MTE100 Project Interim Design Report

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Group 865

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1. Abstract

The design solution repeatedly surveys a defined area, detects any intruders approaching the user, and launches a projectile toward the intruder as a deterrence to any further approaches. Out of the three designs discussed, Design III was selected for our final product. Component changes were conducted with the goal of achieving higher standards for specifically set criteria: detection, controlled fire, autonomy, and stability.

1.2 Main Ideas and Conclusions

Original designs of using a gearbox or mounting the firing mechanism on a single motor proved unstable. Thus, wheels and a ball caster were used instead, and rotation now involves the entire system. This also eliminated the need for a moving support. A more rigid firing barrel made from Lego parts replaced the initial paper barrel due to stress constraints from the ballistics. A motorless magazine was implemented to free up a motor, which allowed the use of two motors for drawback of the ballistic firing mechanism. It was concluded that these allowed for improved stability and controlled fire, which in turn leads to better detection and more consistent autonomy.

2. Introduction

The overarching objective of this project is to design, build, and test a mechatronic system using primarily, the *LEGO MINDSTORMS EV3®* kit, and other materials. The system shall accomplish a self-designated goal alongside constraints and criteria.

2.1 Report Overview

This report details the purpose and functionality of the proposed design. It analyzes the project's timeline, spanning from planning and designing, to construction and testing of different designs. With each new design, critiquing of the options explored are performed. Included also, are discussions on distinct criteria and constraints, resource limitations, and conclusions drawn through the process.

2.2 Problem Description

There is a need to defend personal space. This need exists because our customer may not always be aware of their surroundings. Our project aims to provide a solution to the need for protection of personal space.

2.2.1 Stakeholders

The two main stakeholders are the user and anyone approaching the user unwelcomingly. The user may be impacted negatively by mental stress or a breach of safety by the intruder; the intruder serves as the main point of conflict in the problem. Other stakeholders may be bystanders in the surroundings who observe this breach of personal space. The system may act as an alarm leading any bystanders to initiate action if they feel it is necessary.

2.2.2 Problem Importance

Maintaining one's personal space is important for a multitude of reasons related both to health and safety. Breaches of personal space may lead to anxiety and stress [1]. Especially if victims are focused on tasks that require undivided attention, retaining personal space may lead to higher productivity [2]. Additionally, if an individual is approached by another with malicious intent, protecting one's personal space can be a matter of safety. A method which both discourages approaching persons and warns its users can serve as a self-defense tool. Even in the lack of such serious situations, feelings of safety and reassurance to the user leads to better directed attention and higher productivity.

3. Scope

The function of this project is to defend a defined personal space. The system ensures that no one will enter the owner's space and discourages any further approach by detected persons using a physical deterrence.

3.1 Main Functionality

The robot operates under three main functions: area surveillance, intruder detection, and intruder deterrence. Each uses separate components which, in tandem, accomplishes the desired objective.

3.1.1 Area Surveillance

For surveillance, the first task that the robot needs to perform is a horizontal rotation. Rotation allows for an increased range of detection by surveying an arc rather than a line. This is necessary for larger areas of personal space around the user to be protected.

3.1.2 Intruder Detection

To detect approaching intruders, the robot will stop on detection of an object in range, and lock onto said object. It will then start measuring the range of the object and trigger the firing mechanism if the object approaches. This also suggests that the robot should be able to differentiate between obstacles, and not trigger the firing mechanism when it detects objects that are either moving away or remain stationary.

3.1.3 Intruder Deterrence

The robot will be able to fire projectiles consistently and periodically at the approaching object. After each individual projectile being launched, the robot will automatically resupply the firing mechanism with another projectile. The robot will detect when a projectile is launched and when the firing mechanism is lacking ammunition, and appropriately add additional rounds to continue the firing process.

3.2 Measurements and Detection

The robot's program begins and ends when it receives human input via a button press. The robot will use a gyro sensor, and colour sensor to control each of its tasks, and an ultrasonic for external detection.

3.2.1 Human Input

A large majority of the robot's functions are operated automatically using various inputs from different sensors. However, the initial input to the robot involves the user starting the program on the robot's central control: the *LEGO MINDSTORMS EV3®* brick. As the system is run automatically, the only inputs required are the powering on of the brick and starting the program.

3.2.2 Gyro Sensor

The robot will use the gyro sensor by receiving angles that represent the robot's rotational orientation. This input will be used to define the robot's arc of rotation and serves as a trigger for the robot to swap between clockwise and counterclockwise rotation during its surveillance.

3.2.3 Ultrasonic Sensor

The ultrasonic sensor will be used as the detection system for the robot by taking in object distance data and notifying the system of any changes. The change in distance will be used to inform the system on whether it should stop the robot and arm the firing mechanism or continue with its rotations.

3.2.4 Colour Sensor

The colour sensor is used to detect the input of marshmallows by detecting white, which is used to confirm that the marshmallow storage on the robot is not empty. This input is used to signal an end to the robot's program when the magazine is depleted of ammunition.

3.2.5 Motor Encoders

The encoders in the motors are used to set the position of the lever arms on the side of the robot to pull back the slingshot used to fire the projectile. This is so that the arms can pull back the slingshot at a constant rate by using the encoder position as a indicator of the their position when operating.

3.3 External Interactions

The nature of the robot requires many mechanical interactions operated by but separate from its software aspect. This includes its motor usage on different environments, elastics not included in the Lego® set, and its physical projectile ammunition.

3.3.1 Mobility

For proper motion, the robot must interact with the surface that it is placed on. The robot uses two motors on the bottom of the chassis to rotate itself by gripping onto the surface with two wheels. Rough-terrain tires were used as opposed to flat-road ones for greater consistency with different surfaces. A ball caster supports the backside and allows for range of motion in its environment.

3.3.2 Ballistics and Projectile Use

Physical deterrence is part of the robot's objective, and so it interacts with intruders through its ballistic firing mechanism and projectiles. The system stores marshmallows in a mounted magazine on top of the firing mechanism where they are placed into the sling built with elastics. Two motors with arm-like extensions are used to pull back a sling, where the arms rotate and drop from the sling to release it. The robot then interacts with the target by firing marshmallows that collide with it.

3.4 Program Termination

The robot shuts down under two different conditions. The depletion of its ammunition will trigger a shutdown through detection with the colour sensor to save power. Additionally, there is a manual way for the user to turn off the sentry mode if the client no longer requires surveillance. If that is the case, the user can end the running program by pressing the enter button on the EV3 brick.

3.5 Measures of Success

The success of our robot hinges on the achievement of four criteria: detection, controlled firing, autonomy, and stability. Briefly, the robot must successfully detect intruders consistently. This is vital to the performance of its other functions, including the ability to fire accurately. The ability to fire its projectiles in a controlled manner is also vital to intruder deterrence, to provide a consistent discouragement. Autonomy is significant for the robot to act independently from the user, and stability is needed for the robot to support all its mechanisms. Section 5 elaborates more on these criteria.

4. Constraints

All objectives are done under certain predetermined constraints used to direct the planning and design of the project. These involve consistency in motion, accuracy in detection, and the resources available for construction.

4.1 Consistent Motion

Since one of the tasks is for the robot to pivot on its central axis, the robot itself should not move. The robot's rotation, timing, and motor power should remain consistent for every iteration of the code. Wherever the robot is positioned initially upon startup, it should remain until the system is shut down. The purpose of the robot is to protect the user in their blind spot, however, it will be unable to do so if the robot is altering its center point every time the program runs. Therefore, the robot must maintain a constant and fixed point of rotation and not waver throughout its use.

4.2 Accurate Detection

There is a strict constraint on what will be deemed a threat. This is to ensure that all individuals not approaching the user, or stationary objects, are shot. This allowed the robot to monitor past non-threatening objects reducing chances of missing proper targets. Primarily, ammunition will not be wasted as it may be needed later on when a legitimate intruder enters the area. Additionally, ammunition costs money, and limiting unnecessary waste reduces the cost of operation.

4.3 Resource Limitations

In terms of resource restrictions, a budget was constructed for the expenses that would come up during the process of building, testing, and displaying the robot. The budget is set to be thirty dollars which will be distributed for constructing the parts that must be custom made, buying the ammunition, and any other costs that may occur during the procession of this project. The budget is flexible but not to exceed an upper limit of forty-five dollars.

5. Criteria

The following criteria are requirements for a successful product. As mentioned above in section *3.5 Measures of Success*, each is important for the other as the entire system works in tandem. These criteria include: detection, controlled fire, autonomy, and stability.

5.1 Detection

The robot will detect any objects within a radius specified by the user as well as recognize and differentiate between intruders approaching the client and stationary objects. For example, the machine should not find a water bottle placed on a desk to be a threat to the user. Conversely, an individual who approaches the user will be deemed as a threat and dealt with appropriately. An ideal robot would be able to differentiate between approaching and non-approaching objects and be able to face itself towards the object on an accurate angle when it has detected.

5.2 Controlled Firing

When the robot recognizes an approaching object and deems it a threat, it will fire in a consistent and precise matter. The firing mechanism will launch the projectile at a rate of at least 4 marshmallows per minute. Additionally, the projectile itself will travel a distance of at least 1.2 meters before landing. This is to ensure that the launched marshmallows can reach any objects within the user's personal space, even if it resides on the exterior of this space.

5.3 Automation

The robot will be fully automatic and not require human interference to function. The robot serves to protect the client so that they can focus on their work without worrying about their surroundings. If the client constantly must monitor the robot for it to function, the purpose of the system is defeated. Thus, it is vital to the function of the robot that it does not require tedious maintenance. In this case, the more feasible design will require less human interference.

5.4 Stability

The mechanical system of the robot will be able to support the control brick and the turret while the system is in operation. All movement should remain in a relatively constant position ensuring that the firing maintains a certain degree of precision.

6. Design

6.1 Design I

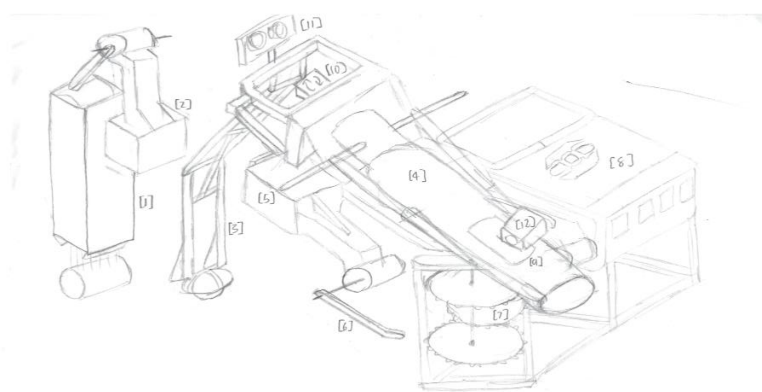

Fig 6.0. This sketch shows Design I, the original planned idea. This idea was scrapped due to the lack of stability. Nonetheless, it paved the way for successive designs.

6.1.1 Gearbox Rotation

Initially, instead of attaching wheels to the bottom of the chassis, the bottom of the system remained stationary as three central gears (7) were used to rotate the firing mechanism about an axle. This resulted in a problem where the gears misaligned often.

6.1.2 Paper Barrel

The firing mechanism is made of two paper towel rolls, with one of slightly greater diameter. The small roll is placed inside of the large and has a long handle protruding from both sides; a rubber band loops around this handle. The material of this design was ultimately too weak to support the stress of an elastic mechanism.

6.1.3 Moving Support

A supporting structure (3) that rests on a pivot ball was added to hold the draw back motor (5). This was designed to combat instability of a top-heavy design but proved difficult to control.

6.1.4 Single Arm Drawback-Fire

A single motor (6) is positioned next to the barrel to draw back the sling in the paper barrel. Multiple tests and minor adjustments showed a single motor was too weak to perform the drawback.

6.1.5 Magazine Design

The magazine (1) which held marshmallows would be positioned on top of the cardboard tube, with a motor (2) fastened next to it to push marshmallows through the magazine. Using a motor was decided to be a poor choice, as marshmallows are soft and vulnerable to deformation.

6.1.6 Sensor Positions

To control rotation of the robot, a gyro sensor (10) is mounted to the firing mechanism. A color sensor (12) is placed next to the slot on the barrel of the cardboard tube (9). An ultrasonic sensor (11) is placed at the back of the robot for detection.

6.2 Design II

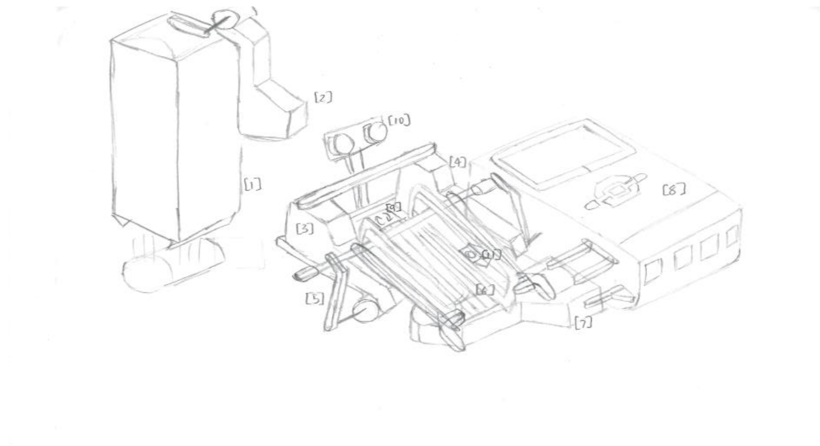

Fig 6.1. This sketch shows Design II, meant to fix the surface problems with Design I. This idea was scrapped due to the a new method of rotation. It also had the newly built Lego barrel.

6.2.1 Single Motor Rotation

Instead, the firing mechanism relies on a single gear and motor. The motor (7) is oriented parallel to the ground and rotates the axle (6) to turn the firing mechanism. The elimination of gear chains increased consistency, but the single motor was still too weak to support the, still top-heavy, design.

6.2.2 Lego Barrel

The barrel is now constructed out of Lego pieces instead of cardboard. This allowed for more precise alignment with the central body, and better resisted stresses applied by the elastics.

6.2.3 Double Arm Drawback-Fire

The design now uses two motors, each attached to an arm to wind back the sling that releases the marshmallow. This allowed for increased strength as well as an even force applied on both sides of the sling.

6.3 Design III

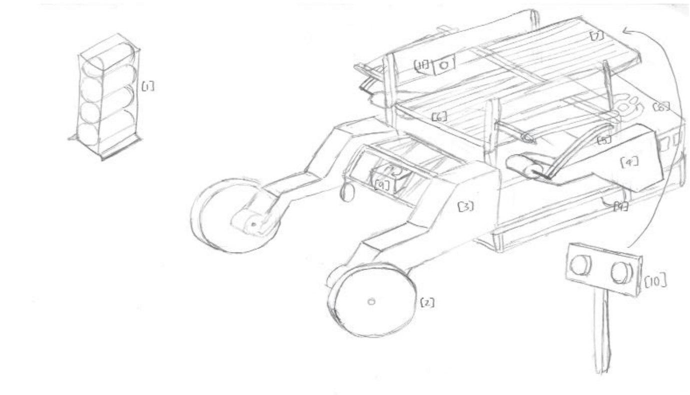

Fig 6.2. This sketch shows Design III, the chosen finalized design. It features wheels commanding full body rotation along with its mounted barrel facing forward.

6.3.1 Front-Wheel Drive Rotation

For a third design, the idea of rotating the system using a gear and axle system was scraped. Instead, two wheels (2) and a pivot ball (4) were attached to the bottom of the chassis, with each wheel powered by a motor. The three point stand allowed for better stability and wheels reduced potential points of failure.

6.3.2 Motorless Magazine

The reloading process has been altered; the magazine no longer requires a motor to feed ammunition into the barrel and relies on gravity to release the marshmallows. A cover on the sling of the barrel (7) stops any additional marshmallows from falling into the chamber while the sling is not pulled back.

6.4 Design Decision

Decision making was carried out through a combination of testing and trial and error. Unique component ideas were attempted and improved in combination with each other. Qualitative judgements were used and applied in a decision matrix shown below.

6.4.1 Decision Matrix

	Criteria				
Design Alternatives	Detection (x2)	Controlled Fire (x1)	Automation (x3)	Stability (x3)	Total
Design I	3*2 = 6	1*1 = 1	2*3 = 6	1*3 = 3	16
Design II	5*2 = 10	3*1 = 3	5*3 = 12	3*3 = 9	37
Design III	4*2 = 8	4*1 = 4	5*3 = 12	5*3 = 15	42

Fig 6.3. A decision matrix allocating quantitative ratings for design components. An important note, detection in Design III was sacrificed for stability, as the weightings show.

6.4.2 Criteria Weighting

The weights were decided based on the relative importance of each criteria to providing a solution for our targeted problem. Stability and automation are considered to be of greatest importance, each having a weighting of 3. Stability is significantly vital to the design, as without enough support to every function of the robot, many elements of the design would fail. For example, without enough rigidity to the firing mechanism, it would not be able to withstand the stress of rubber bands and thus the system itself would not be able to launch projectiles. Automation is also considered to be of great importance to the design because it ensures the system can provide security under a diverse variety of situations. Detection is given a rating of 2. Detection is still important for our robot, as specifying to shoot at approaching objects is vital for the system to defend from intruders. However even if there is a slight error when the system detects an intruder, firing the projectile at an angle close to the intruder will have a similar effect. Finally, controlled firing was deemed as the least important criteria for our robot, with a weighting of 1. This is because the system will still manage to provide some deterrence even if the firing is not consistent or even if not, very many marshmallows are fired at the intruder.

6.4.3 Detection Analysis

Design I was given a rating of 3 for detection. This is consequence of the ultrasonic sensor being placed at the very back of the robot where the supporting structure is. This leads to the ultrasonic being positioned in an unstable position far away from the front of the robot, decreasing the accuracy of any readings. Design III was given a higher rating of 4 because it improved the stability flaw of Design II, where the ultrasonic would be strapped to the very back of the rigid chassis. However, Design III was given the highest rating of 5 because the ultrasonic was strapped to the back of the firing mechanism, granting the sensor stability as it detected. This also allowed the ultrasonic to be positioned closer to the front of the robot, allowing for more accurate readings.

6.4.4 Controlled Firing Analysis

In terms of the controlled firing criteria, Design I was given the lowest rating of 1 because the cardboard tube could not withstand the stress caused by the rubber bands. This caused the tube to deform as the marshmallows consecutively fired. This led to the tube being unable to fire marshmallows consistently and continuously. The second design was improved upon dramatically with a rating of 3, with the design being built out of Lego for greater rigidity. This allowed the firing mechanism to handle the stress of the rubber bands, but also the Lego pieces allowed for the firing mechanism to be strapped to the Lego pieces that the chassis of the robot was built with. This allowed for greater stability, giving the robot more accuracy consistently as it fired. The third design was given a higher rating of 4 as the firing mechanism was hoisted higher onto robot, giving the robot a greater shooting range.

6.4.5 Autonomy Analysis

The second two designs were given the same rating of 5 for automation. This is because every robot would be able to perform all the tasks specified in section 3 of the report without any human interference. Both designs had a way to rotate the firing mechanism by itself, as well as a method for the sling to be drawn back by itself. Additionally, both designs had a mechanism to detect when a marshmallow had fired and automatically reload another upon this detection. Design I was given a rating of 2 for automation. This was because the gears which the base rotated off of often misaligned and disconnected, requiring the user to shift the gears back into place so the firing mechanism could rotate again. This process is often frustrating for the user, justifying the low rating.

6.4.6 Stability Analysis

For stability, Design I was given the lowest possible rating of 1. This was because the supporting structure was an unstable extension of the robot’s main chassis, leading to instability in many portions of the robot, including the drawback motor and ultrasonic sensor. Additionally, the cardboard tube often slid back and forth in its holster on the robot, leading to instability in the firing mechanism as well. Design II was given a rating of 3, because it greatly improved upon the stability in the firing mechanism from Design I with the Lego structure. However, the one axle rotation was not strong enough to support the entire weight of the firing mechanism and marshmallow magazine, causing the top portion of the robot to tilt slightly. Design III was given the highest rating as the usage of two wheels allowed for the entire chassis to rotated while being stable, which improved upon the stability of the two previous designs.

7. Project Plan

The development of the system required careful organization of a 4-week period. Thus, important tasks were split into sub-projects, and estimates of milestones were set to keep track of progress.

7.1 Sub-Projects

Sub-Project	**Description**
Project Description	Develop ideas and solutions for a given need statement
Project Pitch	Presenting the need, ideas, solutions and rough designs of the mechanical solutions
Mechanical Design Project	Developing and presenting designs for the mechanical interface of the robotic system
Interim Design Report	A report to display the full specifications of the project including constraints, criteria, project designs, etc.
Software Development	Writing the controlling software for the robotic system for it to perform the tasks given in the need statement.

Figure 7.0. A summary of each sub-projects is given. These were assigned as deliverables and hold top priority.

7.2 Milestones

The milestones set mark different stages of the design and construction process. Each milestone will require considerable planning, testing, and tuning. The order of milestones set are in relation to the dependency of each on the previous.

Project Milestone	**Description**
Initial Idea	A general idea of a need statement, and design solution.
Sketch	A rough sketch of system body.
Completion of Robot Chassis	Main structure of physical system completed.
Successful Rotation of System	Rotation of body by motor-powered wheels.
Successful Projectile Launch	Projectile can successfully hit target intruder.
Completion of Physical System	Fully functional physical system.
Completion of Source Code	Program that can run robot to complete all required tasks.
Complete Automation of Physical System	System performs without human interference.

Fig 7.1. Summary of Project Milestones

7.3 GANTT Chart

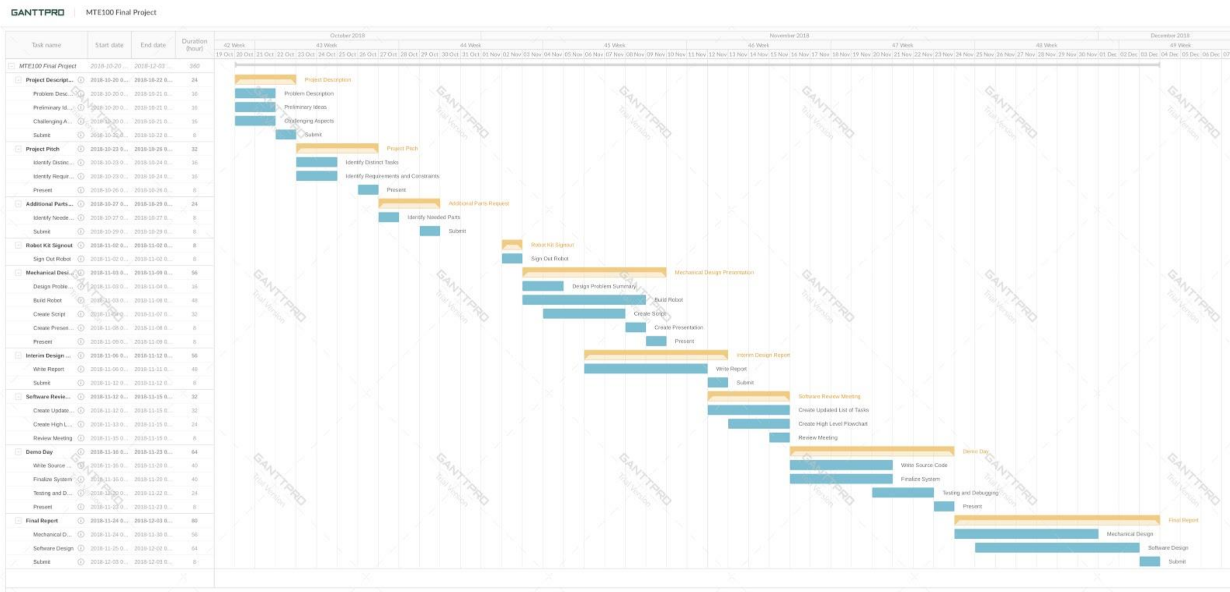

Figure 7.2. The following GANTT Chart outlines the timeline of different aspects of our project. This includes the design, building, coding, and testing phases

7.4 Task Assignment

All members contributed to each task of the project through assignment of specific parts and later editing over each other's works. Discussions for decisions were held objectively on each part, and amendments were made as a group.

7.5 Task Dependencies

The basis for the entire project is the need statement as the design, build, program development, and system testing are all in relation to completing the need. After the need of protecting personal space was determined, the mechanical system can be designed and built around the program development or the code can be written around the mechanical system design. In this case, the program for the system to complete the tasks of the need has been written around the mechanical design selection. After the system programming is complete and mechanical system is built, testing can be commenced to assess the success of the system in completing the criteria set by the need statement.

8. Conclusion

The third design option discussed in section 6 was chosen for our final design. This design consisted of a two-wheel base along with a two-motor drawback system for the firing mechanism. It was chosen primarily due to its significant stability compared to the alternative designs as well as its ability to perform every criterion better or to the same standard.

9. Back Matter

9.1 References

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