to_visualize.shape)
        # Use   imshow   to visualize this two-dimensional array
        plt.imshow(density_map_to_visualize, cmap='jet')  # Generate a heat
            map
        plt.colorbar()  # Display color bar
        plt.show()  # Display image


        rate_feature = F.adaptive_avg_pool2d(fs[:, :, y:(y + h), x:(x + w)],
            (14, 14))
        rate = rate_model(rate_feature).clamp_(0.5, 9)
        rate = torch.sqrt(rate)

```

```python
        if (float(w * h) / (img.size(2) * img.size(3))) > args.area_threshold:

            img_pros = img[:, :, y:(y + h), x:(x + w)]

            img_transed = F.upsample_bilinear(img_pros, scale_factor=rate.item())

            pt2d = target_transform(kpoint, rate)
            target_choose = gt_transform(pt2d, [x, y, w, h], rate.item())

            # target_choose = gaussian_filter(target_choose, 6)
            # plt.imshow(target_choose)

            # with h5py.File(img_path.replace('images', 'gt_density_map').replace('jpg','h5'), 'w') as hf:
            #     hf['density_map'] = k # Store the density map
            #     #hf['kpoint'] = kpoint
            #     #hf['sigma_map'] = sigma_map

            target_choose = torch.from_numpy(target_choose).type(torch.FloatTensor).unsqueeze(0)

            dd2, dd3, dd4, dd5, dd6 = model(img_transed, target_choose, refine_flag=False)

            # dd6[dd6<0]=0
            temp = dd6.data.cpu().numpy().sum()
            original_density[:, :, y:(y + h), x:(x + w)] = 0
            count = original_density.data.cpu().numpy().sum() + temp

        else:
            count = d6.data.cpu().numpy().sum()

        mae += abs(count - target.data.cpu().numpy().sum())
        mse += abs(count - target.data.cpu().numpy().sum()) * abs(count - target.data.cpu().numpy().sum())

    mae = mae / len(test_loader)
    mse = math.sqrt(mse/len(test_loader))


    return mae, original_mae, visi
```