Project Number: SSN-MQP-BLKI

A Multi-Weapon Auto Aiming and Trigger System for Rapidly Deployable Armed Support Robots

A Major Qualifying Project Report

submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science in Robotics Engineering & Mechanical Engineering

by

Sabrina M. Varanelli
Robotics Engineering
Mechanical Engineering
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Project Advisor: Professor Stephen Nestinger
Project Co-Advisor: Professor Michael Ciaraldi

1. Robot
2. Weapon
3. Gun
4. System
5. Integration

ABSTRACT

Current weaponized robotic systems are too expensive for use by law enforcement agencies and yet are being demanded more and more by these agencies to augment existing human teams and to help expedite dangerous missions. In conjunction with Black-I Robotics Inc., this project developed a low-cost robotic device capable of accurately and safely firing a variety of semi-automatic weapons at stationary targets. The project involved the formulation of project specifications as well as the design, fabrication and testing of the device. This system will be further developed by the company and potentially mounted on the arm of a Black-I Robotics' LandShark robotic platform and to increase the marketability of their current LandShark robotic platform for use by law enforcement agencies.

ACKNOWLEDGEMENTS

This project would not have been possible without the support of the following individuals:

Stephen Nestinger

Michael Ciaraldi

Eben Cobb

Ken Stafford

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Taskin Padir

Michael Manning

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INTRODUCTION

The Major Qualifying Project is a capstone engineering requirement necessary for graduation from Worcester Polytechnic Institute. This document is a cumulative report documenting a project sponsored by Black-I Robotics to design a multi-weapon auto aiming and trigger system for rapidly deployable remotely operated armed support robots used in law enforcement applications. Black-I Robotics is a defense company located in Tyngsboro, MA that specializes in quick-deploying unmanned semi-autonomous robotic systems. This company is entering into the law-enforcement robotics industry and is looking for a weapons system to add needed functionality to their existing robotic platform.

As a cumulative project report, this paper outlines the motivation for the project, methodology used to complete the project, and relevant background research on topics related to the project. System specifications as well as design approaches are described and the overall design process is documented. The design results are well documented and relevant design information is contained within the appendix. Suggestions for future work on the project are outlined and discussed, and overall conclusions are drawn from the project as a whole.

PROJECT MOTIVATION

Fifty years ago, the idea of sending a robot into a military or law enforcement situation would have been ludicrous. Recently, robotic technologies have become cheaper and more readily available, and the need for robot deployment in law enforcement situations has increased. These phenomena have opened up a new market for the creators of new robotic technologies. The industry mentality has shifted and agencies are less willing to send a human into a dangerous situation that a robot could easily perform in. According to a study done for the Department of Justice, "A significant need exists in the law enforcement and bomb disposal community to have ready access to low cost robots that are able to perform a wide variety of missions."[1] A study performed by the Space and Naval Systems Command Center, located in San Diego, CA, was performed in an effort to quantitatively identify the areas in which a robot would be useful to law enforcement personnel. One of the results of the study was the following chart that outlines the areas in which law enforcement officers felt that a robot would be useful. The Z axis represents the number of agents who thought a robot would be useful for a percentage of mission types, indicated by the X and Y axes respectively.

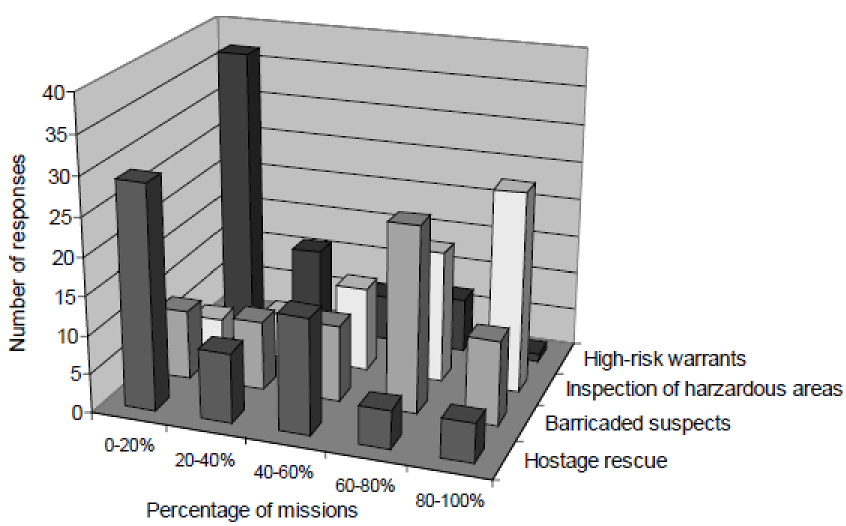

Figure 1: Survey Results of Law Enforcement Robot Use[2]

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[1] Office Justice Systems. Vanguard Robot Assessment. Assessment for Criminal Justice Solutions. Washington DC: US Department of Justice, 2004.

[2] Battelle. "Law Enforcement Robot Technology Assessment." 2000.

The results from this study indicate that over half of those replying believe that robots would be useful 80% to 100% of the time in the inspection of potentially hazardous areas, and that nearly all the respondents believed that a robot would be useful in this kind of application from 40% to 100% of the time. This overwhelming response is evidence that law enforcement personnel are in need of robots capable of navigating dangerous situations and relaying information about the situation back to their human team members. Because of their very nature at being good replacements for humans where "dull, dirty and dangerous" jobs must be performed, robots used in law enforcement activity have the potential to "…multiply the effect of being a team, enabling a more effective and exhaustive investigation in a shorter period of time."[3]

The project sponsors have identified a market need for both teleoperated and autonomous quick-deploying robotic ground vehicles. Their product line consists of a main platform called the "Landshark" that has a top speed of 15 mi/hr, the ability to carry a 500 lb payload and the ability to work with a variety of different attachments to meet customer needs. The company strives to produce robust and reliable robots through the use of commercial off-the-shelf parts that require standard tools and maintenance. This strategy allows the company to provide relatively inexpensive solutions to law enforcement and military personnel, in contrast to other companies such as Foster Miller and iRobot.[4] The average salary for a law enforcement agent is $50,000, and agencies purchasing robotic systems need to make sure that they are getting a good return on their investment in contrast with the amount of money it would take to hire a person to do that same job.[5] Producers of robotic systems for use in the law enforcement market need to ensure that the customers are getting the most utility from a robot that they are purchasing, in comparison with their human counterpart. Black-I Robotics has determined

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3 Weiss, Joseph. "Officer.com." February 2007. Autonomous Robots for Law Enforcement. 2010 2 March <http://www.officer.com/print/Law-Enforcement-Technology/AUTONOMOUS-ROBOTS-FOR-LAW-ENFORCEMENT/1$35337>.

4 Black-I Robotics Corporate Website. 10 February 2010 <http://www.blackirobotics.com/Home_Page.html>.

5 "Report Linker." January 2010. First Responder, Homeland Security, and Law Enforcement Robots Market Shares, strategies, and Forecasts, Worldwide, 2010 to 2016. <http://www.reportlinker.com/p0181150/First-Responder-Homeland-Security-and-Law-Enforcement-Robots-Market-Shares-strategies-and-Forecasts-Worldwide-2010-to-2016.html>.

that in order to keep up with current law enforcement needs, a weapon mount, aiming, and actuation system must be added to their current ground robotic system. This system will allow a robot to act with force on its environment should it encounter an obstacle. A potential use case for a robot with this kind of capability, given by the project sponsor, and also cited in an article on “Officer.com,” may include entering and stability monitoring of a location identified as a methamphetamine production site. A robot equipped with a weapon, cameras and a variety of sensors could potentially drive up to the location, use its weapon to break the locks on the door, enter the site, and use on-board sensors and cameras to scope out the area to ensure that it safe for the rest of its human team to enter.[6]

Black-I Robotics’ current strategy is to produce a cost-effective solution to the need for a law enforcement weapons-mounted robotic system. Their goal is to add a modular mount and very generic trigger actuation system that is capable of working with a variety of weapons generally used by agents in the field to their existing robotic platform. The company desired that this system be modular and inexpensive, thus setting it apart from other solutions that are currently available on the market today. As a “contractor” for the project, the student was responsible for the design and fabrication of a prototype device which provided this necessary extra functionality to their existing platform.

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[6] Weiss, Joseph. "Officer.com." February 2007. <u>Autonomous Robots for Law Enforcement.</u> 2010 2 March <http://www.officer.com/print/Law-Enforcement-Technology/AUTONOMOUS-ROBOTS-FOR-LAW-ENFORCEMENT/1$35337>.

METHODOLOGY

Every well-implemented project needs a plan of action for its completion. This project was undertaken from a systems perspective and was physically designed and completed in a single term by a single student. A second term, but the first in the sequence, was dedicated to background research on the topic. The two terms were divided into six different phases to maintain control over the time management of the project. It was desired that the primary result of this project be a deliverable device that could be given to the project sponsor and would meet their overall needs. The values embodied by the software technique of "Agile Development" were stressed throughout the duration of the project in an effort to rapidly develop a result which could be delivered to the customer. These agile values are directly in line with time constrained projects and include valuing: "Individuals and interactions over processes and tools, working software [and hardware] over comprehensive documentation, customer collaboration over contract negotiation and responding to change over following a plan." The methods used throughout the design process reflect the adherence to these values.

SYSTEMS APPROACH

Due to the interdisciplinary nature of the project and the main objective of delivering a fully-functional device to the sponsor that fulfilled the desired functional and design specifications, a systems-level approach was taken in the design of this device. Design of the device and its subsequent implementation were not divided up by disciplines such as "mechanical," "electrical," and "software," but instead were considered as whole systems, that consisted of their own physical structure, electrical components and software schemes. Taking this kind of approach was much more beneficial than traditional methods of dividing the project because the student was able to focus on delivering a completed system to the customer, which was ultimately the purpose of this project. The diagram below outlines the specific systems involved in the creation of the overall device. Dashed lines represent electrical connections and the solid lines represent physical connections between components.

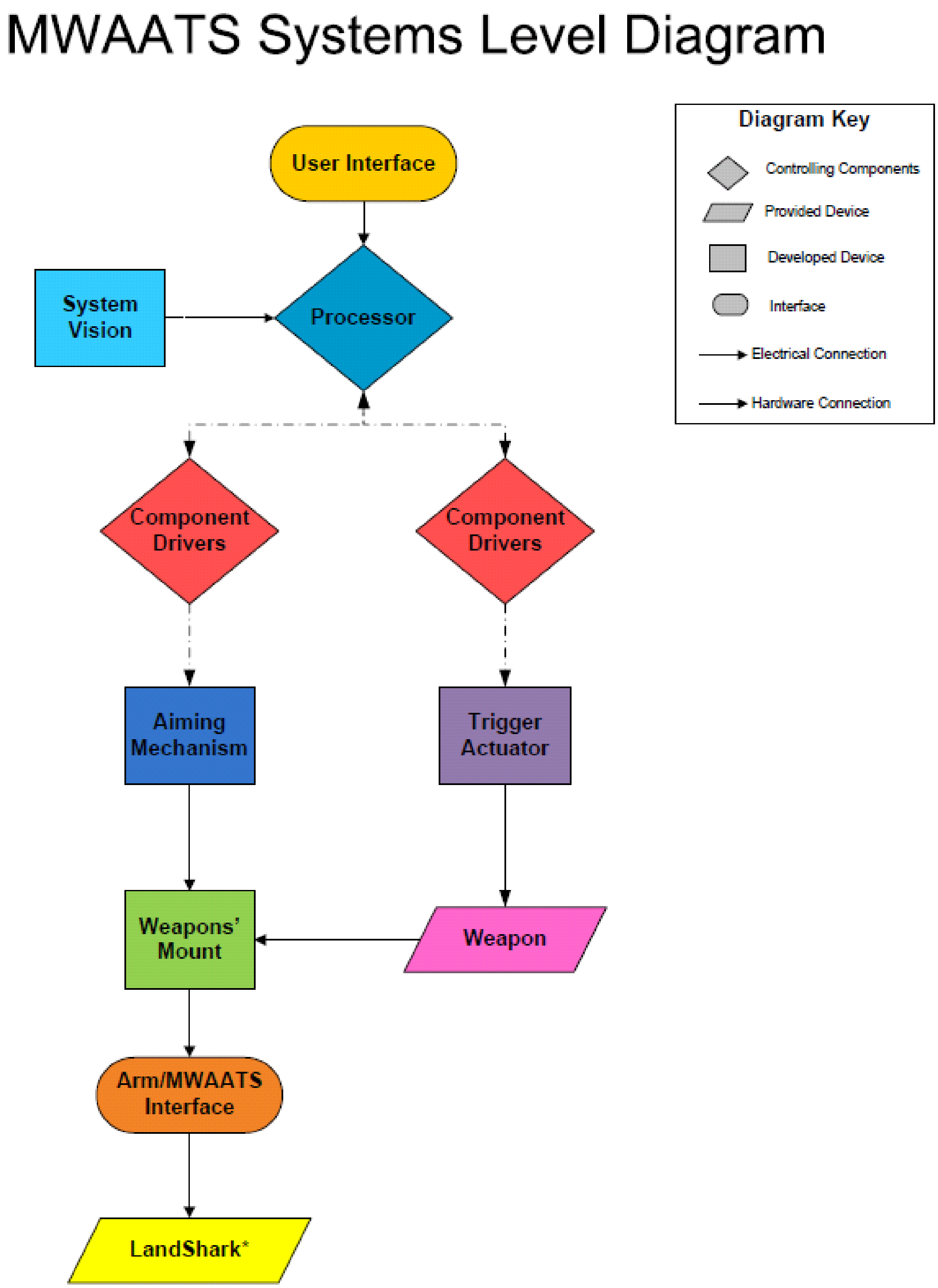

Figure 2: Device Systems-Level Diagram

The three major physical systems that were developed are shown as rectangles and include the Aiming Mechanism, the Trigger Actuator and the Weapon Mount. Both the Trigger Actuator and the Aiming Device each consist of component drivers and sensor systems that give feedback to the controller in order to create a closed-loop control system. After design iterations were made on the Weapons' Mount, it was determined that this particular system should purely mechanical. In addition to the three major physical systems mentioned above, the device also consisted of a vision system which provided visual feedback to the overall device.

WORK DISTRIBUTION

The project was undertaken by an individual student in conjunction with Black-I Robotics Inc. Professor Stephen Nestinger and Professor Michael Ciaraldi were also involved as project advisors. Project work was divided between the C and D terms of the 2009/2010 school year. One-third of a credit of work was undertaken during the C-term and the remaining credit of work took place during the D-term. The C-term activities included organizing and proposing the project, the completion of background research on associated project topics, and initial brainstorming and narrowing down of design choices to meet task and project specifications. The D-term activities included the finalization of the design, modeling, purchasing of parts and stock, the fabrication of proposed designs, development of the software, and the testing of the system.

DELIVERABLES

The deliverables for the project include a functioning prototype that meets agreed-upon project and task specifications, as well as this document which outlines the design process to support future work on the project. Additionally, documentation relating to the fabrication and programming of the device will be supplied to the project sponsor, including CAD files, relevant drawings and a bill of materials.

MEETINGS & STATUS UPDATES

During the C-term, weekly status meetings were held to update all involved parties on the overall status of the project. Status report documents were created and distributed at these meetings. During the D-term, these meetings were held bi-weekly and one weekly status report was submitted as well as any other deliverables that needed to be completed according to the proposed schedule.

Design Reviews

Formal design reviews were conducted in an effort to simulate real-world work environments as closely as possible and to ensure that all WPI academic resources were tapped for their knowledge. A preliminary design review (PDR) was held after the overall final design was decided upon and a few specifics of the design were determined such as actuation methods and overall physical and control structure. The critical design review (CDR) consisted of a demonstration during the WPI Project Presentation Day on April 22, 2010. These reviews were formal in nature and involved the presentation of technical ideas and design processes for the purpose of obtaining feedback from professionals in the field.

Sponsor Presentation

A final presentation to the project sponsor will be conducted to show off the design and to deliver the required materials to their site.

Project Phases

The project was divided into phases developed based on the standard engineering design process and tailored to fit the project.

Phase I: Project Organization

During this phase, a project sponsor was sought. Numerous attempts were made to find an outside sponsor that could provide a project in the areas relating to both mechanical and robotics engineering as well as having a military/law enforcement flavor. The student discovered the sponsor, Black-I Robotics Inc., through the Worcester Polytechnic Institute Robotics Program Advisory Board. Initial contact was made with the CEO, Brian Hart. Afterward, a phone and personal interview were conducted and an agreement was made to develop weapon aiming, shooting and mounting systems for Black-I Robotics' current ground robotic platform, the LandShark. After the project was loosely outlined, project advisors were found and the project was registered with the WPI Registrar's Office. The primary deliverable for this phase of the project was the completion of the registration of the project with WPI.

Phase II: Proposal Process

During the proposal process, open communication with the project sponsor was used to develop project and associated task specifications. Motivation for the project was investigated and general background research on the problem was performed. The deliverable for this phase was a "Project Proposal Document" that includes an analysis of the motivation for the project, research on associated background topics, an overview of the methodology for the project, and project and task specifications. The Project proposal document has been integrated into this final document.

Phase III: Design Planning

During the design planning phase, various methods for achieving the project specifications were developed. These methods were then evaluated based on the priorities of the project sponsor.

Phase IV: Device Design

The Device Design involved the execution of the basic plan developed in the design planning stage. All aspects of the proposed design were implemented, analyzed and optimized to meet project and task specifications as well as the company's priorities.

Phase V: Device Fabrication

Fabrication of the system according to the described design is currently in progress.

Phase VI: Device Test

After the physical prototype of the device is completed during the Device Fabrication Phase, it will be tested during the System Test and Iteration Phase. Evaluation will be conducted and the results will be presented to the project sponsor.

Project Milestones

The overall project milestones and project phases are outlined in a GANTT chart which can be found in the Appendix. As is the case with many engineering projects, towards the end of the project, the scheduling requirements were very ambitious and attempts to follow them were futile. From this experience, the student has learned to allot more time to design, fabrication and test stages of the design process. Even though the document did not reflect time scales that were true towards the end of the project, the creation of the list of project milestones was invaluable to the completion of the project.

Project "Inch-Pebbles"

A helpful concept that the project advisor, Michael Ciaraldi introduced the student to that was used during throughout the project was the making of lists of "Inch-Pebbles." These lists contained items that had to be completed prior to the completion of "Mile-Stones."

Background Information

Existing Weapon-Mounted Robotic Systems

There are a variety of weaponized robotic systems available to law enforcement and military personnel on the market today. The major problem with these systems is their excessive complexity for the required set of tasks that they are performing. Many of the systems are optimized for military applications and are overkill for most law enforcement applications. These systems often carry a price tag that reflects their over-engineered and over specified designs and overall, are not practical for widespread use in law-enforcement settings.

QinetiQ North America makes a robotic system called the TALON which is a 135 lb, all terrain and all weather robotic system. The TALON has the ability to carry a 100 lb payload and boasts a wide variety of cameras and sensors. The option to mount a shotgun to the system is available, and the photograph of the robot below shows an M4 Benelli Shotgun mounted to the robot.

Figure 3: Qinetiq/Foster Miller Talon Robot with a Benelli M4 Mount

The TALON closely resembles the product that the sponsor had in mind for this project. Major downfalls to the TALON's configuration that the project sponsor hopes to have corrected in the completed design include the complexity of the mount and the lack of ability to have the weapon swivel from left to right. This lack of motion forces robot to move its treads in an effort to aim the system. This method of aiming will significantly decrease aiming capabilities for the robot. Additionally, it was noted that the Benelli M4's recoil absorption system works very well with low-force (generally lethal) munitions, and so an alternate method for shock absorption must be found for law enforcement applications not requiring lethal rounds to be shot from the weapon. The current configuration of the Talon does not seem conducive to the higher shock absorption necessary to handle non-lethal rounds in the shotgun.

The company's other product line is a modified TALON system that is called SWORDS (Special Weapons Observation Reconnaissance Detection System). This system is specifically designed for weaponized use and can work with a wide variety of weapons including incendiaries, M16s, machine guns and rifles. An added feature is the mounted TRAP payload mount system on the robot that gives the system the ability to track and fire at a target as the robot is moving. An image of the SWORDS system can be seen in the photo below.

Figure 4: Quinetiq/Foster Miller SWORDS Weapon-Mounted Robotic System[7]

This system as a whole is over specified for law enforcement applications. The system has no practical way to handle non-lethal weapons and is not designed for use with any weapon other than those that are fully or non-automatic, thus ruling out the class of semi-automatic weapons that are generally used for law enforcement applications. Its range of motion for its turret is beyond the necessary speed for law enforcement, and the overall cost of the robot, roughly $230,000, makes it totally impractical for law-enforcement use.[8] The added TRAP platform is also unnecessary and adds extra complexity to the system, since there are very few situations where a law-enforcement robot will need to fire at a moving target, and the focus of most of these applications is shooting a stationary target relatively close range. The project sponsor describes the project as “a classic case of [a] government project gone wild,” and while the system may have numerous applications in a military setting, the system is not readily adaptable, as is, to a law enforcement type application.

Another line of weaponized robotic systems that falls into the same category as this project is Northrop Grumman’s Andros F6A which claims to be the “Industry’s most versatile, heavy duty

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[7] Dean, Charlie. "Foster Miller SWORDS." Live Demonstration. 2006.
[8] Crane, David. "Robo-Soldier Ready for Combat Deployment to Iraq for Urban Warfare/CI Ops." 5 March 2005. Defense Review. 5 March 2010 <http://www.defensereview.com/robo-soldier-ready-for-combat-deployment-to-iraq-for-urban-warfareci-ops/>.

robot on the market." This ~500 lb robot moves up to 3.5 mi/hr and has extensive audio and visual capabilities and a variable speed manipulator arm. Like its Foster-Miller counterpart though, the system also carries a large price tag with base models consisting of the bare minimum components retailing for $96,000.[9] Gun-mounts and guns for the system will cost a user an additional $3000, bringing up the total cost for one system to roughly equal the combined annual salary of two employees. Again, this high price tag is the barrier that is preventing the robot from becoming an integral part of the majority of law enforcement teams. An agency is not willing to spend the same amount of money on a single robot that has limited capabilities when it is able to essentially "buy" the services of two qualified individuals for a full year using the same amount of funds. A photograph of the Andros F6A can be seen in the following picture. The system is raised on its "toes" and is aiming a mounted shotgun over a fence.

Figure 5: Northrop Grumman ANDROS F6A with Shotgun Assembly[10]

iRobot's Packbot is probably the most well known militarized robot. Since its release, the ~50 lb system now has a catalog that contains over 65 accessories for helping the robot perform its dull, dirty and dangerous missions. The retail price for a base model of the Packbot is around $115,000. The Packbot comes in a "First Responder" configuration and can be mounted with

[9] Andros price info <http://www.ogs.state.ny.us/purchase/spg/pdfdocs/3823219745PL_Remotec.pdf>

[10] Northrop Grumman Corporate Website. <http://www.northropgrumman.com/>.

disruptors and hazardous material and chemical sensors in order to aid bomb detection and controlled detonation.[11] The photograph below shows a Packbot equipped with a First Responder kit.

Figure 6: Packbot Equipped with a First Responder Kit[12]

The primary issue with the Packbot as a law-enforcement team supplement is the same as the other robots discussed—its substantial price tag. Additionally, this configuration of the Packbot lacks functionality in the form of a weapon in order to more effectively use force on its environment.

AUTOMATIC FIRING SYSTEMS

Automatic firing systems are used in a wide variety of applications outside of robotics. Gun manufacturers set up test rigs that continuously fire weapons to test them and there are mechanical devices that can be purchased that allow for continuous firing of weapons given a fixed input. Gun companies test their guns repetitively by mounting them on large stands. These stands are often bulky and are built specifically to test a particular type of gun, thus requiring a different setup for each weapon tested. The system was different from this method in that it was very portable and be self-contained so that it is able to be mounted onto a mobile

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[11] iRobot Corporate Website. <www.irobot.com>.

[12] Lombardi, Candance. "iRobot preps pared-down PackBot for civilians." 8 August 2008. Planetary Gear. <http://news.cnet.com/planetary-gear/?keyword=PackBot>.

robot. A method to rapidly fire a semi-automatic weapon is offered by the sports outfitter, Cabela's. Cabela's sells a mechanical device called a "BMF Actuator" that can be mounted on the trigger of a gun to fire multiple rounds per input action. A photograph of this system can be seen below. The rotational motion that is inputted by the user through the crank is transformed into a linear motion through the use of a cam mechanism in the device. This method is a very effective way to take a rotary input and transform the motion into a simulated "trigger pulling" motion.

Figure 7: BMF Trigger Actuator[13]

JOINT ARCHITECTURE FOR UNMANNED SYSTEMS (JAUS)

Black-I Robotics' LandShark robotic platform uses the Open JAUS software framework for its robot and client side code. Eventually the user-interface and the robot-side code will have to employ this framework. This flexible framework was chosen because of its emergence as a commercial standard in robot development. The emphasis in this system is on the creation of well-defined messages that are sent between system modules. Open JAUS was created to provide a standard architecture to aid in the rapid development of unmanned systems. The system is operable with all classes of unmanned systems, including, but not limited to ground, underwater, or aerial systems of all sizes and configurations. The point of the architecture is to create a common ground for development for a multitude of robotic systems. Another benefit of the system is the ability to easily modify the levels of complexity of the system. A user of Open JAUS is able to vary the degree of complexity of a system as the project progresses. Further emphasizing the highly flexible framework that Open JAUS provides, there are provisions for functionally-defined operator control units, rather than structurally defined units.

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[13] Cabela's Sports Outfitters. 20 February 2010 <http://www.cabelas.com>.

This allows for a large range of freedom when it comes to control systems that the robot is using. Open JAUS seeks to combine needs from existing architectures such as the Joint Technical Architecture (JTA), Air Vehicle Standard Interface (AVSI) and Rotorcraft Systems Avionics (ROSA), into one usable, extensible and flexible software architecture package.[14]

[14] "The Joint Architecture for Unmanned Systems." Software Architecture Documentation. 2005.

Project Requirements

The formulation of project specifications was a major portion of this project. The skill of gathering information from a customer and translating their stories, use-cases, theoretical scenarios and other anecdotal pieces of information into a sound basis and a strong set of functional and design specifications was a huge challenge to the student. Unlike most projects where the problem and goal statements are spelled out from the beginning, this project involved the development of these necessary pieces of information from scratch. This experience was definitely worthwhile to the student and was a good chance to exercise a skill that will definitely be needed when the student transitions into the workplace. The below sections outline the general specifications, the problem and goal statements as well as the design specifications that were met upon completion of the project.

General Project Specifications

1. Material costs for development must not exceed $3,000
2. There will be limited access to a LandShark Robotic Platform with an arm at Black-I's facilities after the March 16 tradeshow.
    2.1. The design of the arm is expected to change: "The shoulder and elbow will remain similar, and the wrist and gripper will change considerably. The entire arm will likely have a wider swing than it does now and the entire arm will sit a few inches lower than it does now."
3. A system-level SolidWorks 3D model will be provided to the contractor
4. A confidentiality contract will bind all parties involved with the project

Problem Statement

Current weapons-mounted robotic systems are too expensive and complex for general law-enforcement use.

Goal Statement

Design and prototype a robust, and inexpensive electro-mechanical weapon device that will be mounted on the current LandShark arm linkage. System will have "point and shoot" capabilities and will be both safe and reliable for military and law enforcement use.

Functional Specifications

The final system will:

1. Integrate with existing LandShark platform armature, as well as electrical and software systems
2. Be operable in a range of extreme weather conditions
3. Work with a chosen selection of a given semi-automatic weapon type
4. Have a generic trigger actuator that works with a limited variety of designated semi-automatic weapons
5. Not allow an enemy to easily gain control over the weapon
6. Actively safeguard against accidental weapon discharge
7. Allow a human operator to reload weapon while it is within the system
8. Keep a running count of ammunition rounds fired and remaining
9. Accommodate shell discharge of fired rounds for a variety of weapons
10. Be able to shoot reliably within 6 inches at 10 feet to 2 feet at 30 feet (i.e., hit a door latch at 10 feet and a residential window at 30 feet).
11. Not weigh more than 15 lbs (not including weapon)
12. Not cost more than $1500 in parts and manufacturing in low manufacturing volume.
13. Be able to keep track of and shoot a variety of munitions in the same weapon's magazine. (i.e., frangible slug and a 00 buckshot shotgun shell)

Design Specifications

1. **Operating Environment**
   - 1.1. System must be able to withstand an operating temperature range -10°F to 120°F for prolonged periods of time. Our main concern is the upper temperature.
   - 1.2. System must be able to operate in conditions where sand is constantly present for an indefinite amount of time
2. **Software**
   - 2.1. Operator Control Unit (OCU) code will be in C++
   - 2.2. Robot code will be Linux code that is compliant with Open JAUS standards
3. **Electrical**
   - 3.1. Interface between weapon system and robot may be in the contractor's choice of industry standard interfaces
4. **Operator Control**
   - 4.1. Will be remote and controlled from the OCU
     - 4.1.1. OCU consists of the following: four camera views, a touch screen tablet PC running Microsoft XP, and a Microsoft Xbox 360 controller
   - 4.2. User inputs should be limited to up/down, left/right, point and shoot actions
   - 4.3. Accommodations can be made at a later date for any other input that the system might require
5. **Actuators**

5.1. There will be no limitation on the actuators used, however linear actuators for aiming systems are preferred by the customer because of their controllability and ability to handle kickback.

5.2. DC power up to 36 volts is available but design should attempt to work within the 12 to 24 volt range that is used by most of the arm joints.

6. Sensors and Feedback

6.1. Actuator and aiming system may be closed-loop

6.1.1. Systems may utilize feedback from a variety of sensors to adjust firing pressure and aim

6.2. A camera will be allocated specifically for the weapon system's use

6.3. A laser aiming device will be used to aid in the targeting of the weapon system

6.3.1. Additional readily available sensors could include infrared (~4 ft) and sonar (~20 ft)

6.4. Additional sensors may be incorporated, as needed, to achieve final design requirements

7. Safety

7.1. Must be secure from shock or vibration induced accidental discharge

7.2. Weapon should not be allowed to be easily controlled by an enemy

System should fail in an "open" configuration so as to prevent unwanted weapons discharge upon unintentional system shutdown

8. LandShark Integration

8.1. Mounting point will be on the right or elevated right side of the "forearm" of the robot. A photo of the LandShark can be seen in the figure below.

8.2. Weapon system may extend from ~4-12 inches away from arm's right edge

8.2.1. Recommended: mounting bracket to the arm should be past the elbow and probably suspended on the right side of the arm (to allow for shell case ejection from the M4).

9. Firing System

9.1. Will be designed for the discharge of semi-automatic weapons. The system must work with the weapons shown in the figures below, but should be as generic as possible.

9.1.1. One actuation of the device fires one projectile

9.1.2. Firing frequency should not be more than one shot per 10 second time period

9.1.2.1. The ideal system will have a firing frequency of less than five seconds

9.2. The impact on the system due to recoil should be mitigated by the design

9.3. Will keep track of ammunition fired using at least a simple "count-down" method

9.4. Allows for repeatable actuation for as long as the system is receiving power and the weapon is loaded with ammunition

9.5. Will be able to fire different types of ammunition in one magazine without manual reloading.

9.6. Will discharge the given set of semi-automatic weapons, but should be generic enough to adapt to various types of weapon firing mechanisms

9.7. Preliminary testing will be done with a paintball gun

10. Aiming

10.1. Purpose of the two joints is to fine tune the robot's shooting position

10.2. Priority will be accuracy over speed.

10.3. Shall consist of two joints

10.3.1. Joint 1 will have motion in the vertical direction (pitch) less than ~90° from center

10.3.1.1. Preference shall be the ability to hit targets on the ground or at elevation such as a second story window from 30 feet.

10.3.2. Joint 2 will have motion in the left and right directions (yaw) shall be less than 45 degrees from center

10.3.2.1. Joint will be further limited so that it does not hit the arm or arm attachments on the left

11. Deliverables

11.1. Drawings, documentation and paperwork

11.2. Return of weapons and destruction of CAD drawings and Software

11.3. Functional delivery and demonstration

Figure 8: View of the Land Shark and Current Arm Configuration[15]

Figure 9: M4 Benelli[16]

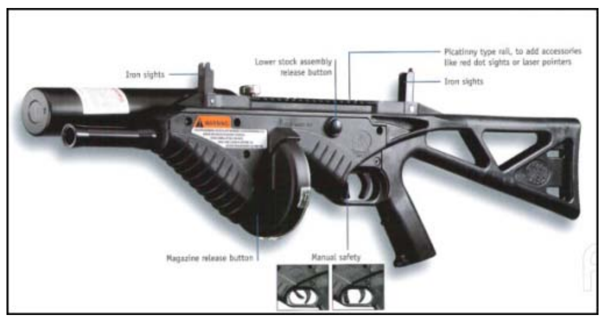

Figure 10: FN 303 Less Lethal[17]

Figure 11: Tippman 98 Paintball Gun[18]

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[15] Image provided by project sponsor.
[16] Image provided by project sponsor.
[17] Image provided by project sponsor.
[18] Image provided by project sponsor.

Company Design Priorities

Based on extensive communication with Black-I Robotics employees, the student was able to create a list of the company's overall design priorities and evaluate what the company would consider to be a "good" design. This process was instrumental in the narrowing down of ideas during the brainstorming process. Additionally, when engineering decisions had to be made and tradeoffs considered, these design priorities proved invaluable because they allowed the student to make a sound decision about what direction to move in with a design that would also be acceptable to the company. A rating system was also applied to the system and a design matrix was created to compare ideas against. Using this quantitative method to evaluate potential designs was a good method to ensure that the student delivered a product to the customer that was in line with their corporate priorities and would be something that they would be able to use for future development.

"COTS" Usage

A major factor that allows Black-I Robotics to be competitive with their product pricing and to have quick deployment rates for new systems is their integration of commercial-off-the-shelf parts. By emphasizing the use of already-developed systems, the company is able to keep their costs associated with the research and development of a completely new system and allows for the rapid deployment and fabrication of their devices.

Cost

The minimization of system cost was key in the design of this device. According to the specifications, for medium volume production, the device cost should be kept under $1500. In order to meet this target, cost must be minimized in every aspect of the design.

Simplicity

Simplicity in design is a key component of Black-I Robotics' operating procedures. One of the reasons why the company is able to produce such quick-deploying systems is its ability to manufacture and build robots quickly. This ability is inherent of a simple design. It is critical, therefore, that the overall design be made to be as simple as possible.

Safety

Safety was high on the list of concerns for the company. Not only was it a priority that the system not accidentally discharge during normal handling, it was critical that an enemy human not be able to take control of the weapon and use it against the robot or the robot's law enforcement team. For these reasons, a design that emphasizes containment of weapon actuation will be deemed better than those that do not.

"Generic-ness" of the System

The customer was very specific in their request for a generic platform. They directly stated that they wanted a generic actuation and aiming device that would be capable of working with a variety of semiautomatic weapon systems. As such, there should be no compromises when it comes to making a device that is capable with working with a wide selection of weapons.

Weight

The weight of the overall device was specified to not exceed 15 lbs, not including the weapon itself. Throughout initial meetings with the customer, they continuously stressed the ability to make the system as "beefy" as necessary. This was exceptionally important because of the lack of recoil data available for the weapon systems used in the device. During initial talks, the sponsor specifically stated that the weight should be minimized, however, it was a lower priority and the weight could exceed the given limit if necessary.

Design Matrix

The design matrix that incorporates these design considerations is as follows:

Item	Weight
COTS Usage	20
Cost	15
Simplicity	20
Safety	30
"Generic-ness"	30
Weight	5
Total	***120***

While it was not necessary to use the design matrix to numerically evaluate designs, the creation of the matrix itself was a learning tool that allowed the student to gain a better understanding of the relative priorities of the sponsor.

Design

As was stated earlier, a systems approach was taken to the design of this device. The trigger actuator was determined to be the most independent system from the rest of the overall product because of the design consideration that it should be as generic as possible, and able to work in a variety of different configurations. For this reason, it was treated like a "black box" with a certain packaging envelope for the design of the aiming and mounting devices. The construction of the aiming mechanism was only minimally dependent upon the construction of the weapons mount system, and so these components were developed almost parallel to each other.

LandShark Simulation Testbed

Since the company was unable to provide a physical LandShark to the project for electronics testing and integration, it was necessary to replace it with a test-bed to facilitate the integration of the entire system. The devised testbed consisted of a device processor and its associated communications scheme, as well as a physical cart and a 3"x4" piece of aluminum tubing mounted to the cart that simulates the robot's arm.

Device Processor

An Asus EEE Seashell netbook was chosen as the primary processor for the device testbed. Extra memory was added to the netbook to ensure quick processing of data. A netbook was chosen over the option of a single-board-computer because it provides an easy-to-use graphical operating system in addition to hardware display components such as a screen and input devices such as a keyboard and a mouse, for roughly the same cost as a single-board-computer. Additionally, the student and project advisors had prior experience using a netbook running Linux to control robots in the past, and so using this method enabled the system to be set up more easily so that time could be better spent testing other more unfamiliar components of the device design. A photograph of the netbook-controller can be seen below.

Figure 12: Asus Eee Netbook/Robot Controller

ELECTRICAL COMPONENT COMMUNICATIONS SCHEME

There are a variety of communications methods that are possible between electrical components. Serial, I^2C, and Serial-Peripheral Interface are all examples of protocols that are used to send information between electrical devices. Overall, the communications protocol choice for this project was not a design-affecting decision, primarily because when the final system is integrated with the LandShark, all of the testbed components will become obsolete. When a standard does not exist for a system (which, for this project was the case) it is up to the engineer's personal preference to choose a means for communication between electrical components. One of the project advisors had extensive experience with the Phidgets brand of components that communicated via USB signal. In the interest of time, the student decided to go with the USB protocol so that she would be better able to spend time elsewhere on the project on creating deliverables for the company.

TESTBED POWER

According to the sponsor, 12V, 24V and 36V power sources would be available on the LandShark for use by the device. It was determined that only 12V and 36V power would be used by the overall device and to simulate the power system found on the LandShark, a 12V Optima battery was used in addition to three WESCO 12V batteries connected in series to provide 36V. Specifications sheets for these items can be found in the Appendix.

TRIGGER ACTUATOR SYSTEM DESIGN

PHYSICAL DESIGN

The inspiration for the basis of the overall trigger actuator comes from the MasterLoc trigger locking system. This device was the first thing that came to mind when trying to come up with a way to mount a generic trigger actuator to a variety of weapons. The features of the trigger lock that are ideal and desirable to be carried into the final design are its ability to fit on a variety of different trigger structures, the small, compact shape, and the ability to adjust the width of the actuator so that it covers the trigger structure entirely. This last trait is desirable to prevent an enemy from potentially taking control of the weapon and using it against the now-defenseless robot, or other law enforcement agents.

Figure 13: MasterLoc Safety Trigger Lock[19]

After initial brainstorming, there were a few major potential design solutions for the actuation trigger actuator, all revolving around the basic idea that the shape would be similar to the trigger lock shown above. The first included the use of a rotary cam system similar to the one in the Cabella's BFM actuator described in the Background Information section of this document. The rotational motion that is inputted by the user through the crank is transformed into a linear motion through the use of a cam mechanism in the device. This method is a very effective way to take a rotary input and transform the motion into a simulated "trigger pulling"

[19] Cabela's Sports Outfitters. 20 February 2010 <http://www.cabelas.com>.

motion. A potential solution using this style of design would include the powered rotary motion provided by a motor and a cam that would rotate the cam to achieve the firing motion. This system, while effective, would require a motor and a motor driver, both of which would be useful for a system where continuous firing of the weapon was necessary. Because the firing specifications were such that the device would not fire continuously, but instead would be fired as-needed in an intermittent fashion, a rotary system does did not appear to be the most simple and ideal method for actuating the trigger. The added complexity that comes from controlling a motor to perform a specified output using methods such as PID controllers or other feedback methods that must also include the addition of sensor systems also make this system less desirable overall. A simpler, “digital” on/off trigger actuator seemed more in line with the simple, robust, repeatable and effective firing mechanism that the sponsor was seeking.

Another idea considered before finalizing the design involved the use of an actuator to actuate a linkage that would squeeze the trigger. To ensure the safety of the device, the system would consist of a clutch mechanism that would disengage the entire linkage from the actuator in an effort to prevent accidental discharge of the system.

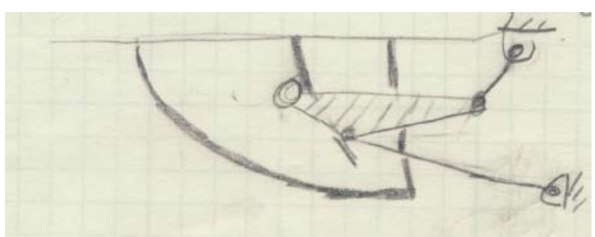

Figure 14: Rough Sketch of Linkage Actuator Idea

This method was deemed too complex and the parts that would have to be manufactured for this kind of system would be small, completely going against Black-I Robotics’ desire for a simple solution. Next, methods for obtaining short quick bursts of motion were investigated in an effort to solve the problem of firing a weapon’s trigger. This made the most sense overall, because the weapon would not be continuously firing, but would be firing intermittently. The simplest solution was determined to be a solenoid-actuated system. Research was performed on the various configurations of solenoids, since the student had limited knowledge of attributes that must be taken into account when choosing a solenoid for use in a device. The main factor in choosing a solenoid for this application was determined to be the force exerted through the entire length of the solenoid stroke. Based on the specifications and reverse engineering of the weapons systems specifically chosen for use in the project, it was determined that an 8 lbf was needed over a stroke of ~.35 inches in order for the system to be able to actuate the triggers effectively. Because of the inherent nature of a solenoid, the force tends to decrease as the stroke length increases, and as a result there were no traditional solenoids that were found that could meet the requirements. Investigation of a solenoid brand called Ledex, however led to the discovery of a solenoid that has the ability to provide a relatively constant force curve with respect to stroke length. A photograph of the solenoid, basic specifications, and its respective force/stroke curve can be seen below.

Figure 15: Ledex Soft-Shift Solenoid[20]

[20] Ledex Solenoid Products and Solutions. 25 February 2010 <http://www.ledex.com>.

Specifications	
Stroke	0.400 ± 0.030 inches (10.16 ± 0.762 mm)
Dielectric Strength	1000 VRMS (23 awg); 1200 VRMS (24-33 awg)
Recommended Minimum Heat Sink	Maximum watts dissipated by solenoid are based on an unrestricted flow of air at 20°C, with solenoid mounted on the equivalent of an aluminum plate measuring 7½" square by ⅛" thick
Coil Resistance	±5% tolerance on all coil awg
Spring Rate	4.41 lb/in; 0.45 lb ±30% preload reference
Weight	12 oz (340.2 gms)
Dimensions	Ø1.875" x 1.935" (See page E10)

Figure 16: Solenoid Basic Specifications[21]

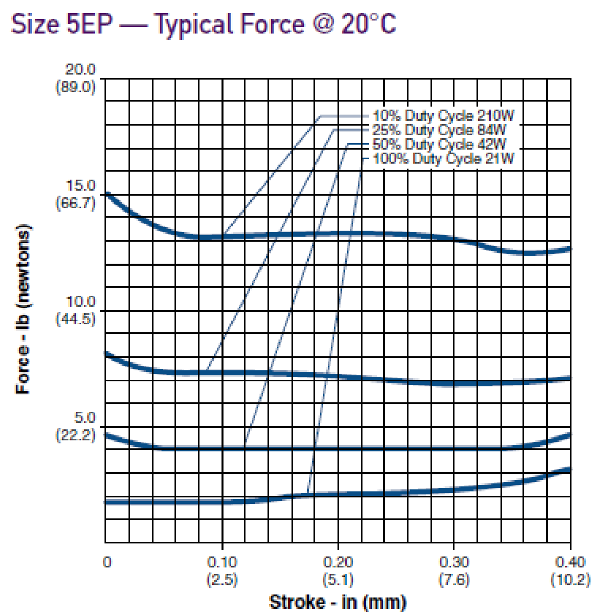

Figure 17: Force vs. Stroke Graph for Solenoid[22]

The idea of a redundant system was investigated, with dual-mounted solenoids providing double the amount of force necessary to squeeze the trigger to the system. This method was dismissed because complexity was added to the system without providing any desired functionality. The goal of this project was to give the customer what they wanted, and a redundant system was not in line with the design priorities.

Another method of solenoid actuation discussed was a two-motion solenoid that would enter the trigger area and then fire the trigger in two distinct motions. The reason for this design was to provide added security in case the system failed. By having two distinct motions necessary to fire the weapon, the system would ensure that the weapon was only fired when it was intended to be fired.

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[21] Ledex Solenoid Products and Solutions. 25 February 2010 <http://www.ledex.com>.

[22] Ibid.

A more simple idea for mounting the solenoid involved an angled position where the stroke of the solenoid directly acted on the trigger. Issues with this method arise in the packaging of the device and the inability to make a generic enough mount to work with a wide variety of weapons if the solenoid was positioned in this configuration.

This potential method added additional complexity to solve the problem of creating a safer method for actuating the weapon that it was discovered could also be easily achieved by mounting the solenoid in such a way that it would fail in an "open" position, or to mount it so that the "powered off" position of the solenoid did not actuate the weapon. This method was deemed to be the simplest way to actuate the overall system.

A main issue regarding the security of the entire system involves the ability of a person to use a screwdriver, or some kind of multi-tool on the actuator to disassemble it so that the weapon would be in their control. Initial methods to solve this problem included the integration of locking mechanisms into the trigger actuator system, similar to those found in the Master Loc trigger lock shown in the beginning of this section. A more elegant method of utilizing security bolts (shown below) was employed instead however, because of the simplicity involved with drilling a hole for a bolt as opposed to designing an entire locking mechanism.

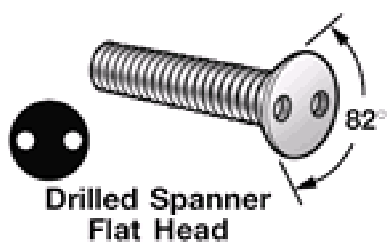

Figure 18: Security Screw Used in Actuator Design[23]

Security screws are regular screws that have a unique feature on their head which enables them to only interface with a special tool. By integrating two security screws into the design of

[23] McMaster Carr. 15 March 2010 <http://www.mcmaster.com>.

the system, a simple method for preventing an enemy from tampering with the trigger actuator was achieved.

The physical structure of the final trigger actuation device incorporated all of these design considerations and can be seen in the CAD model below. The addition of a rubber cover to each of the plates will aid in the positioning of the system by providing a pliable surface as well as the prevention of damage to the weapon. Note that the rubber cover is not shown in the below image.

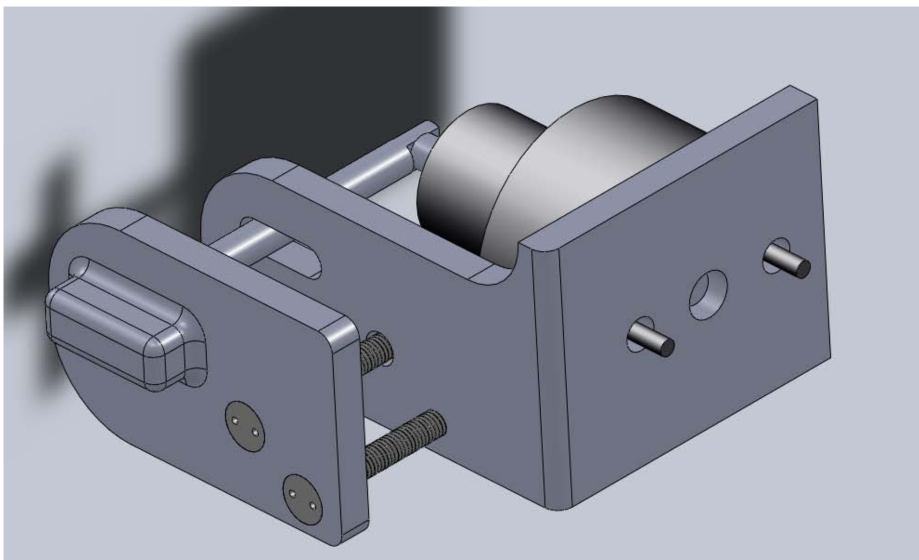

Figure 19: Isometric View of the Physical Structure of the Trigger Actuation System

System Control

Because the Trigger Actuation system utilizes a solenoid to actuate the weapon triggers, it was determined that a relay was the best method for controlling the solenoid. The Phidgets Relay Kit shown in the figure below was the ideal choice for the testbed control of this device. Based on the voltages available on the LandShark, and after looking at the power output for various voltages, it was determined that the system would run off of the 36V power source on the testbed.

The programming for this system shall involve the direct issue of a command to actuate the firing system, thus firing the weapon.

AIMING MECHANISM

PHYSICAL STRUCTURE

It was determined that in order to achieve the project specification of allowing accurate smooth motion through a 180° pitch angle and a 45° yaw angle, that the motion should be broken up into two separate motions achieved by independent actuators. Early brainstorming for this system involved the mounting of the entire system on a turntable to achieve yaw motion and the fixed pivoting of the front of the weapons to achieve pitch angle. This idea was decided against due to the additional complexity involved with the use of a turn table was not worth it because the system only required 45° of rotation in the yaw direction whereas the turn table would allow for that, plus an extra 270° of motion.

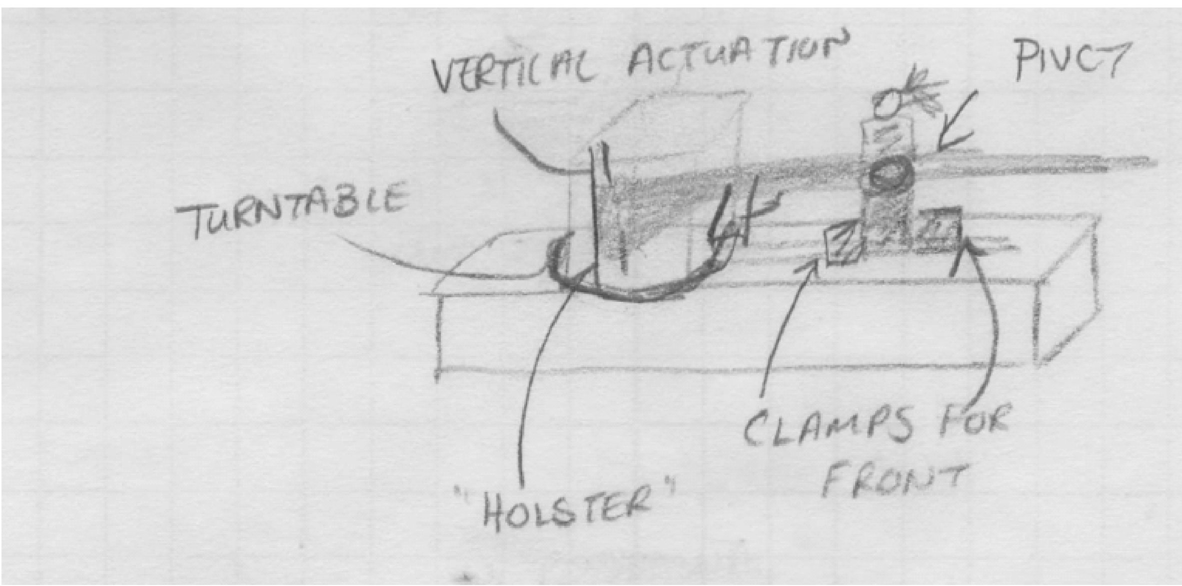

Figure 20: Sketch of Initial Turntable & Pivot Idea

Another idea considered to provide motion in the two directions was an actuated universal joint that was constrained in such a way that it could provide motion in both required directions. Further investigation into this idea showed that virtually no existing devices operate on this kind of principle, and as a result, development from the ground up would have been required to achieve this unique solution. A system designed in this manner would have been effective and possible. It was determined however that it was not a solution that was in line with the sponsor's goals of "commercial-off-the-shelf" solutions to problems that were inexpensive and could be developed quickly. A CAD model of this proposed design concept is shown in the figure below.

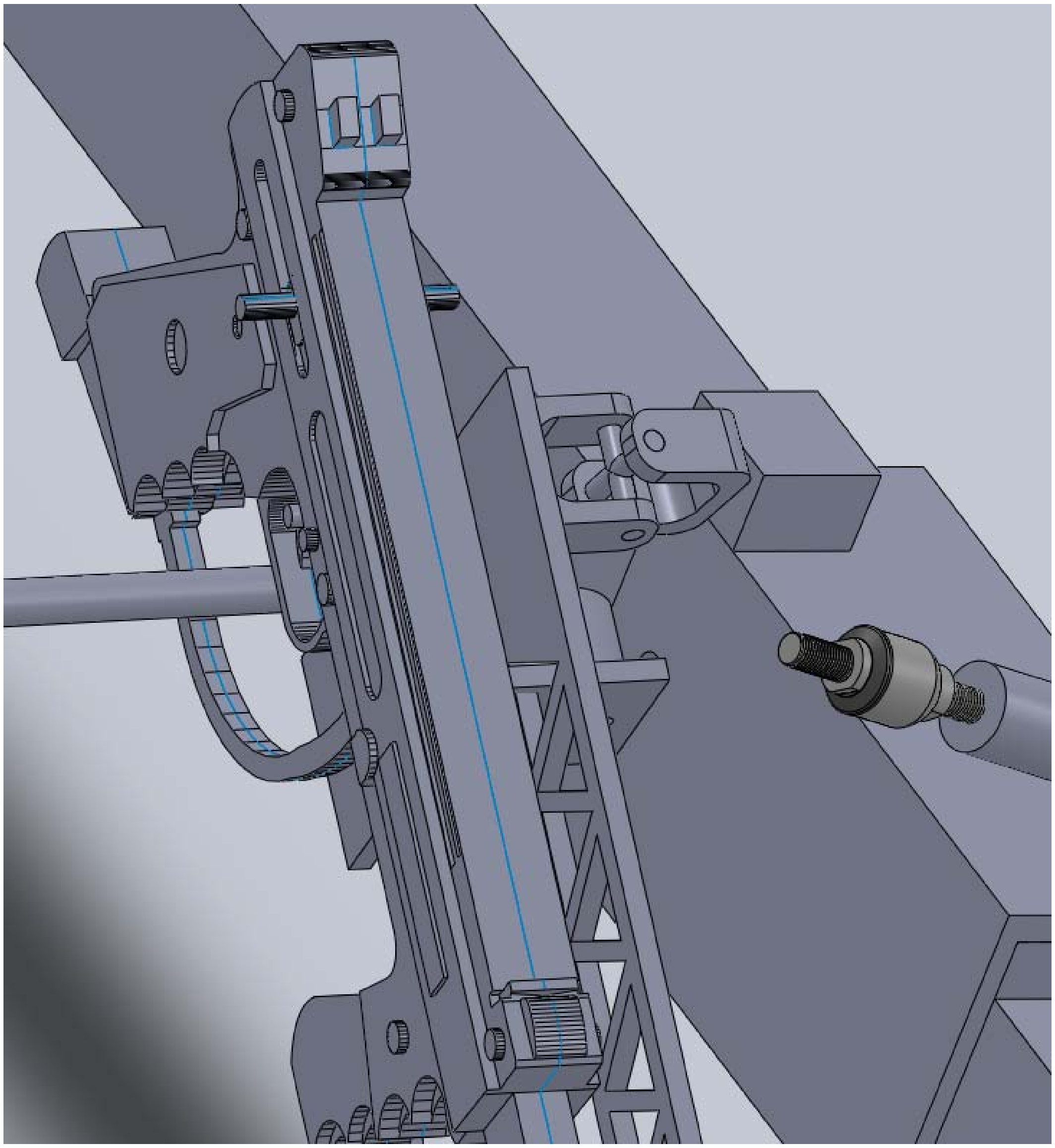

Figure 21: CAD Model of the Constrained Universal Joint Idea

After dismissing the idea for a universal joint, it was determined that a simple hinge that would "hinge" in the yaw direction and rotated to provide pitch motion would be the most simple and effective method for the dual motion necessary for this system. The hinge that was selected was found on the McMaster Carr website and had normal applications as a hinge for industrial freezer and refrigerator doors. A photograph of the hinge can be seen in the photo below.

Figure 22: Chosen Hinge for Yaw and Pitch Motion

When the hinge was purchased, there were no specifications on the loading capacity of the hinge, so alternate solutions were sought as a backup plan. An alternative hinge was found, made by a company called “Innovative Hinge Products, Inc” and costing $150. Due to the high cost, the alternative hinge was deemed a last-resort solution and can be used if the sponsor desires a more solid and finished solution.

Figure 23: Backup Hinge Solution[24]

Actuators to provide motion in the pitch direction were considered first. It was determined that a motor would be the best option to provide motion in the pitch direction, as opposed to a linear actuator, since a smooth rotary motion that was easily controllable was needed.

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[24] “Innovative Hinge Products.” April 2010. < http://www.ihpinc.net/roller.htm>

A low speed, high torque setup was needed for this application and a variety of different types of motors were investigated. A high-speed motor such as a CIM brand motor was investigated, but significant reduction in gearing would be necessary to make this motor work in the application. A quote was obtained for a planetary gearbox from a company called Neugart USA that would provide the necessary reduction in a compact space. Getting the gearbox in the timeframe it was needed and in the desired configuration would have cost over $1000. Since that was two-thirds of the total budget, that option was definitely out of the question. A more simple and less expensive method was then investigated. The least expensive and most functional of all potential solutions involved the use of a automotive motors used in window lift and windshield wiper applications from a company called AM Equipment. The main benefits of these motors were that they were inexpensive (costing $30-$40 each) and that they came pre-packaged with their own worm gear gearbox. The worm-driven system would provide added protection against system backlash caused by recoil, which was a desired trait of the overall aiming device. Once this brand and motor supplier were discovered, torque calculations were performed on potential motors and it was determined that the 14 N-M window motor would be able to provide enough torque to power the system.

Required Torque for Pitch

$$weight_{sysMax} := 15 \cdot lbf$$

$$weight_{gunMax} := 7.8 \cdot lbf$$

$$weight_{yawActuator} := 5 \cdot lbf$$

$$TotalWeight := weight_{sysMax} + weight_{gunMax} + weight_{yawActuator} = 123.661\,N$$

$$TotalMass := \frac{TotalWeight}{g} = 12.61\,kg$$

$hei := 5 \cdot in$
$wid := 4 \cdot in$
$len := 6 \cdot in$

Center of Mass Coordinates

$$radius := len$$

$$h_i := 0 \cdot m$$

$$h_f := len$$

$$I_{zz} := TotalMass \cdot radius^2 = 0.293\,m^2 \cdot kg$$

$$IdealVert := \frac{(90deg)}{7sec}$$

Ideal time to get from horizontal to vertical position

$$\omega_{desired} := IdealVert = 12.857 \cdot \frac{deg}{sec}$$

Velocities for the System

$$\omega_i := 0$$

$$\omega_f := 0$$

$$KE_i := .5 \cdot I_{zz} \cdot \omega_i^2 = 0$$

Initial Energies

$$PE_i := TotalMass \cdot g \cdot h_i = 0$$

$$KE_f := .5 \cdot I_{zz} \cdot \omega_f^2 = 0$$

Final Energies

$$PE_f := TotalMass \cdot g \cdot h_f = 18.846\,J$$

$$F_b := .00015 \cdot TotalWeight \cdot .5 \cdot in = 2.356 \times 10^{-4}\,J$$

Bearing Friction

$$\theta := 90 \cdot deg$$

$$\tau_{PitchNeeded} := \frac{\left(KE_f + PE_f + F_b - KE_i - PE_i\right)}{\theta} = 11.998 \cdot N \cdot m$$

Figure 24: Pitch Torque Requirement Calculations

After finalizing the pitch motion, yaw actuation needed to be determined. One idea for actuation in the yaw direction involved the use of a linear actuation mounted above the system that would be positioned in a slider-crank linkage configuration. In order to achieve the force required to move the system, a linear actuator that costs about $150 was needed.

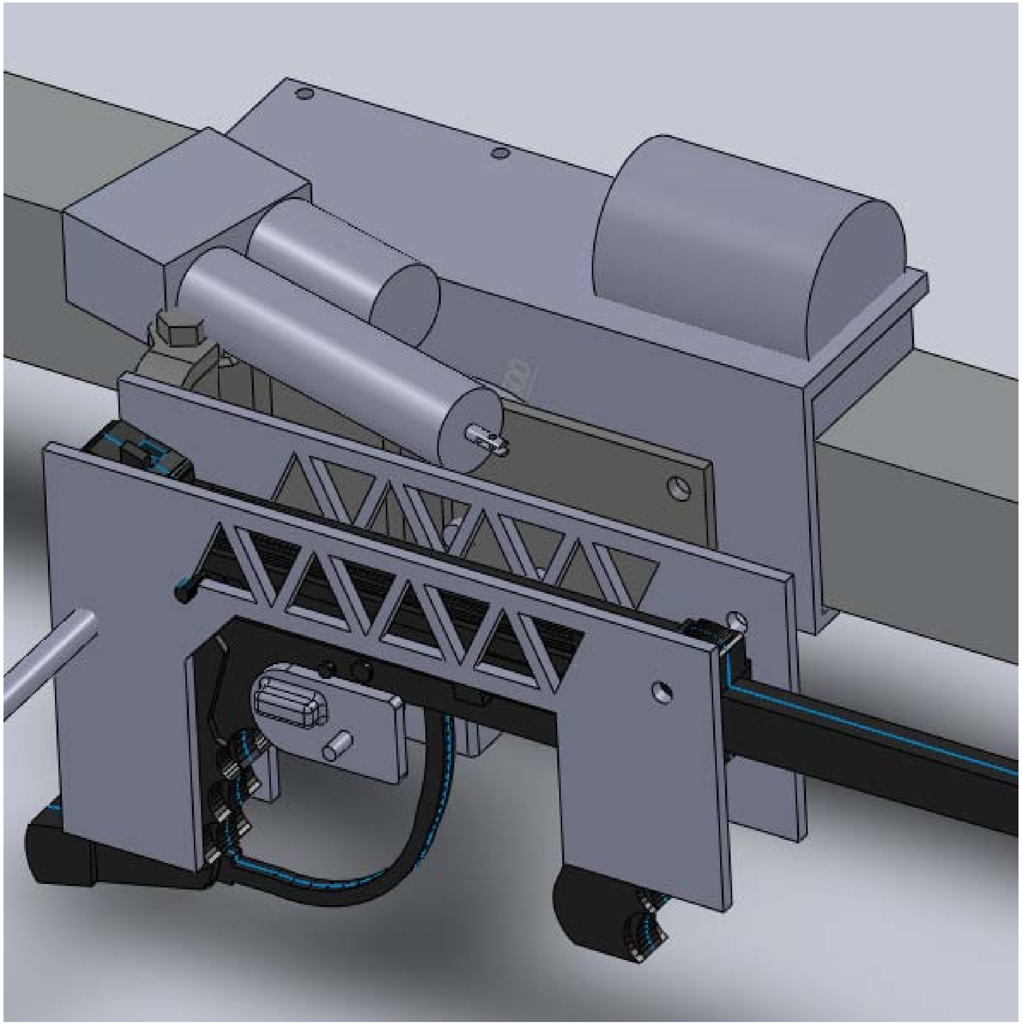


Figure 25: Linear Actuator, Side View

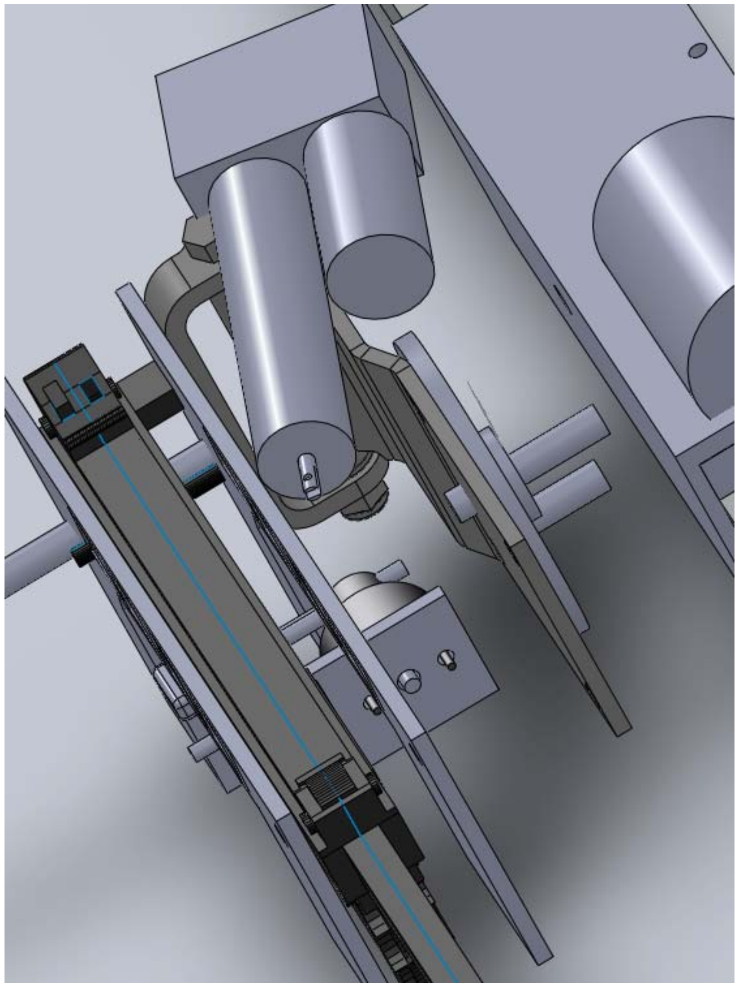


Figure 26: Linear Actuation Idea, Top View

Further thought led to the conclusion that it would be possible to use a directly-driven AM Equipment window motor with the system. Because more force would be required to move the motor in the pitch direction than in the yaw direction, the fact that the moto had sufficient power to actuate the pitch motion mechanism, it would have enough to actuate the yaw motion mechanism. This option was ideal since it would require no gearing and would be involve a relatively simple motor mount and coupler to the rest of the system.

AIMING MECHANISM RESULT

The results of this finalized physical design for the pitch and yaw motion can be seen in the CAD model below.

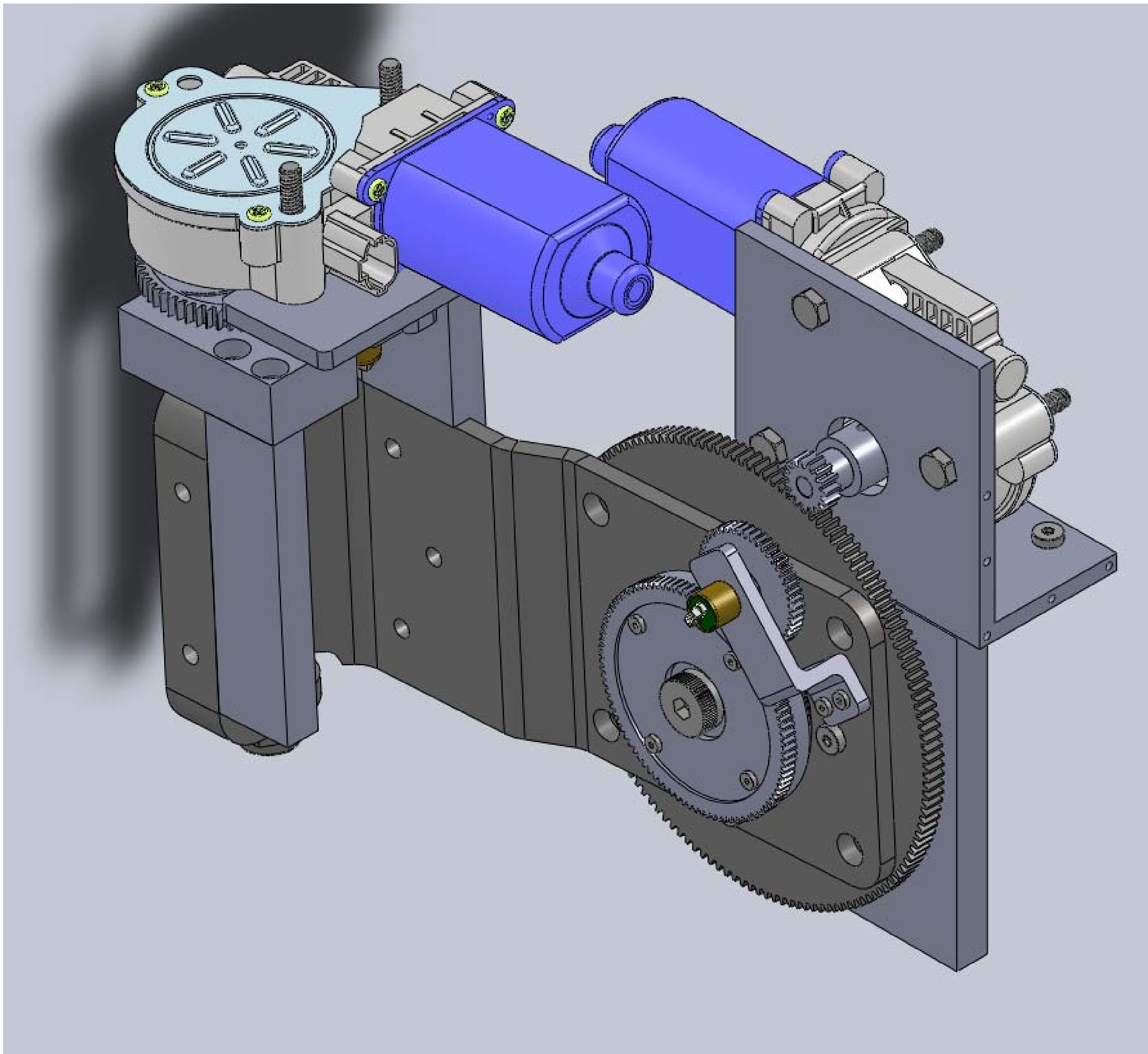


Figure 27: Isometric View of Aiming System

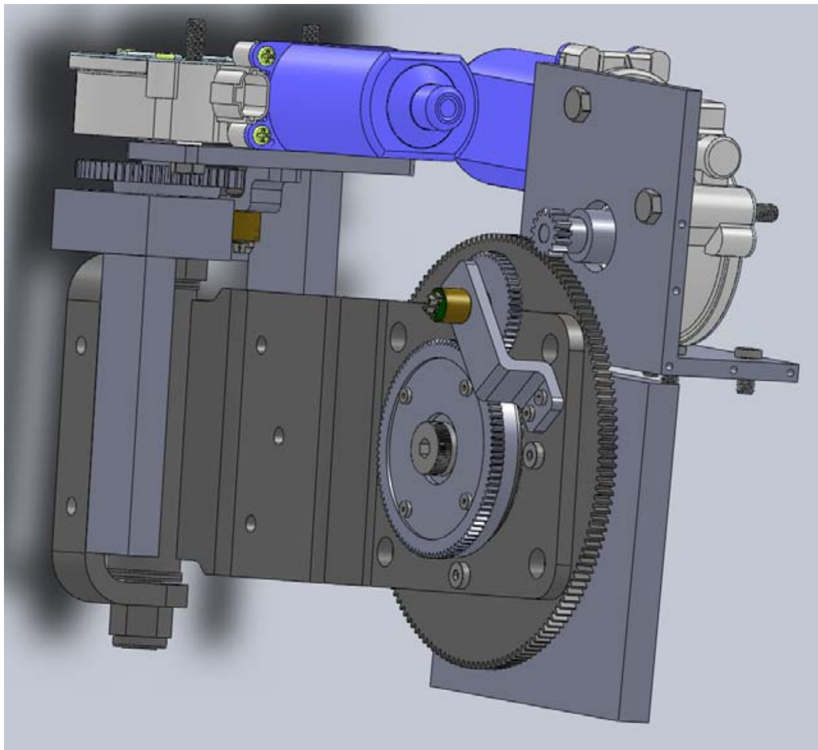


Figure 28: Additional View of Aiming System

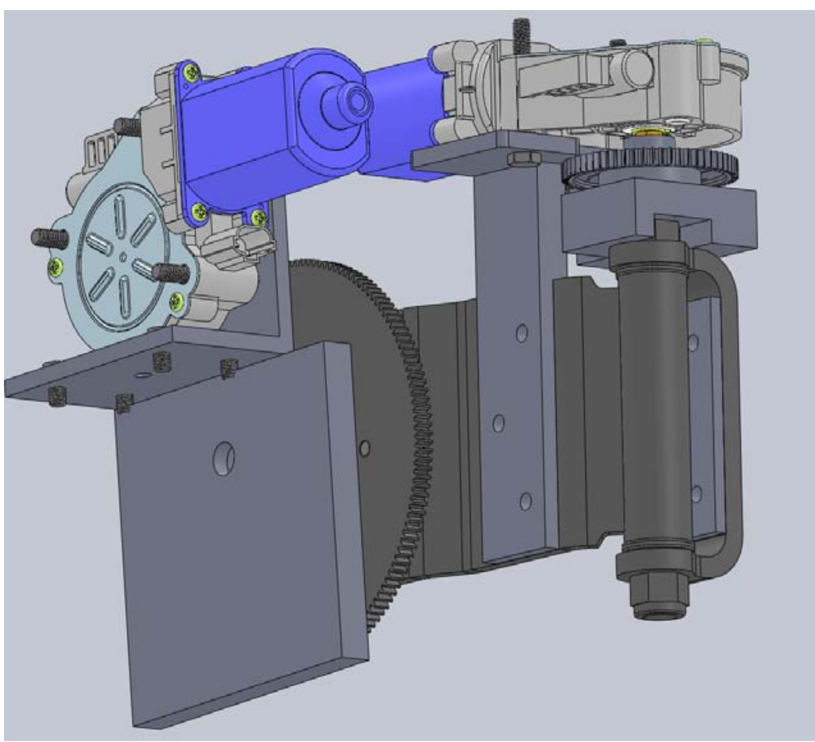


Figure 29: Additional View of Aiming System

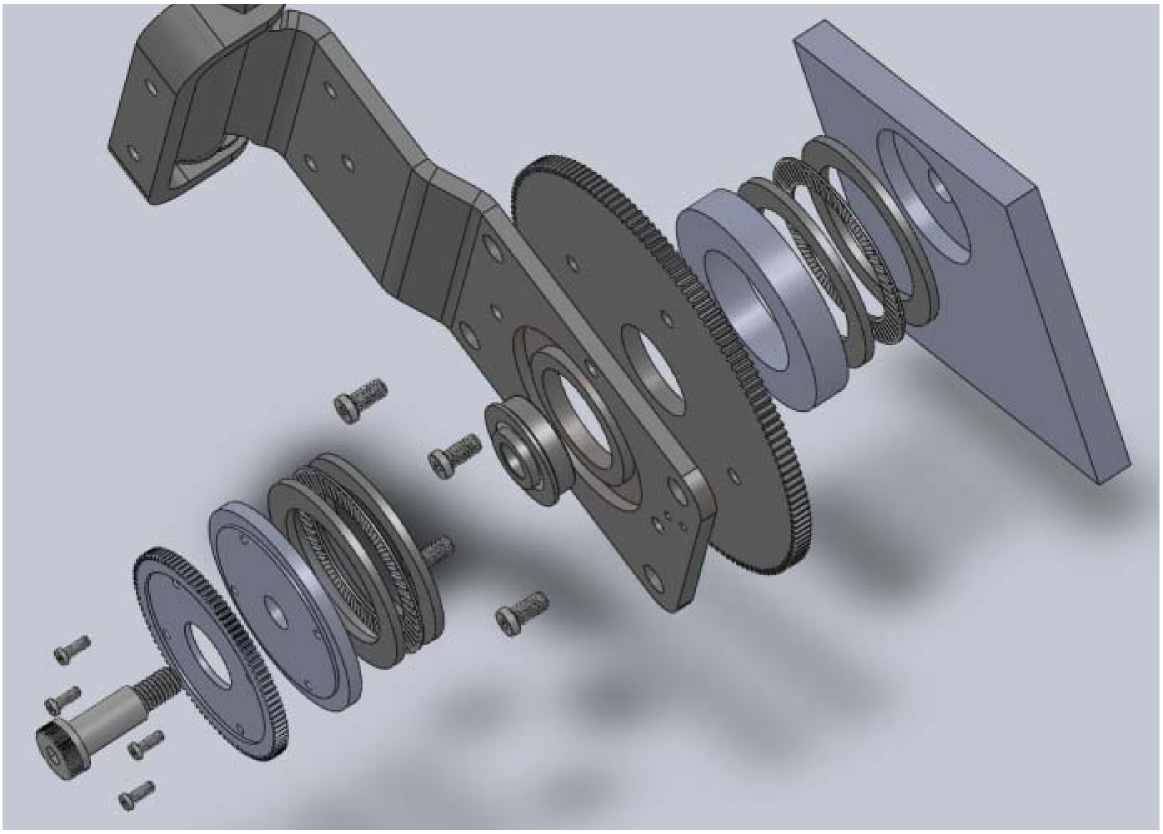


Figure 30: Exploded View of the Pitch Motion Assembly

SENSOR CHOICE

Sensors to track the rotational motion of the aiming system in the pitch and yaw directions were a critical component in the system. Knowing the accurate location of these two positions allows for the ability to aim the weapon at an intended target—a major functionality requested by the sponsor. Rotational sensors considered for the system included optical, magnetic encoders, potentiometers and Hall Effect sensors. The ultimate decision was made to attach two sensors, both an absolute magnetic encoder and a rotary optical encoder to the device.

A Hall Effect sensor was deemed to be an impractical solution because these sensors are generally used to track the motion of gear teeth from a transmission attached to a motor. While this method might have worked on the pitch axis because of the large gear used, the yaw motion involved the direct driving of the system by the motor and the only gear involved with this system that could potentially be sensed was the worm gear located on the inside of the motor which was made of plastic. Additionally, Hall Effect sensors are generally used to measure the rotational speed of a gear. Because precision was needed in the measurement of position, a Hall Effect sensor was eventually ruled out completely.

One of the criteria for the system was its ability to know the position of the weapon upon start up. Knowing this would eliminate the need for time-consuming startup calibration procedures. For this reason, an absolute encoder was chosen to measure the absolute position. This encoder was geared so that it was not permitted to rotate more than 360^{o}. Adding an incremental encoder allows a higher degree of resolution on the yaw and pitch motions of the system. More testing needs to be done to verify the results of this choice.

SYSTEM CONTROL

Precise motor speed control is generally accomplished through transmitting a "Pulse Width Modulated" or PWM signal. In order to control the Pitch and Yaw motors, a LynxMotion SSC-32 PWM signal generator was chosen and is interfaced to the main controller through a USB to RS232 adapter. The outputted signal is transmitted to a Vex brand Victor 884 H-Bridge speed controller which pulses the motors appropriately.

The signal from the absolute encoder is read by an analog-to-digital converter contained within the Phidgets brand Interface Kit and is transmitted to the main controller netbook via USB. Specifications sheets for these components can be found in Appendix 4 and an excerpt from the electrical components diagram that outlines the connections between components can be seen in the figure below. A larger view can be seen in Appendix C.

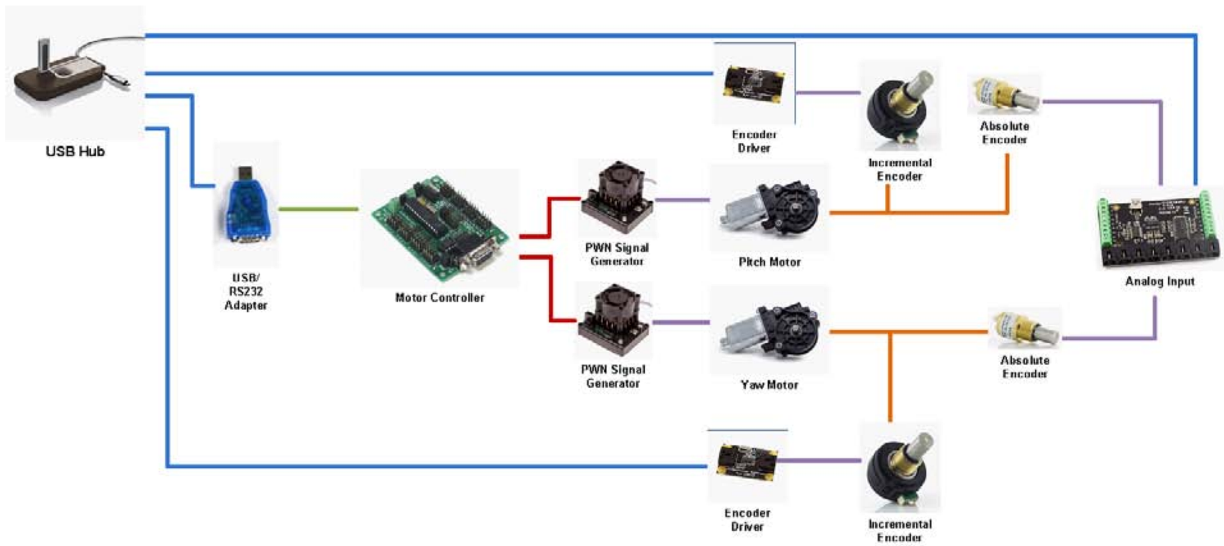


Figure 31: Aiming System Electrical Components Diagram

MOUNTING METHOD

The ability to securely hold the weapon during firing was a major design challenge that needed a solution during this project. The problem of creating a generic enough method for mounting the weapon was definitely a challenge because most systems that are made to mount a variety of weapons are also complex and cumbersome. Initial brainstorming yielded numerous ideas that involved the clamping of the weapons, as this seemed to be the most secure way to fixture a variety of differently shaped weapons. One of the first ideas involved the creation of locking clamps that were shaped like hands. Reasoning behind this idea was that since the weapons were designed to be used by human hands, the most effective method might just be making a system that resembled hands. Attempts to implement this method though were large and complex, and a more simple solution was sought. Another main idea involved ratcheting clamps that would secure the weapon in a few key points. The ratchet would function in a manner similar to the mechanism used on caulking guns shown below.

Figure 32: Caulk Gun with Ratcheting Position Control

The development of this system in a configuration that could fit a large variety of weapons ranging from the FN 303 less lethal (shown in the specifications section) to the M4 Benelli would involve the use of a extra mounting points that wouldn't always be used and that would add weight and complexity to the system.

A more simple and robust method of casting the weapons to be used in a rubber compound was eventually decided upon. Doing this would enable the sides of the mold to be a uniform flat shape that could be more easily clamped by the mounting system in a set of plates. Threaded rods and screws would clamp the two plates together around the rubber mold, thus holding the gun encased in the rubber securely. An added benefit of using a rubber housing for the weapon is the ability of the rubber to absorb some of the recoil that the gun exerts when it is fired. An image of the proposed weapons clamping system can be seen in the figure below.

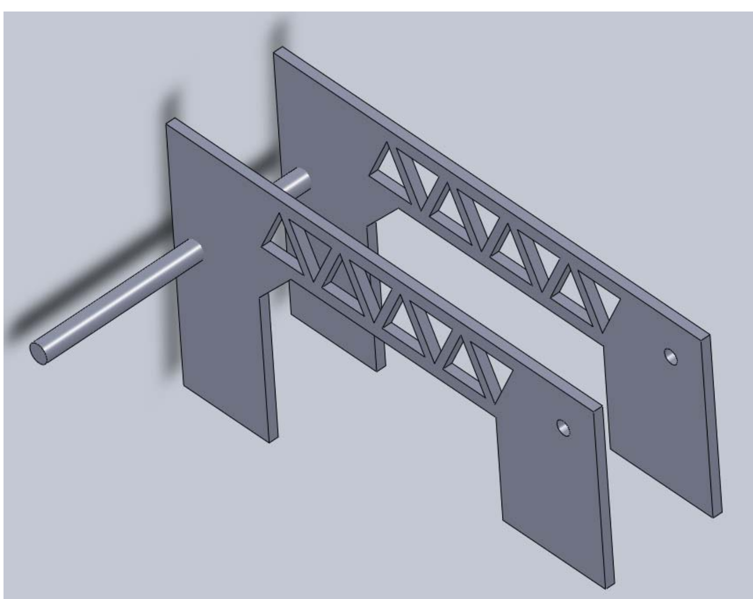


Figure 33: Isometric View of Clamping Plates and Main Screw

A flexible urethane rubber was chosen for this application because of its low post-curing shrinkage properties, and its initial viscosity that would enable it to flow into the many crevices on the weapon, enabling the creation of a truer mold. The rubber compound chosen had a shore hardness of A60, which is roughly the hardness of the heel of a running shoe, was water and abrasion resistant and had the ability to withstand extreme temperatures of -40° to 180°. A specifications sheet for the urethane compound used can be seen in the appendix and a photo of the mixed compound can be seen below.

Figure 34: Urethane Rubber Casting Compound

PROTOTYPE CASTING RESULTS

A test run of the proposed urethane rubber casting process was performed on the Tippman 98 Paintball gun. Prior to casting, various orifices and hardware components on the weapon were masked to prevent rubber from entering them. The photo below illustrates the student pouring the urethane and catalyst mixture into a constructed box containing the prepared weapon.

Figure 35: Pouring of the Urethane Casting Compound into the Prepared Mold

The box and the weapon were heavily coated in a silicone spray to aid in the mold release process. Only half of the weapon was cast in the first round to allow for the mold to exist in two separate pieces. After the first half of the rubber cured (~16 hours later) a plastic film was applied to the top of the weapon and more urethane compound was poured on the top of the weapon. The result was a two piece mold of the weapon that provides a flat surface for the weapons system to clamp on to.

Figure 36: Weapons Mount Mold for the Tippman 98

WEAPON MOUNT SAFETY

A major safety concern was brought up during the preliminary design review by a professor who has extensive knowledge of sport shooting. A major assumption in the overall design was that, in the same way that a human law enforcement agent who is using a weapon walks around with the safety off, once the device was set up and the robot was armed, the robot would function with the safety off. Safeguards against accidental discharge of the weapon would be prevented by means of the ability of the trigger actuation device to fail in an "open" position. From a professional's standpoint, prevention of accidental discharge by making the device fail "openly" is not enough to ensure that the device will never fire when it is not intended to. Active prevention of firing through the use of the weapon's specific safety lock is, from a professional's standpoint, the only way to ensure that the system does not fire uncontrollably. Vibrations, shock to the system and other factors may cause the weapon to accidentally discharge in a manner that is inconsistent with the robot operator's intentions.

For purposes of this project, and to create a "generic" system that works with a variety of semi-automatic weapons, it was necessary to draw the line at a reasonable point in terms of overall weapons functionality. Gun safeties are mounted in a wide variety of locations on different weapons and a system that was designed to turn off the safety each time before the weapon is fired would be an impractical addition to a design specifications list whose main goal is to be as "generic" as possible. Additionally, the robot is performing in situations that it can be assumed that a law enforcement agent is performing in. When an agent is carrying out their mission, they do not stop and turn the safety off each time that they fire their weapon. Doing this would make them extremely vulnerable to attack from the enemy. In the same way that law enforcement agents do not always have their weapon pointed at a potential target, the immediate solution to this potential problem is to program the robot to have the option to stow the weapon in a downwards vertical position when it is driving around completing its other missions. Since the device already has this functionality built in, this solution is both easy to implement solution and will be effective in providing an additional layer of security to the system that directly parallels with a solution that law enforcement agents already implement during their missions.

LANDSHARK INTERFACE

The connection point between the LandShark robotic platform and the device was a critical component to consider when designing the device. The sponsor specifically stated that they wanted a "Picatinny Rail-style" mounting point for the LandShark in order to aid in alignment of the overall system. The proposed design involved a custom slotted system attached to the LandShark with a mating section that is attached to the device. This part was modeled after the slots that can be found in CNC milling machine tables, and a tool used to cut these slots was the proposed tool for cutting these "T" shaped slots. The entire system is aligned using these mating blocks and is actually mounted to the system by a "C" shaped piece of metal that houses the mating piece and is clamped to the LandShark arm rail using bolts. This method should ensure secure and aligned mounting of the overall system to the LandShark robotic platform. A CAD model of the proposed design can be seen in the figures below. Note that the LandShark arm segment is shown as the darker gray tubing.

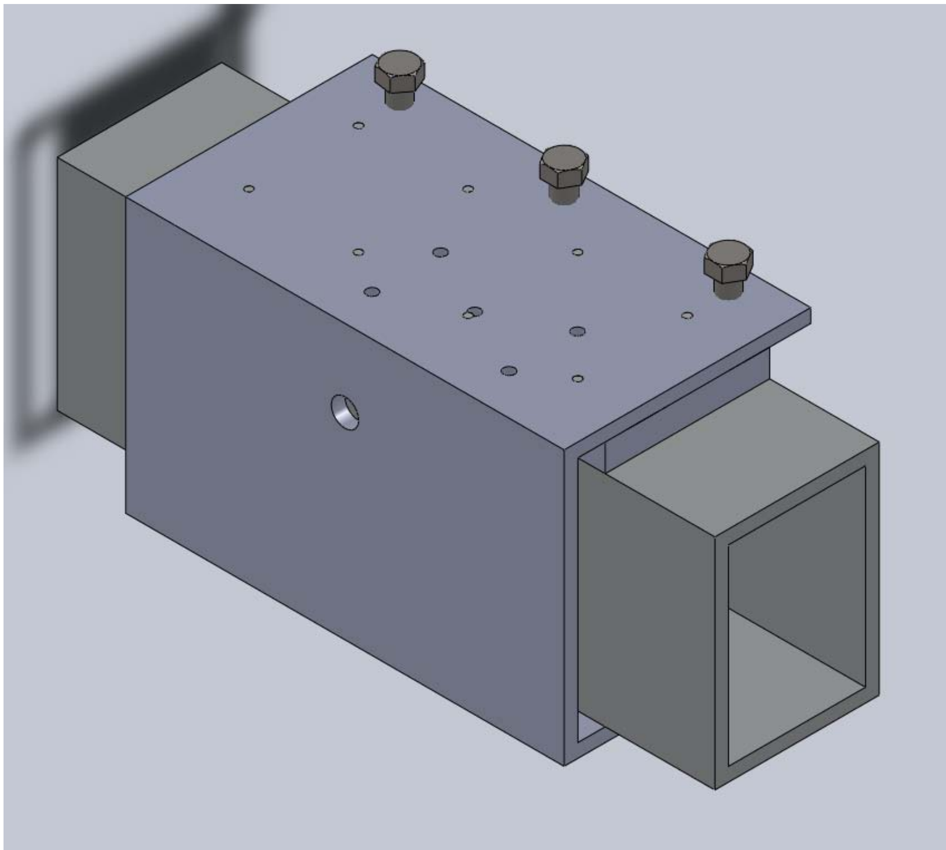


Figure 37: Isometric View of the Mounting Method System

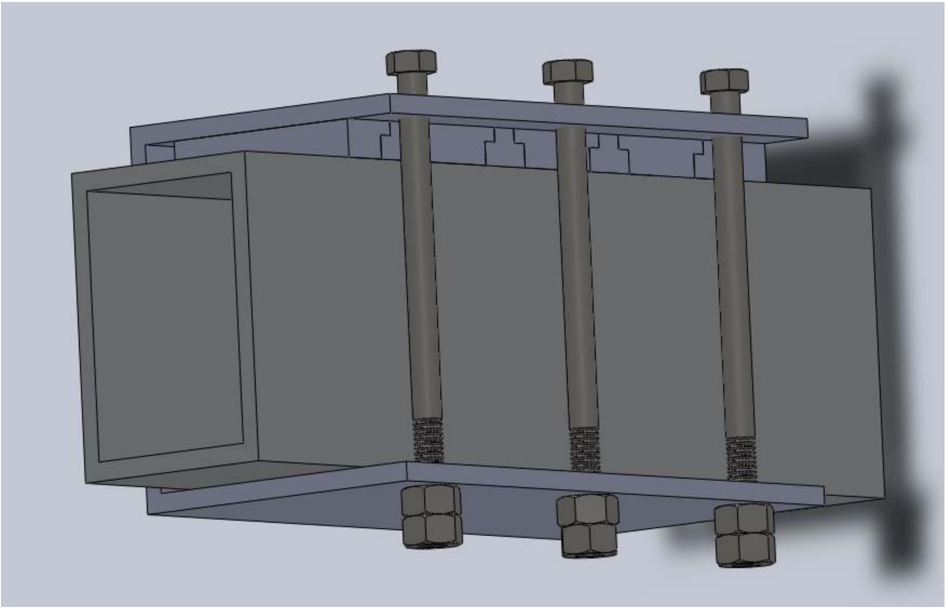


Figure 38: Additional View of the Mounting Method System

VISION SYSTEM

The device vision system consists of a cylindrical shaped KT&C day and night bullet camera that is mounted to the left of the weapon on the back weapon mounting plate. The camera provides a standard output and the image is transmitted to the netbook via a USB connection to a Pinnacle Brand Dazzle DVD Recorder. Photos of these two devices can be seen below. The image is currently directly read into the controller by a Linux program called XawTV that only takes the image and directly displays it on the screen. Future work must be done to process the received image.

Figure 39: KT&C Bullet Camera

Figure 40: Pinnacle Dazzle DVD Recorder

In conjunction with the camera's vision, the system shall rely on existing laser sights that come standard with weapons that will continuously show a laser point where the gun is aimed. Using the vision system in conjunction with this laser point, the robot will be able to figure out where it is aimed in its environment. An offset will be programmed for each of the weapons used with the system, and code will compensate for distance differences between the laser and the barrel of the weapon. Vision processing will later match up the view of the intended target with the sight of the weapon using the laser point as a reference to align the two image segments.

DESIGN RESULTS

Views of the CAD models of the final design results can be seen in the figures below. Please note that there is a rubber casing around the weapon that is not shown in the images.

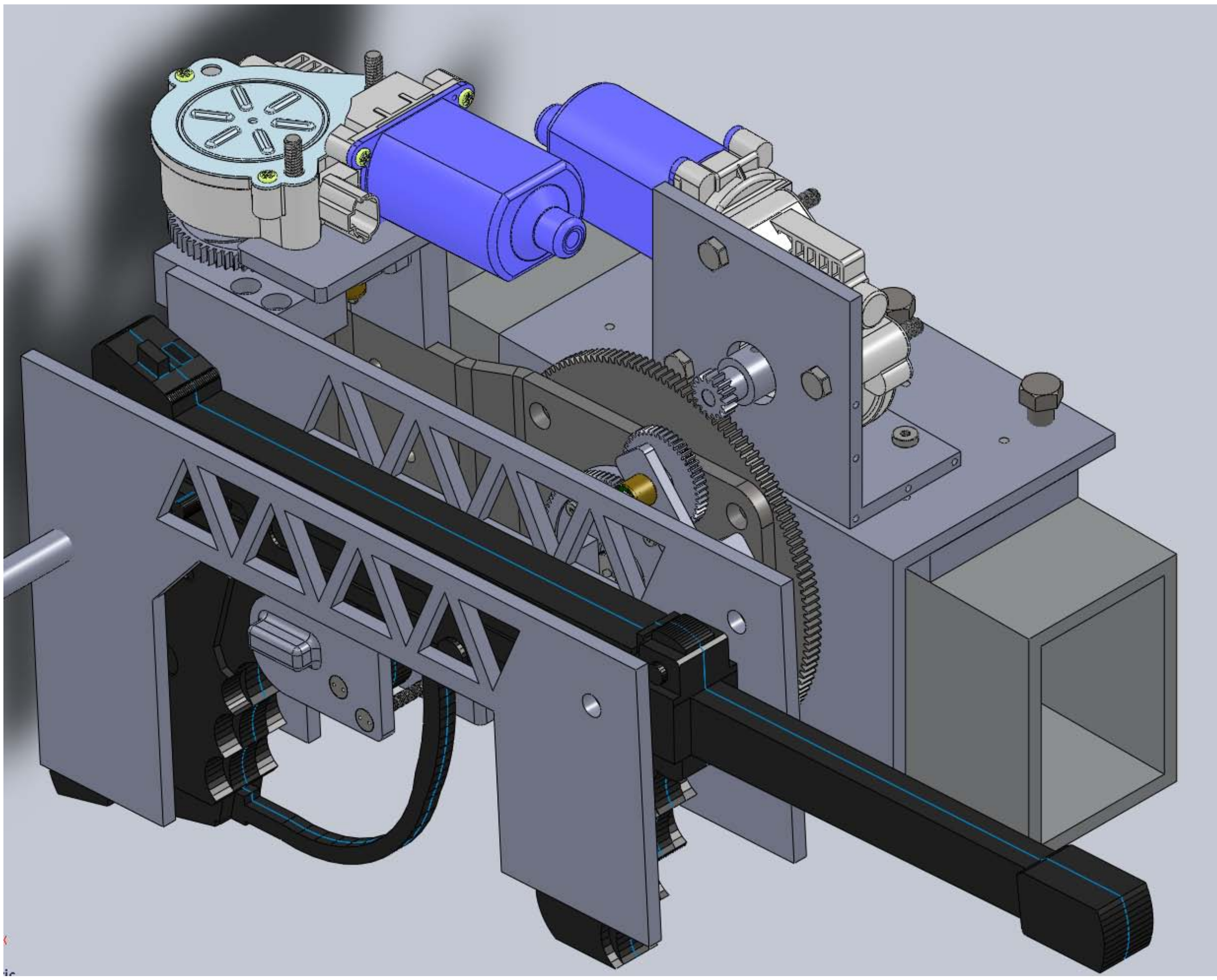


Figure 41: Isometric View of the Device Assembly Final Design Result

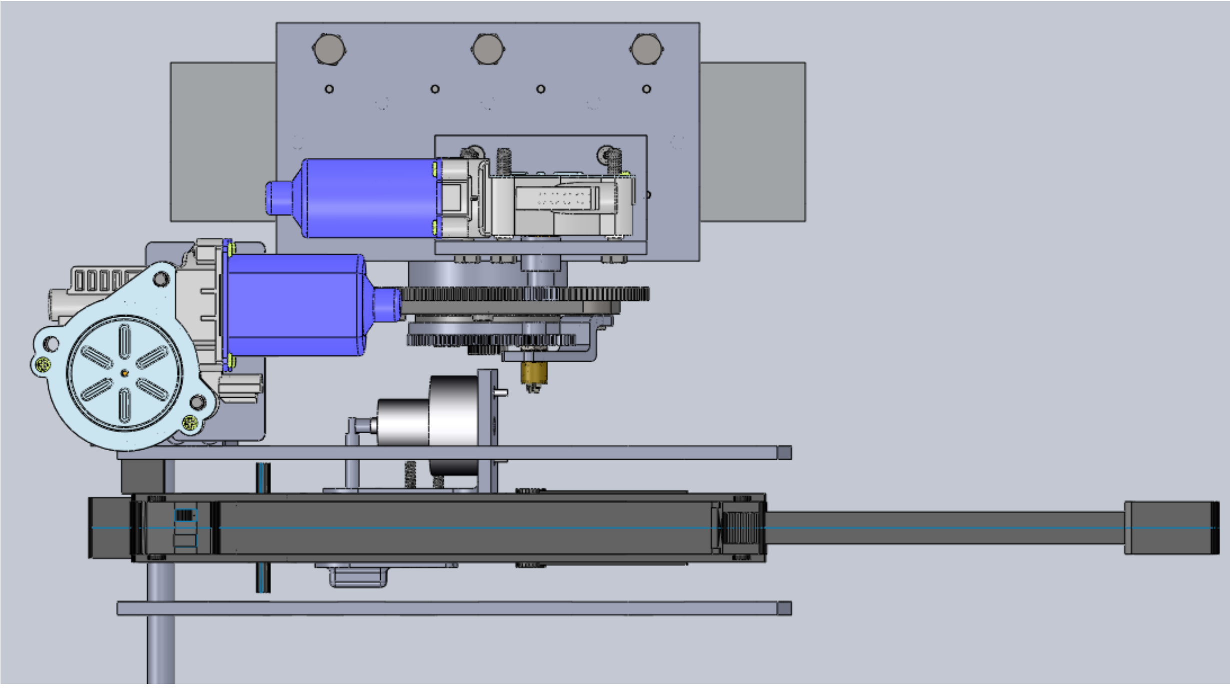


Figure 42: Top View of the Device Assembly Final Design Result

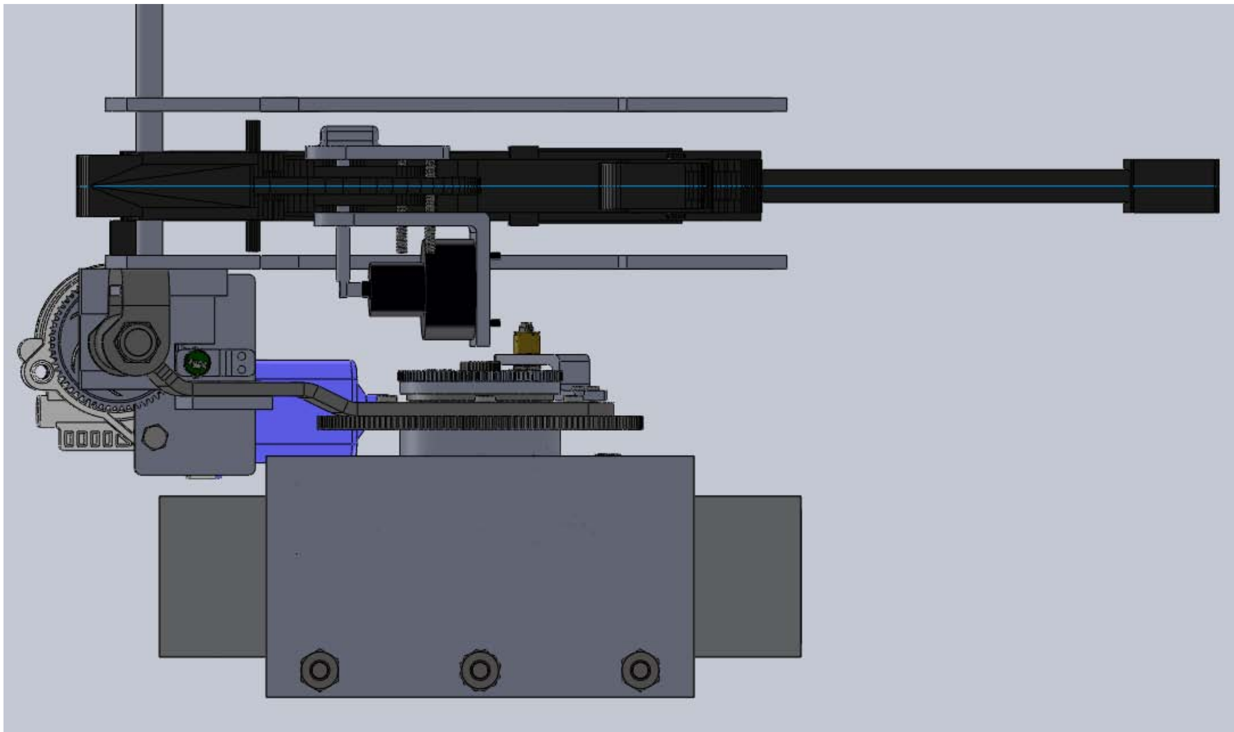


Figure 43: Bottom View of the Device Assembly Final Design Result

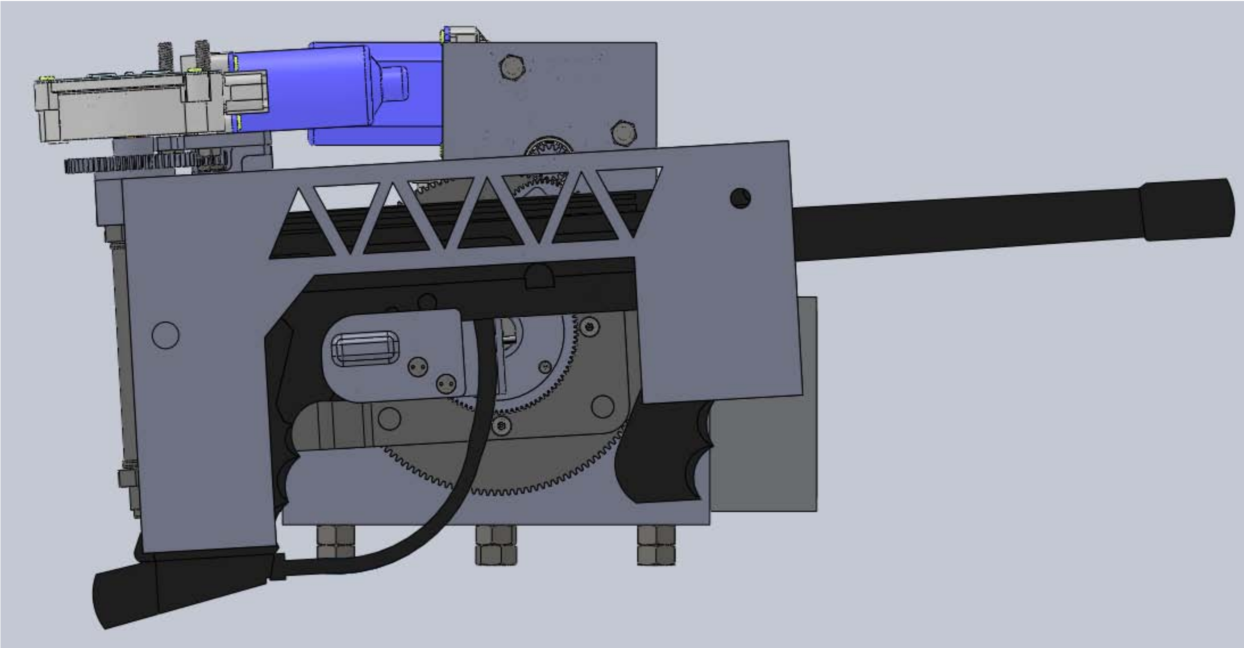


Figure 44: Right Side View of the Device Assembly Final Design Result

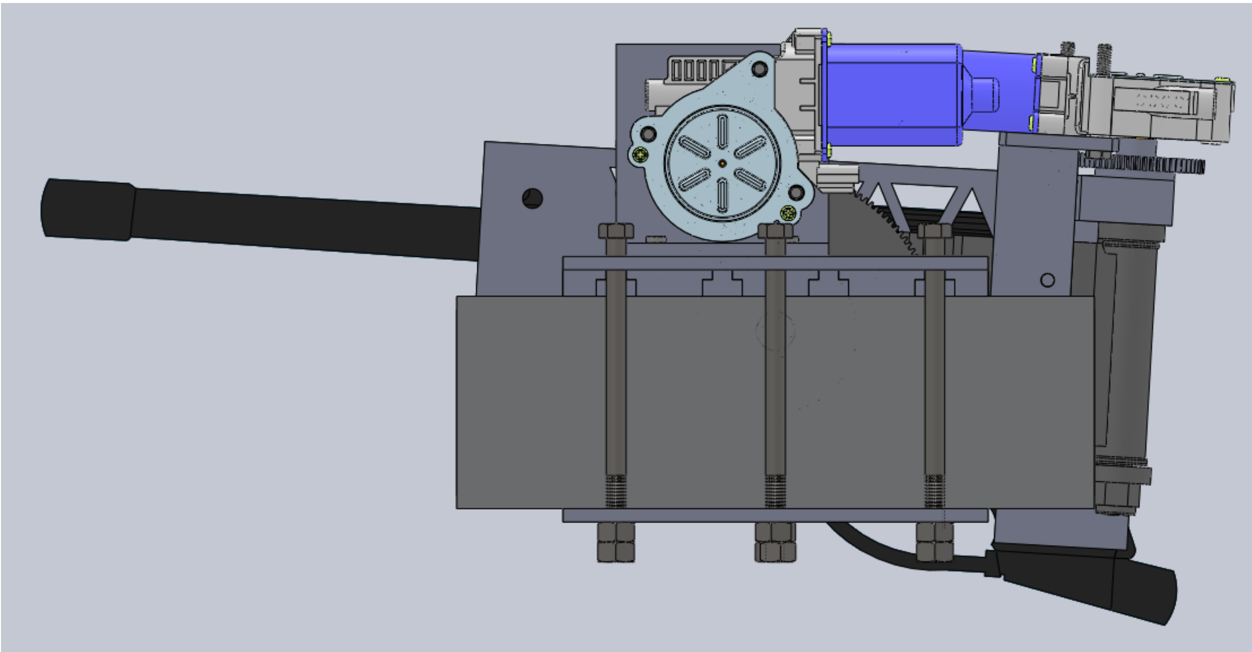


Figure 45: Left Side View of the Device Assembly Final Design Result

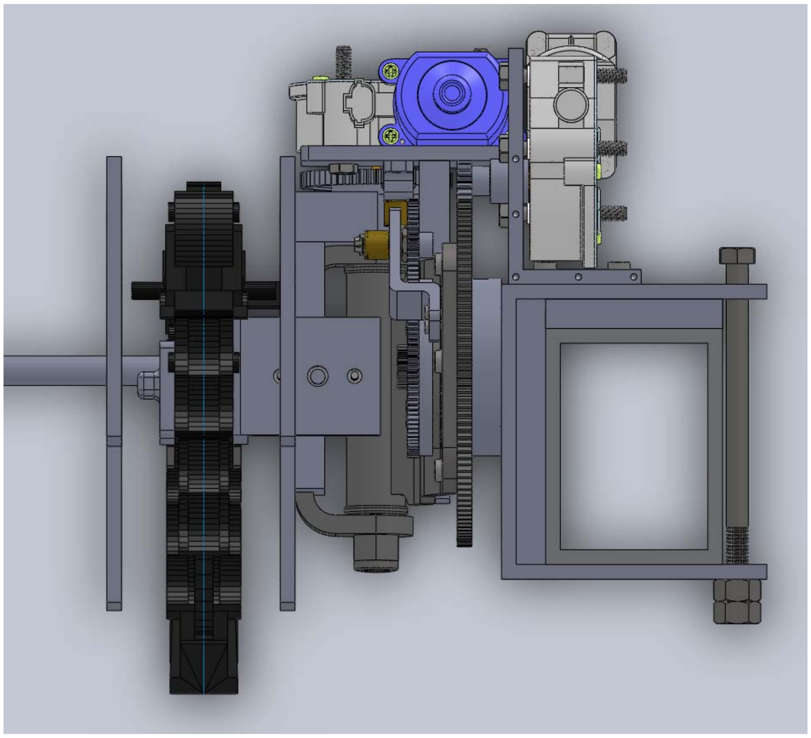


Figure 46: Front View of the Device Assembly Final Design Result

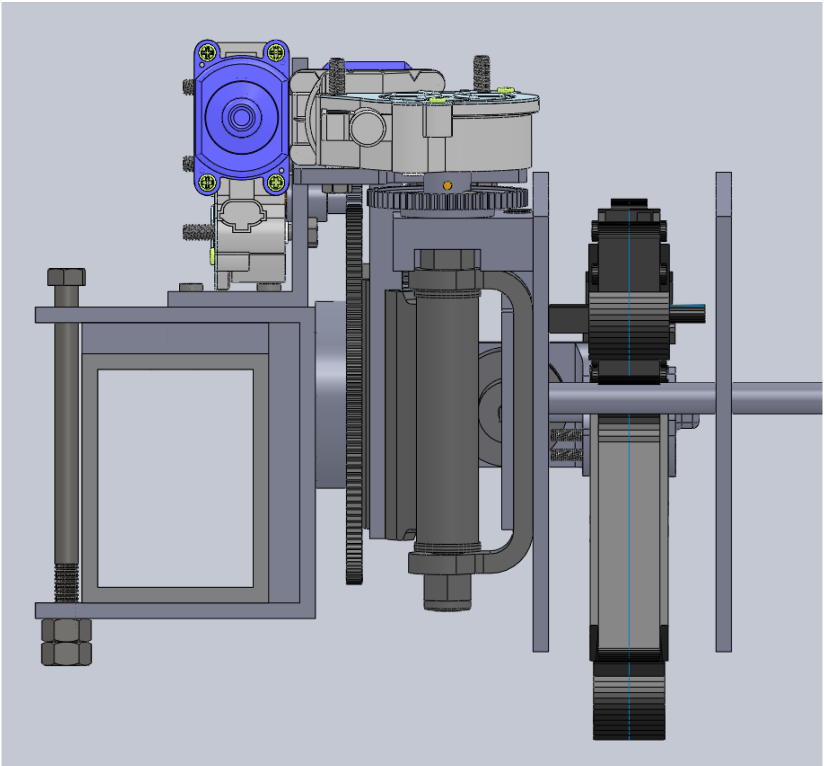
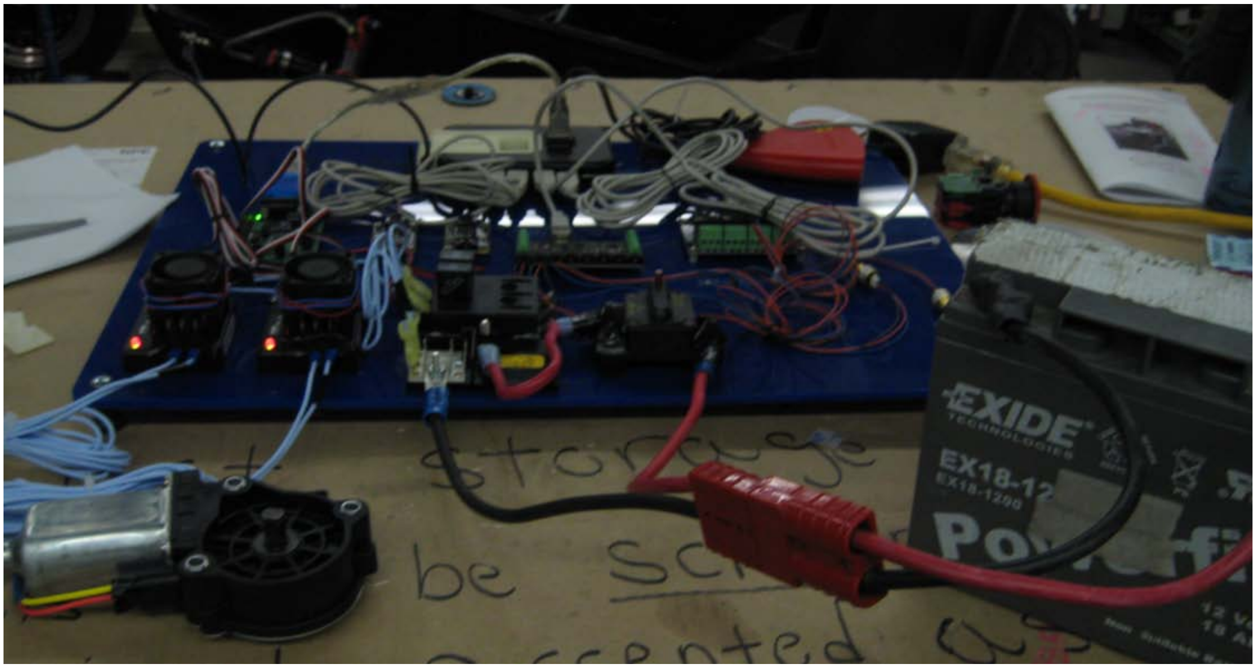


Figure 47: Back View of the Device Assembly Final Design Result

An view of the device testbed can be seen in the image below.



WORK IN PROGRESS

In preparation for the critical design review held as part of the WPI project presentation day, selected components of the overall system were fabricated. During this process it was determined that there were a few significant changes that could be made to the design to make manufacturing more simple and to increase the effectiveness of the overall design. These items are described in detail below and are currently in the process of being implemented

PITCH THRUST BEARING REMOVAL

When the main shaft of the pitch gear was attempted to be assembled, it was found that the seating flanges necessary to position the 2" ID thrust bearings were very impractical to machine. When the overall system was physically constructed, it was also apparent that the original design that included thrust bearings was excessive, and a low-friction bushing surface for running the pitch gears would definitely be acceptable in place of the originally-chosen needle thrust bearings. Thrust bearings are generally used in high-speed applications and the smooth surface provided by a Delrin surface or bronze bushing would be adequate to provide a smooth surface for the pitch axis to rotate about. Making this change will significantly reduce the complexity of the system, as well as the cost. Each bearing and its housing costs about $35, and the system consisted of two of these assemblies, so making this change will save about $70, or 4% of the overall product cost.

LANDSHARK MOUNT SIMPLIFICATION

When components of the physical system were fabricated it was clear that the mounting point between the LandShark and the device contained excessive amounts of material. It was determined that the entire mount could be simplified, and the mating rail that connected the two components could also be reduced and replaced with a standard Picatinny rail (shown below). This rail would provide a common alignment point, and will not be a structural member in the attachment of the device to the LandShark.

Figure 48: Picatinny Rail[25]

USER INTERFACE

The user interface for the LandShark robotic platform was not provided to the student by the sponsor, and in place of the real UI, the student will be developing a simple GUI that allows for joystick and auto-aiming control of the device as well as a window that provides the view from the camera that is mounted to the device.

[25] "MA Parts Inc." 28 April, 2010. < http://www.mapartsinc.com/>

Completion of System Assembly

The system is currently partially built and will be completed with the above design improvements. Partially built components can be seen in the photos below.

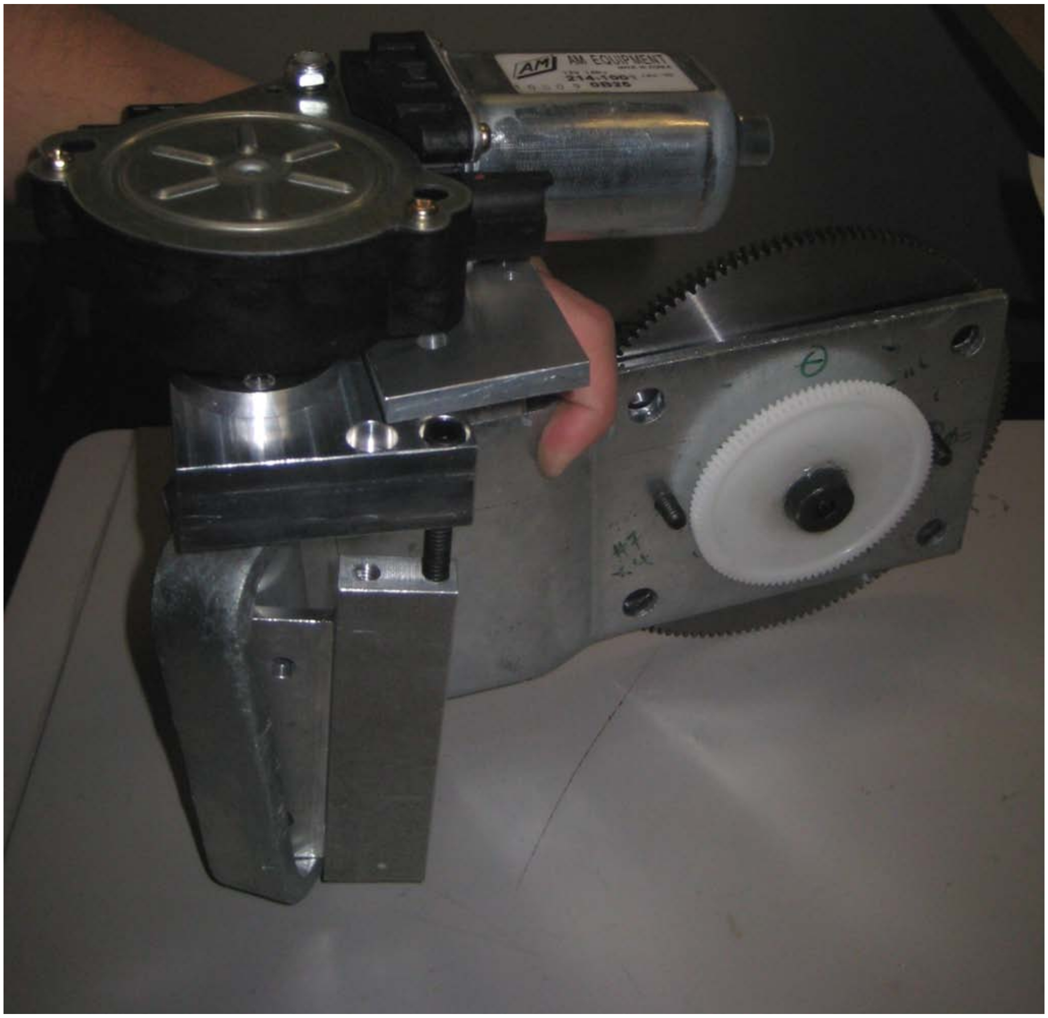


Figure 49: Partially Assembled Aiming System

Completion of System Programming

Current programming allows for reading of the sensors and basic motion of the motors. Work in progress includes the programming of a PID controller to accurately position the motor according to a joystick input, as well as basic autonomous aiming functionality based on user inputs to the device.

System Testing

Once the physical device has been fabricated, it will be tested for overall functionality as well as shooting accuracy that were outlined in the design specifications. A two foot target will be placed at the specified distance of 12’ high off the ground at a distance of 30’ and a 6 inch target will be placed on a door handle with the device located 2’ away, and the weapon will be aimed at the targets both manually and autonomously and will fire its ammunition.

Suggestions for Future Work

Gun Mount Rubber Research

A major area where improvement could be done and significant weight and cost savings could be achieved is the design of the rubber mount systems that hold the different weapons themselves. Preliminary research was only performed in this area and a very rough prototype was made. This prototype was extremely heavy due to the density of the urethane rubber used and the cost of the rubber used to make one mold for a relatively small weapon was roughly $210, or roughly 14% of the desired overall final cost of the entire system. More research into different casting methods and rubber types could be done in an effort to reduce this cost for subsequent iterations of the device..

Re-Design of the Hinge

As described in the “Aiming Mechanism” part of the “Design” section, the original hinge components consisted of the commercially available off-the-shelf freezer door hinge available from McMaster Carr. When the Hinge was bolted to the main pitch gear in a semi-final configuration, it was discovered that the hinge face was not straight. This phenomenon can be seen in the photo below

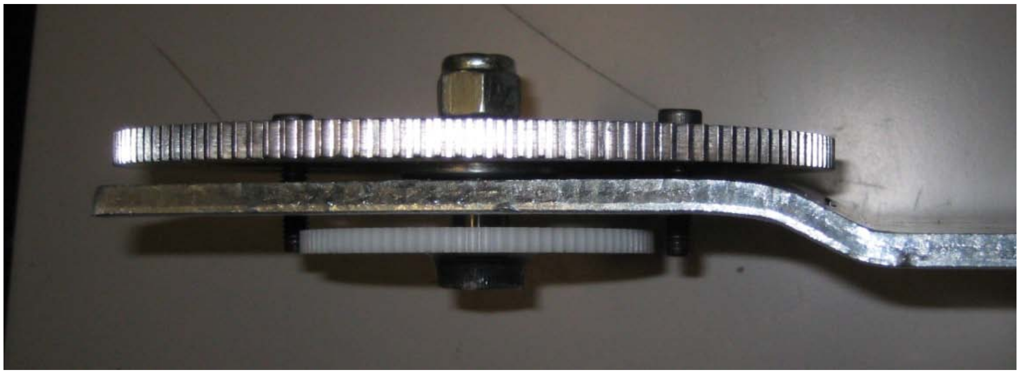


Figure 50: Image of Bent Hinge

Because of this lack of precision on the hinge itself, and the inability to purchase a hinge that would always be flat with respect to the pitch gear face, the student determined that it would be better to, in the future, design and machine a hinge as part of the design. Hinges of a similar scale and build are not readily available and would be expensive to purchase, so the company's emphasis on "COTS" would probably not have to be sacrificed for quality and cost in this case. Also, this might be something to open for discussion with the project sponsor in the future, because they may have a different view on the relative importance of a flat hinge.

Weapon Safety Locks

As discussed in the "Mounting Method" part of the "Design" section of this paper, a potential critical issue for further investigation might be another solution to the problem of the gun locks. While the current solution is acceptable from a logical standpoint,. There might be legal or other factors that might not allow the outlined solution to be a permanently viable solution to the problem. Future work in this area could include development of a more accepted method of locking the weapon while not in use, or to further prove that the current method for achieving system safety is acceptable.

Recoil Testing

Throughout the design process, there was a lack of solid data on the recoil impact of the weapons being used by this system. The current design is likely significantly over-designed because of a lack of this force data, and significant cost and weight savings might be accomplished by perfecting this design. A future area for work might involve the testing of the recoil for a variety of the weapons used so that the design could be better optimized for a specific value of force.

CONCLUSION

Overall, there seems to be no doubt as to the effectiveness of robots for use in law enforcement applications. Agencies are very willing to invest in new robotic technologies that will aid in their efforts and help protect personnel; however the entrance pricing point is much too high to be reasonable for fixed-budget agencies. To increase the utility of a robotic system in the eyes of an agency purchasing a robotic system, more functionality must be added, and price must be decreased. Black-I Robotics hoped to accomplish these tasks by contracting a WPI student to produce a device to aid in the aiming and firing of semi-automatic weapons that will be attached to their current Land-Shark System. Implementation of this device this will give the LandShark the capability to exert nonlethal force on its environment and aid it in carrying out the various types of missions that it might be assigned. Black-I Robotics' commitment to cost effective solutions was carried through this project, and the result is a prototype of a weapons mounting system that costs a fraction of what other systems are offered for. Modularity and generic design were emphasized in all aspects of the product and the result will be a weapons system prototype that is ready to be move through subsequent design phases on its way to being a product.

This project was instrumental in combining all of the knowledge that the student gained through coursework throughout her time at WPI. The project, overall, was less creating a specific device, and was more a project that forced the student to integrate a variety of systems to accomplish a predetermined task that she had to come up with on her own, given information from the sponsor. Skills learned in the classroom were put to the test in a real-life engineering setting. Lessons learned from this capstone project will not be soon forgotten and have positively and dramatically altered the way that the student looks at engineering, projects in general, and systems integration.

APPENDICES

Appendix A: Solidworks Assembly Model
Appendix B: Assembly Concept Drawing with BOM
Appendix C: Electrical Components Diagram
Appendix D: GANTT Chart
Appendix E: Electrical Components Specification Sheets
- E.1. Asus Eee PC Netbook
- E.2. USB Hub
- E.3. Phidget Relay Interface Kit
- E.4. Phidget High-Speed USB Encoder
- E.5. Phidget Interface Kit
- E.6. Lynxmotion SSC-32
- E.7. Victor 884 Speed Controller
- E.8. USB/RS232 Converter

Appendix F: Sensor Specifications
- F.1. Absolute Encoder
  - F.1.1. Absolute Encoder Cable
- F.2. Incremental Encoder
  - F.2.1. Incremental Encoder Cable

Appendix G: Aiming System Mechanical Components
- G.1. Motor
- G.2. Pitch Driving Gear
- G.3. Pitch Driven Gear
- G.4. Pitch Encoder Driving Gear
- G.5. Pitch Encoder Driven Gear
- G.6. Yaw Encoder Driven Gear
- G.7. Yaw Encoder Drive Gear
- G.8. Needle Bearings
- G.9. Needle Bearing Washer
- G.10. Hinge
- G.11. Backup Hinge

Appendix H: Weapon Mount Specifications Sheets
- H.1. Urethane Rubber

Appendix I: Vision System Specification Sheets
- I.1. Camera
- I.2. Dazzler DVD Recorder