Law Enforcement Training Robot

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Abstract

Currently, for law enforcement training exercises, a number of situational training systems are being used to simulate high stress situations. In order to better train police officers, these training systems expose the trainees to high stress scenarios to improve their skills. Many of these systems offer high quality simulations of real life law enforcement encounters. As helpful as the systems have proven themselves to be, they have a drawback: the price tag tends to be extremely high making it difficult for some police departments and training centers to utilize them in their exercises.

The purpose of this Major Qualifying Project is to explore the possibilities of a low cost high stress situational firearms training robot at a lower-than-market price, accessible to all police departments. The required characteristics of the training robot include maneuvering on all terrain, reaching speeds similar to a human and being easy to transport, use, and repair. Focusing on manufacturability and cost, we utilized off the shelf hobby parts where possible and only used custom parts where deemed necessary. Throughout our project we designed and prototyped a successful firearms training robot ready for use on the range.

Executive Summary

In today's world, the widespread use of social media has led the practices of Law Enforcement to become more scrutinized by the public eye. The training which officers receive often dictates their responses in the field to real world situations. Officers who receive high stress situational training will often perform better in high stress real world situations (Davies, 27).

Although new types of training offer a huge advantage for law enforcement, they come with a hefty price tag. Modern methods of simulation training, whether it be virtual or real life, are often quite expensive and are not affordable across all levels of law enforcement departments. Limited functionality of current systems can also be an issue in offering a wide range of simulations and use of different force options.

The goal of this project was to design, build and test a fully functional firearms training robot that is affordable and easy to use. The main goals were for it to have a six hour run time on a single battery charge, to be as fast as a running human, and to weigh less than 50 pounds. This robot is meant to be shot at with real ammunition, thus providing trainees with a more realistic experience that will test their abilities.

Currently, a number of situational training robots are being used for a variety of purposes. For example, companies such as Marathon Targets produce robotic targets for live firearm training that are capable of moving naturally, as a human would in order to train trainees to anticipate and interpret situations when they encounter them. These robots are being designed to navigate through buildings just like an active shooter would as well as to maneuver off-road at speeds comparable to that of a human. This includes all uneven and inclined terrain as well as any unpredictable weather that may occur. A robot which fits these standards and is capable of mimicking human movement/human habits provides a more realistic experience. Thus, trainees will improve all sides of their skills from weapons handling to team communication (Marathon Targets, 1). As a result, these standards will be applied to the final design of the project.

In a survey sent out to a few members of law enforcement, it became clear that safety is a major concern on the range. The possibility of ricochet is one of the main concerns out on a

shooting range. Most shooting ranges have systems in place such as bullet traps and berms to catch the bullets and prevent them from flying anywhere unwanted.

Through an experiment using a variety of different robot base designs and airsoft BBs, the effects of angles and ricochets were tested. The goal was to find a design for the base which would direct all ricochets either straight into the ground or backwards into the berm. This design would also need to be manufacturable. From these tests, a conclusion was drawn that the design of the robot base must have side angles somewhere in between steep and shallow in order to control ricochets while keeping it cost effective.

To begin the manufacturing process, lengths of the tubing were all cut on a horizontal bandsaw. The individual pieces were then clamped and welded together to form the base of the robot. Learning TIG (tungsten inert gas) welding had a steep learning curve, especially for a material like aluminum which melts away easily and oxidizes quickly. Individual tubes were clamped to the table so they would not move while welding. With multiple clamps in the way of the welder, this made welding the joints more of a challenge. For future production, welding jigs can be made to more easily weld many pieces together consistently. The use of a jig would allow a procient welder to weld these frames together very quickly and effectively. Consequently, the cost of the frame assembly would drastically lower over time.

The electronics and drive system of this platform consist of all COTs parts. Not only does this keep the costs down, but it also allows for a plug and play system in which all the separate components can be swapped easily.

Due to logistical issues that were out of our control, the robot was not able to be completely assembled and tested. If given the necessary time in the shop, a few more parts would be manufactured in order to achieve a fully assembled prototype.

To evaluate if the designed system could be successful or not, the manufacturing costs needed to be calculated. To estimate this in large batches, an assumption of time spent in the shop was made to be around $75 per hour. In a larger scale operation, parts would be made differently compared to how they were made in this project. Instead they would be manufactured on CNC lathes, mills, plasma cutters and waterjets in batches. For parts of a given complexity this will approximately mean that cost is proportional to weight, more or less, so some coefficient (>1) times the cost of the aluminum itself. Somewhere around twice the material cost in reasonable volume production. The fewer the number of units the higher this factor will be as the set-up cost gets shared over fewer parts.

Through the use of these estimates, the cost was able to be calculated of each one of these training robots in different quantities. The table below shows our estimated cost per unit.

Quantity	100.00	500.00	1,000.00	10,000.00
Estimated Cost of Manufacture per unit	$1,094.00	$1,044.40	$983.20	$922.12

Overall and based on the original goals set out in the beginning, the costs of the training system are nearly a quarter of the cost of some law enforcement training robots on the market today. Along with this, the overall design is compact and easy to transport to and from the training site. Additionally with the ability to easily repair the robot at a cheap cost makes it a desirable training system. The robot demonstrated a wide range of mobility during our preliminary testing which will offer trainees a realistic high stress scenario to sharpen their responses to real world situations. With a low starting cost and inexpensive components that are easily replaceable when out on the field, this would be a low cost solution for high stress law enforcement firearms training.

Introduction

In today's world, the widespread use of social media has led the practices of Law Enforcement to become more scrutinized by the public eye. The training which officers receive often dictates their responses in the field to real world situations. Officers who receive high stress situational training will often perform better in high stress real world situations (Davies, 27).

Years back, firearms training for officers only consisted of marksmanship and not real world scenarios. Newer training techniques are now becoming more widely used because of their advantages. Firearms simulators offer realistic, high stress scenarios where the officers are truly put to the test. Exposing trainees to these scenarios gives them the tools and techniques to perform at a higher and safer level out in the field.

Although new types of training offer a huge advantage for law enforcement, they come with a hefty price tag. Modern methods of simulation training, whether it be virtual or real life, are often quite expensive and are not affordable across all levels of law enforcement departments. Limited functionality of current systems can also be an issue in offering a wide range of simulations and use of different force options.

The goal of this project was to design, build and test a fully functional firearms training robot that is affordable and easy to use. The main goals were for it to have a six hour run time on a single battery charge, to be as fast as a running human, and to weigh less than 50 pounds. This robot is meant to be shot at with real ammunition, thus providing trainees with a more realistic experience that will test their abilities. It is also meant to take hits from a variety of different force options used by Law Enforcement, such as a baton, Taser and pepper spray. Since the platform could be taking a substantial blow from any of these weapons, it is designed to be able to withstand hits from any weapon available to Law Enforcement. The overall shape of the robot protects users and bystanders from unwanted ricochets by deflecting objects down into the ground or straight down range. In the case that the robot does become worn down, the design allows for parts to be easily replaceable.

1.0 Background

1.1 Law Enforcement Tactics

Currently, a number of situational training robots are being used for a variety of purposes. For example, companies such as Marathon Targets produce robotic targets for live firearm training that are capable of moving naturally, as a human would in order to train trainees to anticipate and interpret situations when they encounter them. These robots are being designed to navigate through buildings just like an active shooter would as well as to maneuver off-road at speeds comparable to that of a human. This includes all uneven and inclined terrain as well as any unpredictable weather that may occur. A robot which fits these standards and is capable of mimicking human movement/human habits provides a more realistic experience. Thus, trainees will improve all sides of their skills from weapons handling to team communication (Marathon Targets, 1). As a result, these standards will be applied to the final design of the project.

There are a variety of tactics which law enforcement officials use in order to control certain situations such as an uncooperative subject. One of these tactics involves drawing or displaying a firearm. This tactic normally occurs in situations involving threats or potential lethal assaults, but many law enforcement officials have used it in lesser circumstances. While using this tactic may subdue certain situations, it tends to be problematic as it can lead to an escalating situation. There have also been reported cases where officers that have drawn their weapons were not able to maintain a safe distance from the suspect. Furthermore, several of those officers also lost control of their firearm to the suspect. The New York Police Department (NYPD) have instructed their officers that if they draw their weapons, they should maintain a safe distance of 10 feet or more from the suspect when possible (Rostker et al., 2008). With a training robot, law enforcement officials could practice scenarios where officers need to determine whether or not to draw their weapon based on what weapon the robot is carrying. They could also practice their reaction time on deciding which weapon to use, whether it would be lethal or non-lethal, and correctly assessing the situation.

1.2 Training

Law enforcement officers receive two types of training: pre-service and in-service training. Pre-service training is not restricted to one department and is done with recruits from different locations. In-service training deals more with officers training from within their department. Pre-service training is more cost-efficient and effective as it is able to train a large group of recruits at one time. States and communities place a high investment in this type of training because individual police departments may not be able to deliver the same quality of pre-service training as others can. Pre-service training involves familiarity with firearms, tactical decision making, gun handling and marksmanship. Tactical decision making usually involves one to one trainee to instructor as they go through several different situations and scenarios. A large amount of money is also invested in equipment, targets, and ammunition. This makes firearm and deadly force training a very costly expense (Morrison, 2006). As a result, individual departments cannot offer their officers the same quality of training. With a training robot, both pre-service and in-service training could reduce some of its cost as the robot is reusable and it can help replicate more realistic situations, improving the quality of the training.

Law Enforcement training has a direct impact on a police officer's performance in the field. In a recent study, *An Analysis of Firearms Training Performance among Active Law Enforcement Officers in the USA*, law enforcement training types were analyzed for performance. Performance was measured in this study by the percentage of targets hit or missed and the heart rate of the trainee. The study found that, "force-on-force situations decrease performance and increase heart rate" (Thomasson et al. 225). Meaning that when trainees were put through more realistic situations, they performed at a lower level than if they were just shooting at normal targets down range. The study concludes, "training programmes should incorporate a greater proportion of training time devoted to combat situations involving high-stress exercises" (Thomasson et al. 225). With more training using higher stress exercises, trainees develop stronger skills to take to the field. If police officers can only perform well in a controlled environment, then they are likely to not perform well in the real world where tension and stress can be much higher. Exposing trainees to more lifelike scenarios throughout their training would give them the necessary skills to perform under pressure. Consequently, a training robot could aid in the improvement of police officers' performances.

Shoot don't shoot exercises are training exercises conducted in a manner in which the trainee needs to react to a live scenario and decide which level of force to use. Normally this training is conducted in a simulator room with a replica gas fired pistol and a can simulating OC spray. A recent study on this type of training was conducted on 372 police recruits by Amanda Davies (Davies). The aim of the study was to determine the effectiveness of high stress training. Davies collected multiple data points from the recruits to determine the value of certain simulations and scenarios. Scenarios were based on interactions which recruits could experience in their jobs. Some included warehouse visits, homeless man encounters and various others. Davies clarifies "it is acknowledged that no two policing response incidents will be identical, although there can be core similarities" (Davies, 27). Even though recruits may never encounter the same scenarios in their training, certain aspects of the scenarios will be seen in their day to day jobs. Davies concludes the "study indicates that the key transferred influence from participation in a use-of-force simulation exercise is centred on building their personal reference point for times of crisis" (Davies, 27). From this study one can determine that shoot don't shoot exercises play an important role in Law Enforcement training and it gives officers the skills to perform in life or death situations.

There has been more of an emphasis on close-quarters combat training in recent years. This is due to the number of incidents in which officers encounter the threats in plain sight. The FBI decided to take new training protocols because of a majority of incidents where shots were exchanged only yards away from agents. Such training models could be implemented in law enforcement training as they face similar situations. Simulations of different variations are being implemented in order to train agents to be more vigilant and smart in a variety of situations and environments (Johnson, 2). Some scenarios require agents to fire off three to four rounds at a target that could be as close as three yards away. In fact, the pistol-qualification course for FBI agents requires agents to participate in exercises in which they fire 50 rounds as close as 15 yards. Other exercises require agents to draw their weapon from a concealed carrying position which is how it would be in a real world situation. A new emphasis on training techniques like these can prepare law enforcement officers alike FBI agents for encounters with armed suspects in schools, office buildings and other locations where close quarter armed attacks may occur, thus limiting the potential casualties (Johnson, 3).

Being able to expect a number of unpredictable situations is vital to handle high stress situations effectively and safely. Statistics say that there is about a 60% chance that an assault will involve more than one attacker. One never knows when a bystander will go from being completely uninvolved to being a threat. Learning to engage multiple threats with total awareness of the surrounding “uninvolved” subjects rationalizes shoot/no shoot training, increases the chances of survival and decreases liability issues. This type of training would have to involve multiple targets that can be controlled to create different, unpredictable scenarios by having targets in varying positions (Miller, Kurata, 2). To go along with this, officers must be able to shoot effectively while incorporating lots of movement in order to gain a tactical advantage. Effective movement techniques can be taught with a variety of equipment such as running man targets and automated turning targets, which make the experience much more realistic; And when equipped with steel target plates, this provides positive instant feedback from the sound of the bullet hitting the steel (Miller, Kurata, 5). In fact, training on moving targets has become mandatory for law enforcement agencies across the country. It is important to train for both lateral and charging movements from any threat because each requires a unique response from the officer.

Currently, firearms training systems which use a projector and a simulated firearm exist and are used by some departments and agencies. The goal of these simulations are to expose the trainee to lifelike scenarios as they stand in front of a big screen. The trainee has to react and respond to the threat presented in the scenario. When the trainee draws his or her weapon and fires, a gas canister inside the weapon simulates the blow back of the gun as it fires a laser. A camera tracks the laser and the computer processes where the shot went and if it was a hit or not. Though these simulations have been proven useful in the studies above, nothing compares to firing a real firearm. These simulator systems are also only compatible with a small range of firearms. Thus, training is limited to only the use of a firearm and not other force methods such as OC spray (Pepper Spray) and ASP (Collapsing Baton). In a survey we sent out to different law enforcement/police departments, we asked if they had ever used a system like this before and some commented that they have only used virtual simulators. However, our robot training system's intention is to be shot at using real bullets rather than a laser with the intent on making the training more realistic. A training system like this could also be hit with an ASP or sprayed with OC spray. Taking into account other realistic training elements when building a robotic training system is key in creating a useful platform.

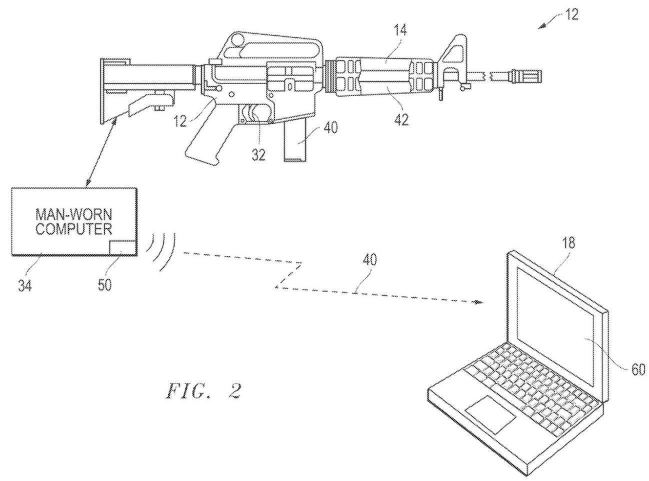

Figure 1: *Shooting simulation system and method,* US Patent US8459997B2

1.3 Bullet Ricochet

In a survey sent out to a few members of law enforcement, it became clear that safety is a major concern on the range. The possibility of ricochet is one of the main concerns out on a shooting range. Most shooting ranges have systems in place such as bullet traps and berms to catch the bullets and prevent them from flying anywhere unwanted. The risk of ricochet becomes greater on objects such as targets that are added to the range. For example, a robotic training system should minimize the risk of ricochet instead of increasing it. It should also never allow for a bullet to ricochet over the berm or past other safety equipment.

A ricochet occurs when a bullet hits a target and on impact gets deflected, changing its direction and travel path while maintaining its integrity. A study done in 1969 to understand bullet ricochets discovered that the bullet becomes unstable and deformed after the ricochet. The study also found that bullets fail to ricochet on targets in which it penetrates, as either the bullet will penetrate the target or disintegrate upon impact. The amount of bullet deformation that occurs depends on several factors such as bullet material, the target, and velocity (Jauhari, 1969).

Then in 1992, a more comprehensive study was conducted on bullet ricochet. In *Bullet Ricochet: A Comprehensive Review*, Burke and Rowe characterized certain types of ricochet to gain a better understanding of its direction. They describe that the *angle of incidence* is the angle at which a bullet contacts a surface and the *angle of ricochet* is the angle between the surface and the bullet after contact. Their study concluded that all surfaces have “a critical angle of incidence” (Burke, Rowe 1254) at which bullets will ricochet. It was determined that angles above the critical angle will cause the bullet to become destroyed. They found that the critical angle for soft ground was around 7 degrees, similarly to water (Burke, Rowe 1254). They also determined that the shape and make had an effect on ricochet. Bullets with round tips and or full metal jackets were more likely to ricochet than were ones with flat tips and or lead alloys (Burke, Rowe 1254). Burke and Row also came to the conclusion that velocity had a hand in causing ricochet. They were able to determine slow moving bullets would have a greater chance of ricochet than faster ones (Burke, Rowe 1254). Overall, the study concluded that the angle to cause a ricochet is normally a low one as it typically alters the shape of the projectile instead of destroying it. Also the angle at which the projectile flies after hitting the target increases with the angle of incidence as seen below in Figure 2 (Burke, Rowe 1254). Having a low angle could increase the chance of causing a ricochet whereas a steep angle would normally destroy the bullet or projectile.

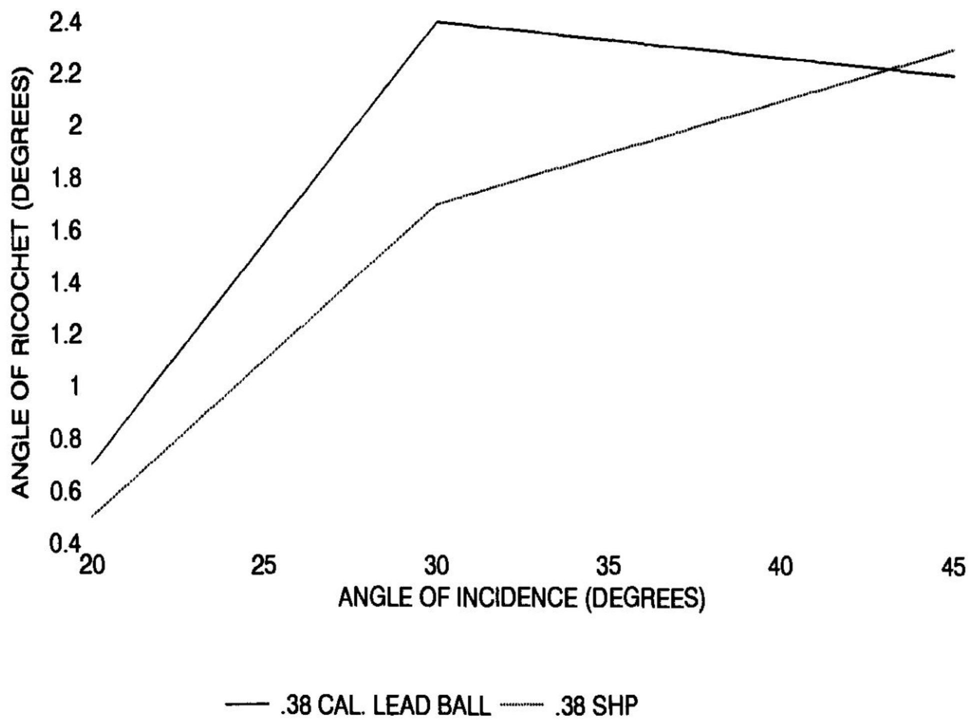

Figure 2: *Angle of ricochet versus angle of incidence. Solid line = .38 caliber lead ball; dashed line = .38 caliber semi-jacketed hollow point.,* Burk, Rowe.

When examining a fire range, it is vital to have a clear mindset on identifying any potential ricochet hazards as this can help avoid a number of problems in the long run. Hazards might include rocks, metal posts, or virtually any metal hardware. Ricochet hazards can be removed altogether or covered with something that can help suppress the blow of a bullet impact. There are a number of techniques for lessening the risk of a ricochet. For example, granulated rubber has potential to be an effective material for absorbing bullet impact. Another effective method is creating designated shooting lanes that keep bullet paths controlled while also monitoring trainees easily. If possible, the use of a certain type of ammunition that does not ricochet as easily would reduce the risk of injury by a considerable amount. The easiest and most logical solution to keep people safe out on the field is to encourage the use of safety goggles and protective clothing which is easily accessible and may reduce the risk of injury.

2. Methodology

2.1 Requirements

Designing this robotic platform began with the users' needs in mind. For the project, it was crucial to clearly understand these needs so they could be met in the final design. In order to accomplish this, a number of goals were set:

1. Talk to potential customers and get their opinions on these types of training tools.
2. Mock up simple designs based on those needs.
3. Test these designs against bullet impact to study ricochet.
4. Design the robotic platform based on the information and data gathered in the previous steps.
5. Manufacture and iterate the design wherever necessary.
6. Test the platform in real life training scenarios with members of law enforcement.

Plans were constructed for the completion of the project based on interviews with potential customers, research on similar systems currently being used as well as total material cost. The hope was to fill any gaps in knowledge with interviews and survey responses from those who rely on these types of training tools for their profession.

2.2 Interviews/Surveys

In order to gain an idea of what the stakeholders are looking for in a system like this, a survey was sent out to different law enforcement departments asking a number of questions related to past experiences using a similar training system and personal design preferences. Four main questions were asked leaving room for any comments at the end:

1. Have you experienced a similar system (as described above) in the past? If so, what are your thoughts about the system, and how much did your department pay for it?

2. What features would you expect from this training robot? (Ex. Speed, being able to take a taser, carry certain targets, etc).
3. Any size preferences as well as thoughts on portability?
4. How often would a system like this be used?

For the first question, the majority of the responders said they have no prior experience using a system like this. There was one person who did explain how this system works well in testing reaction time and marksmanship on a moving target. It was also mentioned that this system is great for allowing the trainer to set up various shoot don't shoot exercises. For our second question, the majority of the responses leaned towards the robot having the ability to move as human-like as possible with the ability to fall to the ground and drop a mock weapon or object. This would allow the robot to be used in a wider variety of situations. Additionally, the robot should be able to travel across all types of terrain, both rough and smooth, as the terrain on different shooting ranges can vary. Another common theme among the responses was incorporating a way for the robot to vary its speed, like a human could. The robot should be able to travel as fast as a human could run. Lastly, there was and still is a common concern for ricochets that can potentially injure someone or unintentionally damage property. The robot is going to be shot at often and needs to have certain features which keep ricochets under control.

An interview was conducted with Worcester Polytechnic Institute's (WPI) Police Deputy Stephen Marsh and firearms instructor, Officer Stuart Fuller. The questions mentioned previously were discussed. Officer Fuller stated that he had worked with a similar training system before. He remarked an important note that it should be expected that the robot will get shot in unpredictable locations, so it needs to be very durable. One suggestion to make the robot durable was to encase important parts of the robot, such as motors and electronics, in armored materials while the outer body be made with another material that is easy to replace. Additionally, the robot should be stable and not exceed a weight in which it would become non transportable. The need for a cheaper training robot is high. Although training and financials differ from department to department, small departments tend to have less money in their budget but are in more of a need for the type of training that this robot offers. Large police departments spend more money on training because of the need to train more officers. Having a mobile target improves training quality and increases the officers' skills. Lastly, an important takeaway from the interview was that the robot should incorporate two key aspects: safety and reliability. Police departments do not want to take any unforeseen risks and if there are any, they should be minimized. As mentioned above, one safety concern is the bullet ricochet off of the robot. If a bullet were to ricochet, it should be directed into the ground or in a direction which will not cause any harm to humans and property. In order to account for the bullet ricochet, an experiment was conducted to minimize the safety risk.

2.3 Ricochet Experiment

As mentioned previously, there is a common concern among stakeholders for dangers that can arise from ricochets. Ricochets occur when a projectile traveling at high speeds deflects off of a surface and travels in another unpredictable direction. In order to gain a better sense of how bullets will deflect, small scale versions of the robot base were 3D printed and shot with airsoft pellets to observe the ricochets.

To begin designing a safe yet effective firearms training robot, all of the feedback from the survey and interview were collected and taken into account. Two points that were realized with this information were that the robot would act like a platform which different targets would be attached to and that ricochets needed to be mitigated. Starting with these ideas in mind, different shapes were prototyped for the base of the robot. There was one prototype with very steep angles on all four sides, one with shallow angles on the front and back sides, and one in between. With the help of the WPI Police Department, airsoft pellets were shot at the prototypes and the ricochets off of the models were observed and recorded.

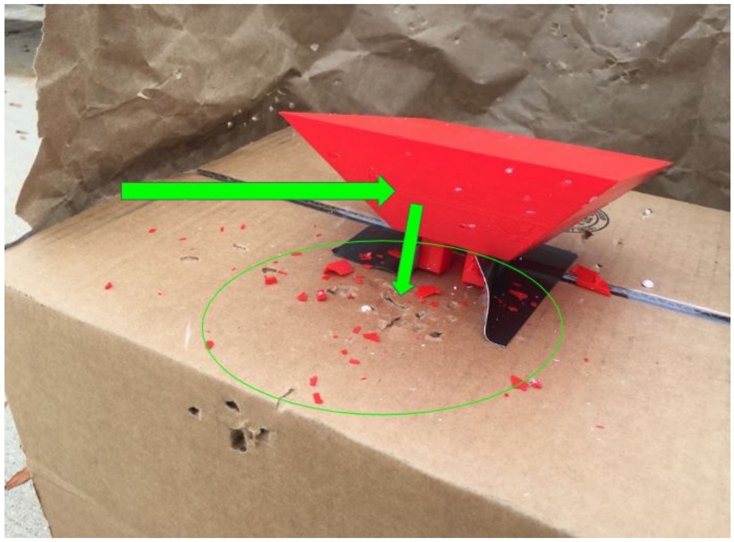

Figure 1: The results of shooting at a steep angle base

As shown from the figure above, shooting the steep angle base at its side caused the ricochets to deflect straight into the ground. This is the type of outcome that was desired to have in the final design, however, cost could become an issue when building a base with that steep of an angle.

Figure 2: The result of shooting at a base with shallow angles

The figure above shows how shallow the side angle of the other base is. Since the angle is not as steep as the previous model, the ricochets did not deflect into the ground and some bounced back at the shooter. From these tests, a conclusion was drawn that the design of the robot base must have side angles somewhere in between steep and shallow in order to control ricochets while keeping it cost effective.

2.4 Design and Cost Reduction

The design process of the actual robot began in Solidworks by designing a simple frame made up of 1”x 2” aluminum rectangular tubes that allow side panels to be attached at an angle.

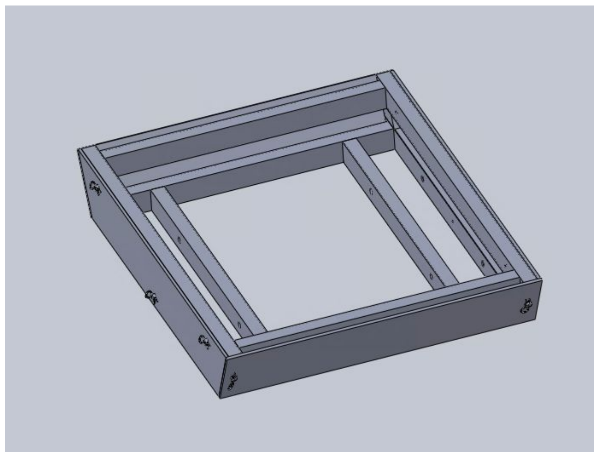

Figure 3: The initial stage of metal base frame

We decided the most cost effective method is to screw in short lengths of aluminum rods on to the side of the frame and use pins to secure amor plates in place, this is also called a clevis and pin. Only using a 6 foot rod of aluminum and pins, this method for attaching the panels is significantly cheaper than purchasing bolts and nuts. Additionally, if a bullet hits and destroys a pin or the aluminum rod, the material to fix the broken pieces costs less than a dollar. Being able to quickly remove sides of the robot to replace any other broken components is another benefit of using a clevis and pin. This also allows the side panels to be easily detached and replaced if worn down.

From here, the wheels were designed to fit in the frame such that they are protected by the outer panels. The wheels are made of solid rubber so there is no worry about puncturing a pneumatic tire.

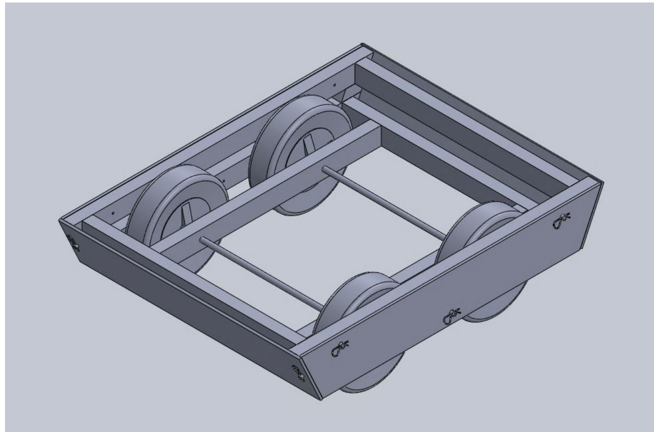

Figure 4: The frame assembly with the wheels installed

The wheels were originally designed to be 12" in diameter with the axle running all the way through the frame. However, in order to cut down costs and reduce the amount of material needed, the axles were trimmed to the length between the two support beams holding the wheels in place. The wheels' reduction in size also saves space within the frame assembly. The wheel assembly consists of a simple wheel and sprocket mounted to each other that spins freely on the axle. This allows for the wheels to be driven by two motors on each side of the frame via a chain.

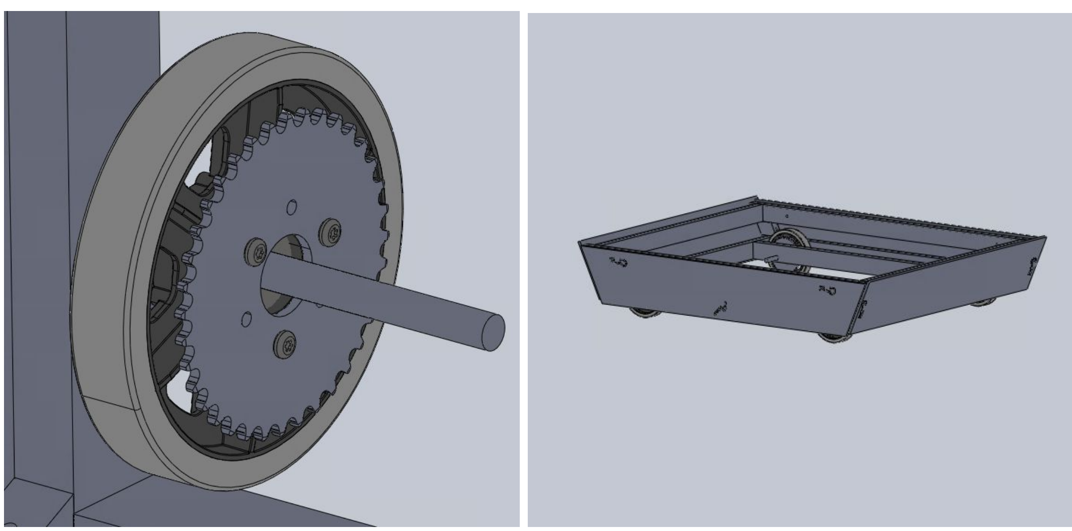

Figure 5: The frame assembly with a trimmed axle and wheel assembly

2.5 Manufacturing and Assembly Process

To begin the manufacturing process, lengths of the tubing were all cut on a horizontal bandsaw. The individual pieces were then clamped and welded together to form the base of the robot. Learning TIG (tungsten inert gas) welding had a steep learning curve, especially for a material like aluminum which melts away easily and oxidizes quickly. Individual tubes were clamped to the table so they would not move while welding. With multiple clamps in the way of the welder, this made welding the joints more of a challenge. For future production, welding jigs can be made to more easily weld many pieces together consistently. The use of a jig would allow a procient welder to weld these frames together very quickly and effectively. Consequently, the cost of the frame assembly would drastically lower over time.

The sides of the frame were the first to be welded, starting off with spot welds to hold it in place (as shown in the figure below).

Figure 6: Side of the frame spot welded together.

After creating some spot welds, the team was able to more easily complete the weld. Starting from the spot welds, a bead was formed when welding was done as shown in the figure below.

Figure 7: Complete weld compared to spot weld

The completed weld of the two sides of the frame are shown in the figure below.

Figure 8: Completed weld of the sides of the frame

Once the sides of the frame were completed, they were connected through the use of four crossbars. In order to keep the frame from warping, a square tool was used to maintain a 90 degree angle at the joints. Holes were drilled on the inner and outer portion of the sides of the frame where the axles were to be inserted. The end result is shown in the figure below.

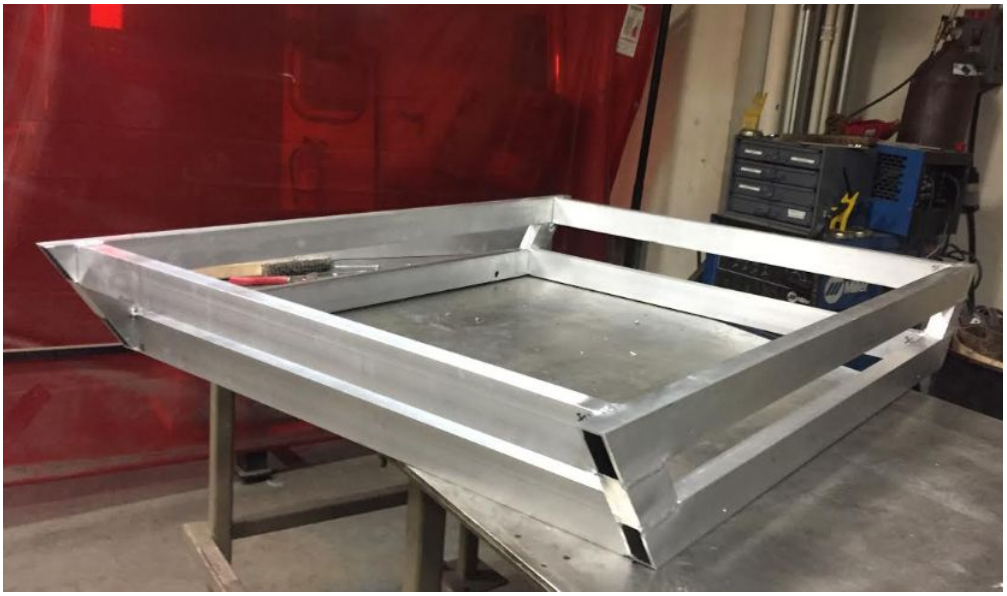

Figure 9: Four sides of the frame welded

In order to complete the rolling chassis, two more crossbars were welded along the length of the frame for the axles to go through. Each bar was welded three inches from the sides of the frame and was relatively straightforward to weld. Two holes were drilled on each crossbar where the axles were to be mounted. The axles for the wheels did not fit into the bearings initially. To fix this issue, the axles were turned on a manual lathe in order to trim off a very small amount of material. This decreased the diameter of the axles and they were able to fit into the bearings. Using a mill, holes were created on the axles in order to insert cotter pins to fix the axle in place with the wheel. For commercial production of axles, a CNC lathe with a milling head could very easily drill the necessary holes and cut the axles to size. For larger quantities of this part this would drastically cut down on the manufacturing costs of these axles.

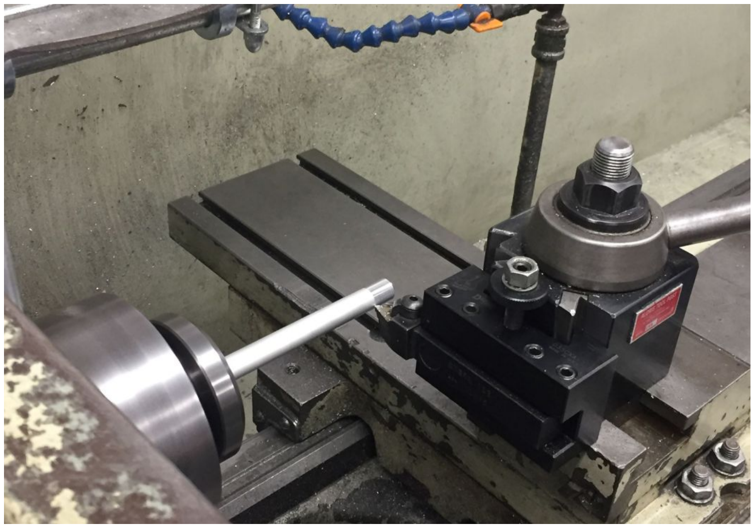

Figure 10: Turning the axles on the manual lathe

Once the cross bars were welded to the frame and the axles were inserted, the rolling chassis was completed. The rolling chassis was easy to build as it consists of mostly Commercial Off the Shelf parts (COTS Parts).

Figure 11: Rolling chassis

Spacers were manufactured on the manual lathe from scrap tubing. These spacers slide onto the axles and constrain the wheels at a certain position within the gap for the wheels. The spacers and the cotter pins secure the axle and wheel in place.

Figure 12: The finished spacers

Two mounting plates were manufactured on a waterjet from ¼ inch aluminium.

Figure 13: Motor mount plates

Using the motor mount plates as guidelines, the plates were clamped onto the frame and two sets of holes were drilled into the frame. This allowed the motor mount plates to be mounted using ½” bolts and nuts.

Figure 14: Motor Mount plates on the frame

The built-in adjustable motor mount was not enough to tension the chain properly, so to substitute for the limited range on the motor we added nylon chain tensioners to the bottom of the frame. This not only helps tension the chain properly, but it also keeps the chain up and off of the ground.

2.5.1 Electronic Assembly

The electronics and drive system of this platform consist of all COTs parts. Not only does this keep our costs down, but it also lets us easily have a plug and play system in which all the separate components can be swapped easily.

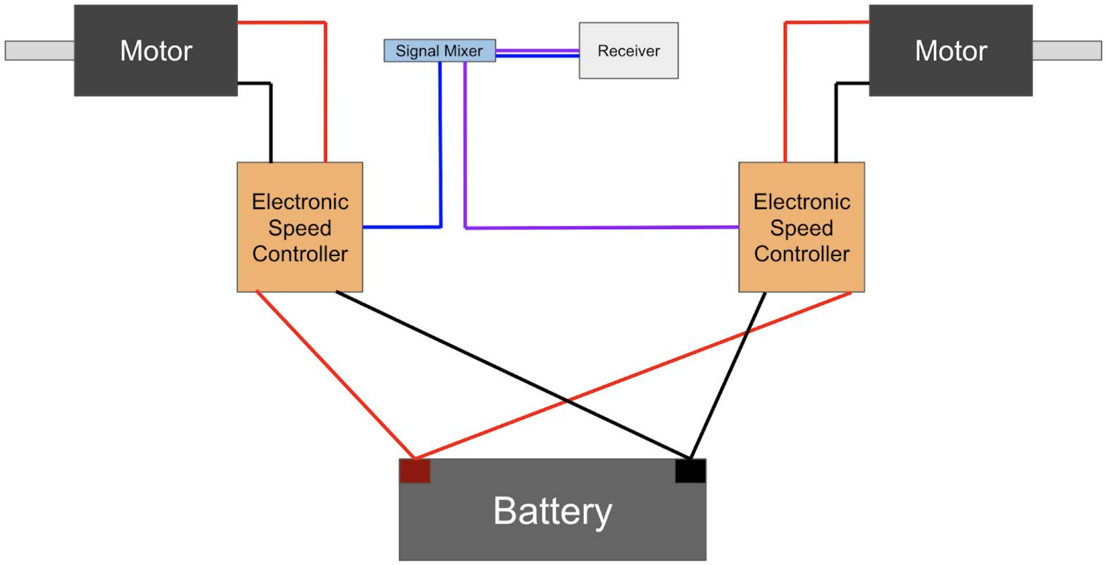

Figure 16: Electronic Assembly

The electronic assembly consists of 2 CIM motors which individually drive the left and right sides of the robot, like a tank. These motors are controlled by hobby electronic speed controllers (ESCs). These ESC take an input from the receiver and in turn power the motors. The receiver and controller are common hobby parts which normally are used to control RC cars or boats. Using this type of controller allows us to have an easy to operate control interface at an extremely low cost. In between the receiver and ESCs is a signal mixer. This signal mixer, also a COTS part, takes the steering and throttle channels from the receiver and converts them to left and right for our tank drive. This allows for the robot to steer by slowing down or speeding up each side of the drive base. Powering all of the electronics is a lead acid battery. We chose to go with a lead acid battery because we were not constrained by weight and space. The advantage to this battery is it can be charged with a car battery charger and the risk of a spill is lower than that of a battery catching on fire. Therefore, these batteries cost very little compared to others and can be charged with lower cost battery chargers.

3. Next Steps

Due to logistical issues that were out of our control, the robot was not able to be completely assembled and tested. If given the necessary time in the shop, a few more parts would be manufactured in order to achieve a fully assembled prototype:

3.1 Mounting Studs

These are the short pieces of aluminum rod that are used to easily mount and unmount the side panels to the frame. In order to efficiently machine these, a system would be designed and implemented starting on the lathe by turning the aluminum and cutting it off at the desired length using a stop block, then drilling and tapping a hole for mounting the stud to the frame. From there, a hole is drilled through the stud on the manual mill for a cotter pin to stick through in order to prevent the side panels from slipping off when moving. To automate this process, all these operations can be done on a CNC lathe with an autofeed and a milling head. These machines are also known as Swiss Machines. Using one of these would allow us to mass produce these studs for a fraction of the cost.

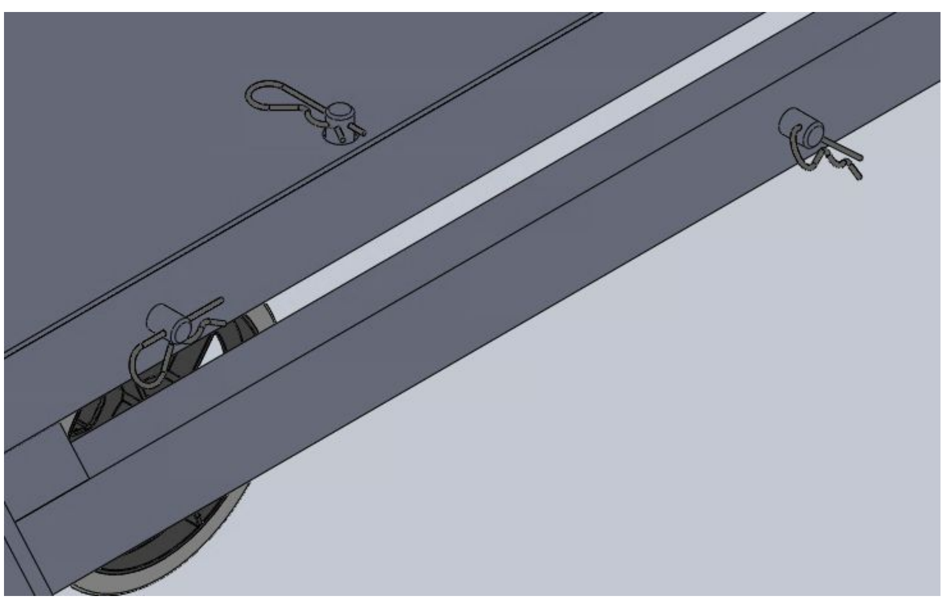

Figure 17: CAD Model showing Aluminum studs

3.2 Steel Armor

The steel armor attaches to the sides of the frame using the studs and cotter pins as mentioned above. These panels are used to protect the electronics on the inside of the chassis from any misdirected bullets. The panels were modeled in Solidworks and mated onto the assembly in order to get an idea of how it would all come together. Once satisfied, .dxf files were generated from the models so they could be cut on a waterjet. Using a waterjet as a form of manufacturing for these panels is cost effective and time efficient. The figure shown below is the .dxf for the top “lids” of the robot. They were designed with two halves so one side could be easily taken off without having to remove the entire lid to access the inner electronics.

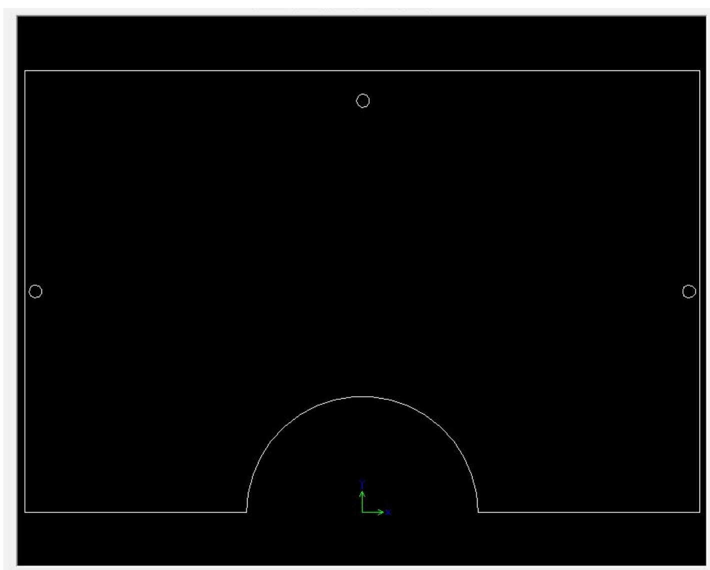

Figure 18: .dxf of top “lid”

The top panels were also designed to form a hole (as shown from the semicircle) so the target mount can stick out from the inside of the frame. The .dxf for the front and back panels is a simple rectangle with two holes on each end for attachment to the frame because the simpler the part is, the easier, faster and cheaper they are to manufacture.

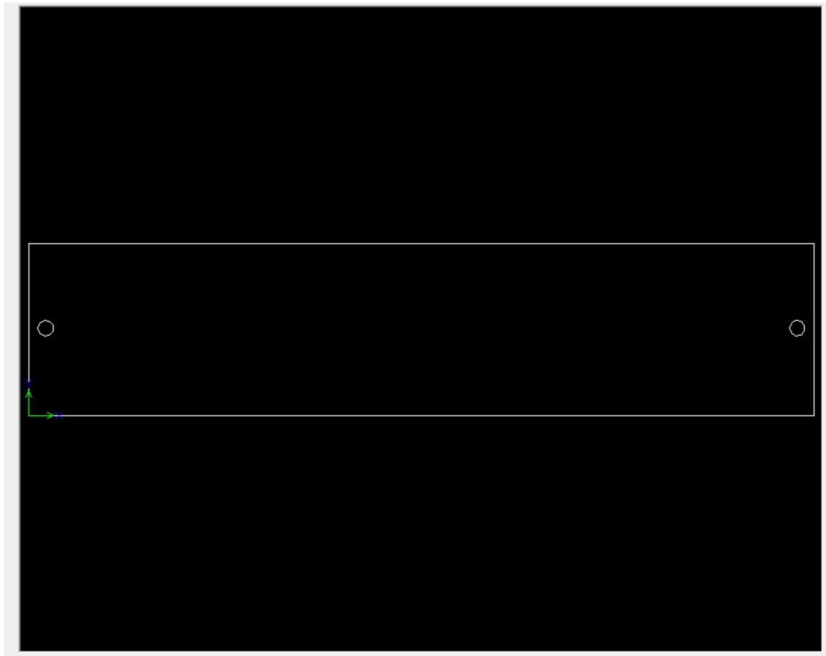

Figure 19: .dxf for front and back panels

The left and ride side panels are designed with an angle on each end to form to the shape of the frame. This is so any bullets that hit the angled side deflect into the ground in order to prevent injury (this was tested in our ricochet experiment with the 3D printed models).

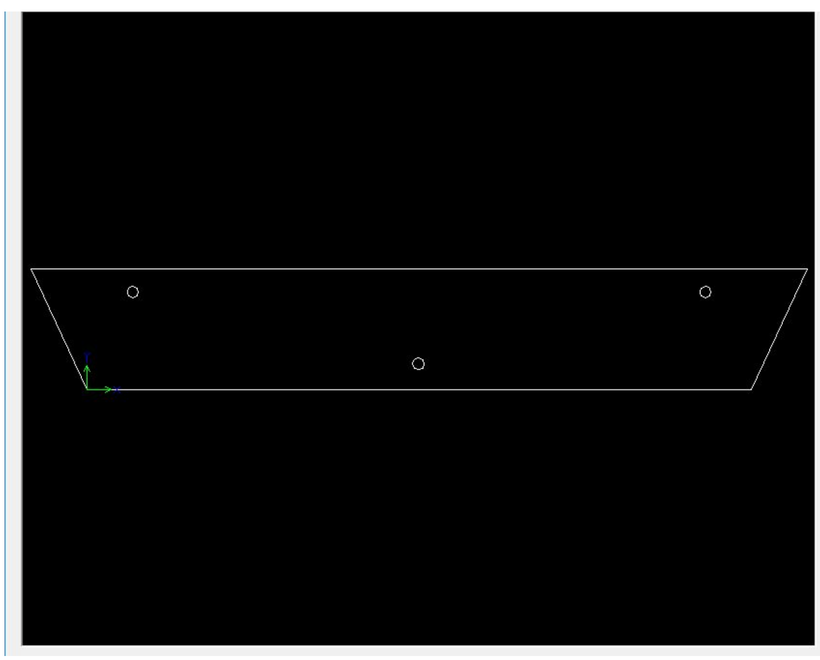

Figure 20: .dxf for left and right side panels

3.3 Target Mount

To mount a target we added an aluminium cross beam through the middle of our frame. This runs directly under the two motors. This cross beam would then be used to bolt on a 2x4. Using a 2x4 is an extremely cost effective target stand which benefits us by cutting manufacturing costs and also benefits the user as it is going to get shot and would need to be replaced. This allows the user to quickly and cheaply replace it when needed. The targets would then be stapled to the 2x4 at the proper height for the trainee.

3.4 Finishing Touches

Once the bulk of the work above is completed, a few things need to be done to completely finish up this training robot. A protective coating such as a powder coating should be sprayed onto the steel armor in order to prevent rust. The electronics should be mounted onto the frame of the robot. A small plate and velcro strap needs to be added in order to properly secure the battery for operation. Once these things are complete, this training robot is fully operational and ready to be taken to the range.

4. Cost Analysis and Break Down

Below is a table listing every component used to build one prototype of this training robot. The parts are organised in a few categories, most of which offer cheaper prices for bulk purchases. To build one system, it cost us $760 in parts.

Part Type	Cost	Quantity	Desc.	Total Cost
Raw Stock	$78.81	5	Aluminum Tubing for base 40ft and 1/2in Al Rod 6ft	$153.50
Raw Stock	$150.00	1	Armor Plating (Estimate Cost)	$150.00
Raw Stock	$3.04	1	Target stand (2x4)	$3.04
Fasteners	$15.21	1	Zinc-Plated 1050-1095 Spring Steel Cotter Pins	$15.21
Fasteners	$8.50	1	10-24x3/4 Thread Forming Screw [Qty-50]	$8.50
Fasteners	$0.70	2	Key for motor shaft	$1.40
COTS Part	$4.00	4	6 in. SmoothGrip Wheel	$16.00
COTS Part	$16.00	4	S35-36L Aluminum Sprocket	$64.00
COTS Part	$3.00	8	1/2 in. id Flanged, Shielded Ball Bearing	$24.00
COTS Part	$12.00	1	#35 Single Strand-Riveted Roller Chain, 10'	$12.00
COTS Part	$2.17	5	Cardboard targets double sided, shoot don't shoot	$10.85
COTS Part	$12.21	2	Roller Chain Sprocket for ANSI 35 Chain, 9 Teeth, for 3/8" Shaft Diameter	$24.42
COTS Part	$8.98	1	Nylon Chain Tensioning Piece 1/2in x 1/2in x 6in	$8.98
Electronics	$27.82	1	3 Channel Reciever and Transmitter	$27.82
Electronics	$20.07	1	Signal Mixer for tank drive	$20.07
Electronics	$32.75	2	2.5in 12V motor	$65.50
Electronics	$43.00	2	Hobbywing QuicRun 80A ESC (Motor Controller)	$86.00
Electronics	$35.99	1	12 volt 18Ah Motorcycle Battery	$35.99
Electronics	$32.99	1	Battery Charger 12v 6Amps	$32.99
				$760.27

Figure 21: Cost analysis

To estimate the cost to manufacture large batches of our training robot, we can assume time spent in the shop to be around $75 per hour. In a larger scale operation, parts would not be made the way we made them by hand. Instead they would be manufactured on CNC lathes, mills, plasma cutters and waterjets in batches. For parts of a given complexity this will approximately mean that cost is proportional to weight, more or less, so some coefficient (>1) times the cost of the aluminum itself. Somewhere around 2x the material cost in reasonable volume production. The fewer the number of units the higher this factor will be as the set-up cost gets shared over fewer parts.

Using these estimates we were able to calculate the cost of each one of these training robots in different quantities. The table below shows our estimated cost per unit.

Quantity	100.00	500.00	1,000.00	10,000.00
Estimated Cost of Manufacture per unit	$1,094.00	$1,044.40	$983.20	$922.12

Figure 22: Estimated cost of manufacture

5. Conclusion

This project proved to be a challenging engineering experience that focused on design and manufacturing. Even though the project was suspended before completion, a majority of the robotic base was assembled and performing the way it was intended to. The remainder of the project was planned in order to efficiently and cost effectively reach completion.

Based on the original goals set out in the beginning, the costs of the training system are nearly a quarter of the cost of some law enforcement training robots on the market today. Along with this, the overall design is compact and easy to transport to and from the training site. Additionally with the ability to easily repair the robot at a cheap cost makes it a desirable training system. The robot demonstrated a wide range of mobility during our preliminary testing which will offer trainees a realistic high stress scenario to sharpen their responses to real world situations. With a low starting cost and inexpensive components that are easily replaceable when out on the field, this would be a low cost solution for high stress law enforcement firearms training.

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