[Robotic T-shirt Launching System Mark II]

By

[Hao ding haod3@]
[Moyang Guo moyangg2@]
[Yixiang Guo yg16@]
[Ziyu xiao ziyux2@]
illinois.edu

TA: Qi Wang

Design Document for ECE 445 / ME 470, Senior Design, Spring 2023

March 24, 2023

Project No. 06

1. Introduction

The problem identified is the limitations of the previous T-shirt launcher design, which was a single-shot launcher that required manual reloading and could only adjust the angle and direction automatically. This design limited the efficiency and effectiveness of the launcher, making it unsuitable for certain scenarios.

1.1 Objective

The previous class completed Mark1 of the T-shirt launcher, but the professor was not satisfied with the results. Mark1 is mainly composed of two parts, one is the bottom platform, used to adjust the direction and angle of the launch; The second is the launcher, which is powered by a high-pressure gas tank to achieve the purpose of launching the T-shirt. However, first, the size and weight of the launcher meant that the entire device could only be moved on a cart, rather than held in hand; Second, each launch requires reloading and inflating the tank, making the launch interval very long. In addition, the launcher does not have the ability to automatically recognize moving objects and adjust the direction of fire. Therefore, our goal is to improve the T-shirt launcher to solve these problems. We will reduce the size and weight of the device as much as possible to accommodate the handheld function, while allowing multiple launches in a short period of time. In addition, a detection system is added to realize the automatic aiming function through the linkage with the platform.

1.2 Background

The main problem of the previous generation of T-shirt launcher was that they used over-sized and over-thick barrel and tank. In fact, it didn't need that much air and pressure to launch the T-shirt. Too large launching mechanism not only increases the weight of the system, but also leads to a large load on the platform and has to use a larger motor, which eventually leads to the excessive size and weight.
So we focused on reducing the size and weight of each system, which would also free up space for the detection and reloading mechanism to solve all the problems.

1.3 High-Level requirements list

a. Functionality: The launcher should be able to launch T-shirts accurately and consistently at a controlled angle and velocity. The system should be able to handle multiple T-shirts without the need for manual reloading, and the entire launch process and angle control should be initiated and controlled by a single button.

b. Airtight and Adequate Air Pressure: The launcher's air channel should have high airtightness and be able to generate sufficient air pressure to launch T-shirts effectively. The air pressure should be able to be adjusted and controlled to suit different launch scenarios.

c. Automation: The loading system should be fully automated, with T-shirts being automatically loaded into the air chamber without the need for manual intervention. The loading mechanism should be designed to be reliable and efficient, and the electrical control system should be able to manage the entire process automatically.

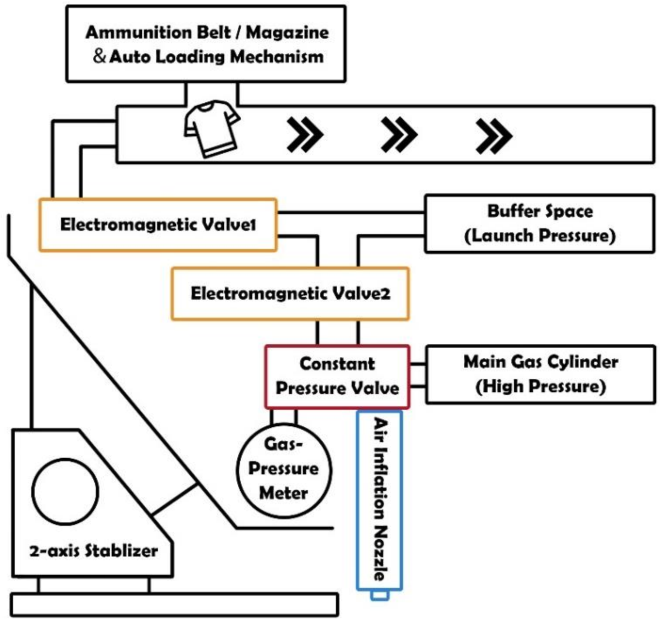
d. Portability: Compared to the previous version of the launcher which was bulky, we will pay attention to limiting the weight and size of the entire launcher, making it capable of being carried by an average person and easy to operate.

2. Design

- Solution

Our proposed solution is the development of the Robotic T-shirt Launcher Mark II, which is an advanced and fully automated system that addresses the limitations of the previous model. The launcher will be able to launch multiple T-shirts without manual reloading, and it will include more advanced features such as the ability to adjust the trajectory of the launch. Additionally, we plan to build it into a wearable device that could be carried on our shoulders, allowing for greater mobility and flexibility in use.

The launcher will consist of various components that work together to provide a powerful and reliable weapon system. The automatic loading system will be designed to be fully automated without the need for manual intervention. The control system will be responsible for managing the various components of the system, including the electromagnetic valves that control the airflow, the actuator controllers for the loading mechanism, and the gimbal controller for targeting. Overall, our proposed solution will provide a more efficient, reliable, and advanced launcher system that meets the needs of users.



Visual Aid

- Explanation of visual aid

Our T-shirt launcher is a complex system consisting of several interconnected components that work together to provide a powerful and reliable weapon system. At the heart of the system is the main gas cylinder, which contains high-pressure gas that provides the necessary power and pressure to shoot out the T-shirt. The gas pressure is monitored by the gas-pressure meter to ensure the launcher is operating within safe limits.

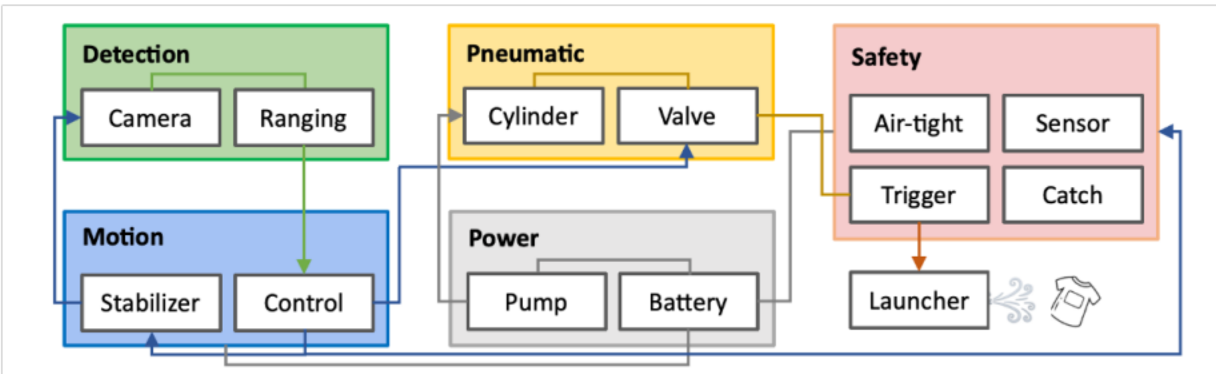
To control the release of gas, we use an electromagnetic valve, which opens and closes based on signals from the control system. This valve is an essential component of the launcher, as it enables us to precisely control the timing and amount of gas released, ensuring accurate targeting of the T-shirt.

Before the gas is released, it is stored in a buffer space, which serves to maintain a constant pressure and improve the consistency of the launcher's performance. To ensure the pressure is always within safe limits, we use a constant pressure valve that regulates the pressure inside the buffer space.

The ammunition belt and auto-loading mechanism work together to automatically load T-shirts into the launcher's barrel. This feature allows the system to launch multiple T-shirts without manual reloading, increasing its effectiveness in crowd control situations. The bottom stabilizer ensures that the launcher remains stable during firing, further improving its accuracy and reliability.

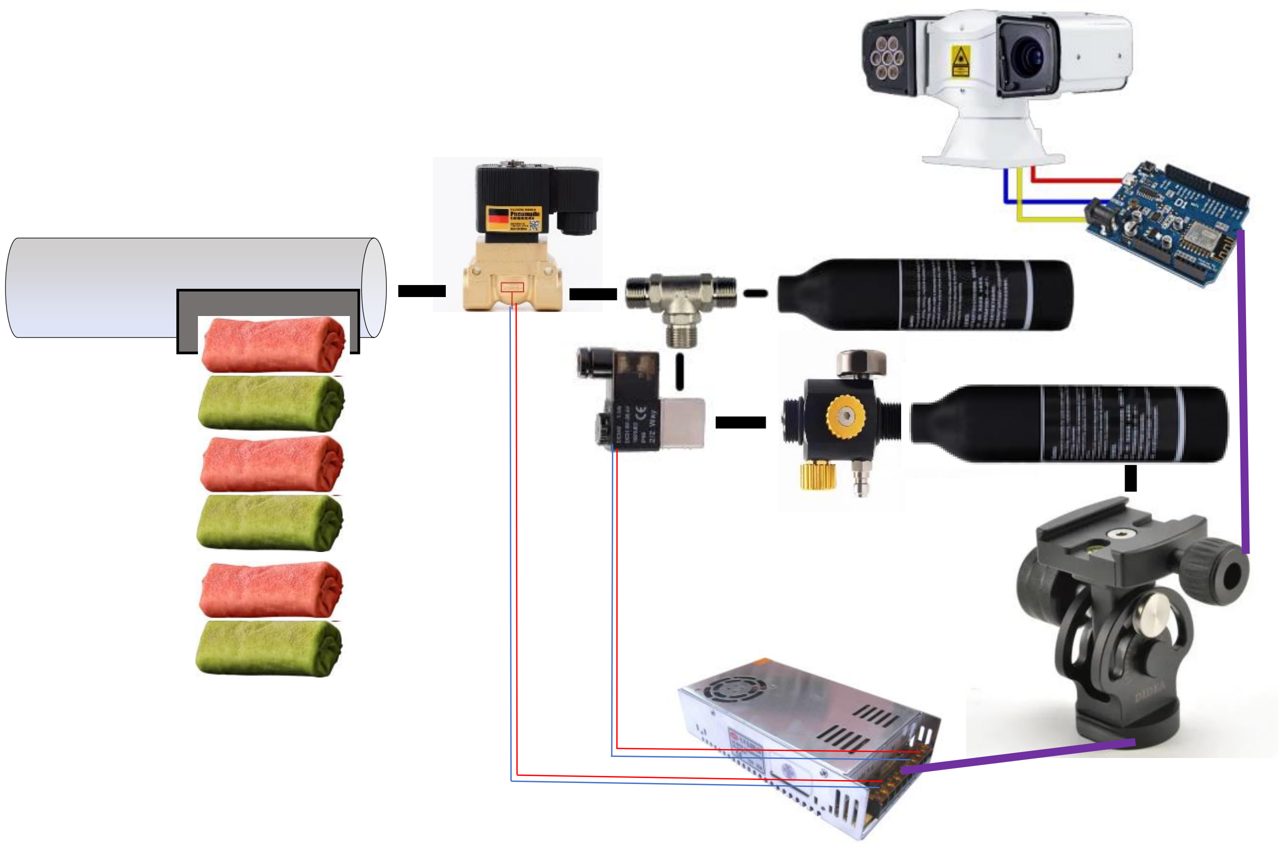
Finally, the air inflation nozzle provides an easy way to inflate the T-shirts before launching, while also ensuring they are firmly secured in the barrel. With all these components working together seamlessly, our T-shirt launcher is an advanced weapon system that can deliver rapid and effective crowd control.

- Block Diagram



The automatic system is highly valued in our design block diagram, which aims to satisfy the high-level requirements. For the transmission system, we will test various parts made of different materials and sizes, different assembly methods, etc., in order to minimize the size and weight as much as possible while ensuring pressure and air tightness. The loading design and the gimbal section will realize automatic loading and aiming under the control of the central control unit Arduino board.

- Physical Design



Explanation of physical design

The physical diagram of our T-shirt launcher consists of several interconnected components that work together to provide a powerful and reliable weapon system. The Ammunition belt and Auto Loading system is responsible for providing a steady flow of ammunition to the system. The Electromagnetic Valve block controls the airflow and allows for precise regulation of the launching pressure. The Gas Cylinder block provides high-pressure gas that powers the system. The Bottom Stabilizer block ensures the stability of the launcher during the launch process.

The Arduino board is the central control unit of the system, responsible for managing the various components of the system, including the Electromagnetic Valve block, the Stepping Motor block, and the Camera block. The handle controller allows for human interaction with the system, providing manual control over the launching direction and switch. The Camera block is responsible for automatically detecting and tracking moving targets, allowing for effective engagement.

Finally, the Motor is responsible for controlling the launching direction and launching switch, ensuring accurate and effective targeting of the enemy. Together, these blocks form a robust and efficient T-shirt launcher that can handle a variety of situations with ease.

2.1 Launcher

The T-shirt needs a barrel to be fired. The length of the barrel should be moderate to maximize the T-shirt's exit velocity and limit the size of the system; The barrel should be of appropriate material and thickness to withstand adequate gas pressure and minimize weight. Through the test, we chose 63mm diameter, 5mm wall thickness, 400mm long PVC water pipe to act as the gun barrel, which can withstand the maximum pressure of 1MPA, and achieve the comprehensive optimal result of size and exit velocity.

Requirement	Verification
A barrel can withstand a minimum pressure of 0.8MPa and a length capable of achieving an overall optimal result of size and exit velocity	A. Directly use a 1MPa gas tank to launch the T-shirt, and observe whether the gun barrel is damaged after several experiments; B. Test the T-shirt exit velocity of different lengths of barrel and compare whether the selected length is the best choice.

2.2 Safety

Sufficient air tightness is required between each connection to ensure sufficient driving pressure; "Trigger" is a high pressure gas solenoid valve, by the control panel to give signals to control the launch; Barometers are installed throughout the system for real-time detection.

2.2.1 Air-tight

Since the T-shirt is fired by a high pressure, the air tightness of the system directly affects the final performance of the launcher. We use variety of methods to ensure the air tightness of each part, including the use of sealing rings, precision metal parts, thread seal tape, metal cable ties, PLA glue and so on, to achieve the air tightness of the connection between various parts.

Requirement	Verification
The air tightness of the whole system should be high enough	A. Keep each gas tank sealed after it is inflated to the rated pressure, and measure whether the rate of pressure drop is low enough; B. Place connectors, barrels, etc. into the water under the inflated state to check whether there are bubbles.

2.2.2 Trigger

The final launch of the T-shirt requires a "trigger" to control. The trigger must be fired quickly enough and allow a large amount of high-pressure gas to pass through the valve instantaneously. So we used a high-flux solenoid valve to act as the trigger.

Requirement	Verification
Instantaneous excitation, large flux.	A. Test whether the time interval between receiving the signal and fully opening the solenoid valve is within an acceptable range; B. Test the discharge speed of the solenoid valve for the 1MPA gas tank.

2.2.3 Sensor

In order to monitor the air pressure in the system, the air pressure sensor is necessary. We have added barometers to each tank and to the important connectors.

Requirement	Verification
Real-time air pressure detection	A. By switching on and off various valves, verify whether the barometers of the same pressure show the same value, to judge whether the barometer is working accurately.

2.3 Pneumatic

The basic principle of the launcher is to use high-pressure gas to push the T-shirt through a limited cavity, and continuous firing requires that we are able to supply high-pressure gas for multiple times during short time interval. Therefore, we need several gas tanks to store high pressure gas, and the application of various air valves to achieve constant pressure, constant current, input, output and other functions

2.3.1 Cylinder

To achieve continuous launch, we will need multiple high-pressure gas outputs for a short time, so our design structure is multi-barrels launch controlled by multiple sub-cylinders. To make it easier to inflate, we also added a finished cylinder that can withstand great pressure to serve as the main cylinder to supply gas to each sub-cylinder. Since the sub-cylinder needs to bear very little pressure, we will use our homemade products to reduce weight.

Requirement	Verification
A variety of cylinders capable of bearing sufficient pressure	A. Inflate each cylinder to its rated pressure. Repeat the operation, always pay attention to the cylinder deformation and damage. B. The rated pressure of finished gas tank can be queried; Homemade gas tank can query the rated pressure of the material water pipe. Check

	whether the rated air pressure of both is greater than or equal to the required air pressure;

2.3.2 Valve

The launcher needs many air valves to achieve constant pressure, constant current, input, output and other functions. The solenoid valve as "trigger" has been mentioned in the Safety Part. The main and sub-cylinders also need to be connected to the valve, so that the main cylinder can automatically inflate the empty sub-cylinder to the rated pressure. We decided to use an integrated constant pressure valve and a one-way valve to achieve this.

Requirement	Verification
One-way valve that automatically inflates to rated pressure.	A. Connect the main and sub-cylinders with the integrated valve, inflate the main gas cylinder to the rated pressure, and then open the valve to determine whether the sub-cylinder can be inflated to the rated pressure and measure the required time.

2.4 Power

High pressure gas needs an air pump to generate, while electric control systems need batteries to provide power.

2.4.1 Pump

As mentioned above, the air pump will be used to inflate the main cylinder, so we use a high-pressure air pump with an inflation pressure of more than 5MPa to achieve the rated pressure of the main cylinder and reduce the inflation time.

Requirement	Verification
The inflation pressure exceeds 5MPa, and the inflation speed is fast.	A. Use the air pump to inflate the main gas cylinder, observe whether the barometer can reach 5MPa, and determine whether the inflation time is within the acceptable range.

2.4.2 Battery

Battery is used to support electronic power to the other system, now the battery refers to a non-portable version, we will try to make it mobile in the future.

Requirement	Verification
The battery should be able to power the launch and relaunch of the T-shirt.	A. Fully charge the battery and check one time release, if the T-shirt is launched successfully then it is working correctly.

2.5 Motion

Including the tripod head and the control board (Arduino). The control board accepts parameters from multiple sensors and sends signals to the tripod head to redirect the launcher, by which we can change the launching direction of the T-shirt.

Requirement	Verification
The tripod head is under control by the control board by wired signals. And the motion in response should not be delayed.	A. Start the whole system, control the motion by sending direction signals from a joystick, the tripod head should move accordingly.

2.6 Detection

It is composed of multiple sensors to detect the gas pressure and wired signals. It sends these signals to the control board for reference.

Requirement	Verification
All sensors are working correctly and sending signals to the control board in time.	A. Start the system and read the sent signals from the Arduino IDE which monitors the output, if every sensor works correctly then we can see the corresponding signals.

2.7 Software

It provides the fundamental support to generalize and cooperate with every system. In this program, the coding language is C for Arduino programming. The framework is mainly designed for accepting, processing, and sending signals.

Requirement	Verification
The software program must support all systems to work correctly, it can process each signal correctly and make sure all requests are processed and responded to in time.	A. The program will not exit incorrectly or yield any bug. All instructions are executed in the right manner.

2.8 [SUBSYSTEM NAME] Discussion

The power system of the block diagram consists of an air pump, air cylinder, quick exhaust valve, and connecting elements. These components are responsible for providing the necessary power and pressure to the system to shoot out the bullet. The air pump is responsible for pressurizing the air cylinder, which stores the compressed air needed to launch the bullet. The quick exhaust valve is responsible for rapidly releasing the compressed air, allowing the bullet to be launched at high speed. The connecting elements are responsible for joining the components together, creating a complete power system.

The control system is responsible for managing the various components of the system, including the electromagnetic valves that control the airflow, the actuator controllers for the loading mechanism, and the gimbal controller for targeting. The control system consists of a gimbal controller, actuator controllers, electromagnetic valves, and a microcontroller such as an Arduino. The gimbal controller is responsible for aiming the launcher, while the actuator controllers manage the loading mechanism. The electromagnetic valves control the airflow, regulating the compressed air to launch the bullet. The microcontroller acts as the central control unit that manages all the components, ensuring they work together efficiently.

The detection system consists of a camera, aim assist, rangefinder, and detection software. The camera is used to provide visual feedback to the user, enabling them to aim and lock onto targets effectively. The aim assist system is responsible for helping the user aim the launcher. The rangefinder measures the distance between the user and the target, providing crucial information for accurate targeting. The detection software enables advanced features such as automatic firing, angle adjustment, and target recognition lockon, allowing the user to engage targets effectively. The human-machine interface can be used for advanced users to provide intuitive interaction with the system.

The secure system of the block diagram consists of a one-way valve, airtightness, and pressure sensors. The one-way valve ensures the compressed air only flows in one direction, preventing it from flowing back into the air pump. The airtightness of the system is critical to ensure that no air leaks from the system and that the pressure remains consistent. Pressure sensors are used to monitor the air pressure, ensuring it remains within safe operating limits.

The pneumatic system of the block diagram consists of an air cylinder and a pressure release valve. The air cylinder stores the compressed air needed to launch the bullet, while the pressure release valve is used to vent the air cylinder, allowing it to be reloaded safely. The pneumatic system is an essential part of the launcher, responsible for providing the necessary power to launch the bullet.

2.9 Tolerance Analysis

One aspect of the Robotic T-shirt Launcher Mark II that poses a risk to successful completion of the project is the air channel. The airtightness of the air channel is crucial for generating sufficient air pressure to launch T-shirts effectively. To ensure that the air channel is airtight, we will conduct a tolerance analysis to determine the allowable tolerances for the various components of the air channel.

For the launcher, the most important calculation is whether the shooting distance of the T-shirt is far enough. It is known that the length of the barrel is L1=40cm, and a self-made air cylinder with a length of L2=30cm is connected to its bottom. The diameter of the air cylinder and the barrel is d=76mm, and the pressure in the air cylinder is P1=1MPa at first. The volume of high-pressure air in the cylinder is:

$$V1 = L2 \cdot \pi \cdot (d/4)^2 = 0.00136m^3$$

The volume after the high-pressure gas expands:

$$V2 = (L1 + L2) \cdot \pi \cdot (d/4)^2 = 0.0032m^3$$

Assuming the adiabatic index of air is =1.4, the resulting pressure of the gas after expansion is:

$$P2 = P1 \cdot (V1/V2)^\gamma = 0.305MPa$$

As the launch time is very short, we assume that there is no heat exchange between the high-pressure gas and the outside world, that is, adiabatic expansion. It can be known that the gas does work:

$$W1 = (P1V1 - P2V2)/(\gamma - 1) = 960J$$

Work done by atmospheric pressure:

$$W2 = P \cdot A \cdot L1 = 181J$$

The mass of the T-shirt was measured to be approximately 250g. Assuming a frictional force of 20N during the motion of the T-shirt inside the barrel, the exit velocity of the T-shirt can be calculated using the kinetic energy formula:

$$1/2mU^2 = W1 - W2 - f \cdot L1$$

$$U \approx 79m/s$$

This exit velocity is found to be very high, which means that if the air tightness of the device is not too poor, the shooting range of the T-shirt is long enough.

3. Cost and Schedule

3.1 Cost Analysis

According to the U.S. Bureau of Labor Statistics, the wage is around $28.00 per hour for entry-level positions,[1] so our fixed development costs are estimated to be $28/hour, 8 hours/week for 4 people. We consider approximately 60% of our final design in this semester (16 weeks):

$$4 \times \frac{28}{hr} \times \frac{8hr}{wk} \times \frac{16wks}{0.6} \times 2.5 = 59733\ (\$)$$

Part	Cost (Prototype)	Cost (Bulk)
Integrated Constant Pressure Valve (Yi Xin, #1)	238RMB	238RMB
High-Pressure Solenoid Valve (HIGHEND, #1)	150RMB	150RMB
Gas Cylinder (Cong FA, #2)	142RMB	142RMB
High-Pressure Air Pump (Ji Feng, #1)	123RMB	123RMB
Pneumatic Joint (Hu Bang, Includes all required sizes and models)	94RMB	20RMB
Water Pipes and Related Accessories (Hui Huang, Various sizes)	158RMB	52RMB
Arduino board + Handle controller (ELECFANS ＆ SONY, #1)	240 RMB	240RMB
Stepping Motor (Xing, #1)	70 RMB	70RMB

Total	1215RMB	1035RMB

All this yields a total development cost of $59880.

3.2 Schedule

Week number	M Team – Yixiang & Hao	E Team – Ziyu & Moyang
6	Finish the experiment of power needed.	Know how to control actuators.
7	Establish buffer room, Test Pressure room.	Test and find the best electromagnetic valve.
8	Finish the single shot system.	Finish the single shot system.
9	Design the loading system.	Design the stabilizer system.
10	Build the loading system. Build the stabilizer system.	Build the stabilizer system. Finish structure of control system.
11	Build and test of loading system.	Build and test of loading system.
12	Integrate all the system together.	Integrate all the system together.
13	Debug and decorate.	Debug and decorate.
14	Debug and decorate.	Debug and decorate.

4. Discussion of Ethics and Safety

There are several potential safety hazards in our project. The primary concern is the risk of high-pressure gas cylinder explosion. We have researched the relevant information for both purchased and self-made gas cylinders and have ensured that they operate within their rated pressure limits. We have also conducted multiple tests to verify their safety.

Secondly, shooting T-shirts can also pose a risk to people and property. We promise to conduct every experiment in an open and unobstructed area and ensure that the launch direction is not aimed at specific individuals or objects to avoid accidents.

The electrical part, involving circuit boards, wire soldering, etc., will be completed in the school's laboratory. We have attended lab safety training to learn how to use this equipment safely and avoid risks.

Our project is to develop a launcher, which may pose some danger. However, we will follow the first article of the IEEE Code of Ethics, which is “to hold paramount the safety, health, and welfare of the public, and strive to comply with ethical design and sustainable development practices...” [4] we will ensure that the launcher is designed with safety in mind. This will include incorporating safety mechanisms such as emergency stop buttons and implementing additional components to measure critical values such as ga tightness to prevent gas leaks. In addition, we will consider potential ethical issues that may arise from the misuse of the launcher. The ACM Code of Ethics states that professionals should be mindful of the potential impact of their work on society and take steps to minimize negative consequences.

We will make the launcher more suitable for entertainment and research purposes, and not cause harm to others.

We will also review state and federal regulations, industry standards, and campus policies to ensure that our design meets all applicable safety and regulatory standards. We will conduct thorough testing and ensure that the launcher is safe for use by both operators and bystanders.

References

1. United States Department of Labor 2021, U.S. BUREAU OF LABOR STATISTICS , United States Department of Labor, accessed 23 March 2023, <https://www.bls.gov/oes/current/oes172071.htm#st>

2. Arid, G., Makadir, I., Naji, A., Chergui, M., & Elghorba, M. (2015). Comparative study of the mechanical behavior of polymer materials: between ABS and PVC. *The International Journal Of Engineering And Science (IJES)*, 4(4), 55-60. < https://www.theijes.com/papers/v4-i4/Version-2/H0442055060.pdf>

3. Rudawska, A., Abdel Wahab, M., Müller, M., & Stančeková, D. (2022). Mechanical Properties and Leak-Tightness of Polymeric Pipe Adhesive Joints. *Applied Mechanics*, 3(1), 64-77. https://doi.org/10.3390/applmech3010004

4. Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 7- April-2016].