Semester Final Report

Team 23

Development of a Multi-functional Robotic Platform for Use in Athletic Environments

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ABSTRACT

Each year the American Society of Mechanical Engineers (ASME) hosts a unique Student Design Competition (SDC) at its Student Professional Development Conference (SPDC). For the 2016-2017 school year teams have been tasked with the development of a multi-functional robotic platform to compete in a series of five athletic-based competitions: a sprint, tennis ball throw, stair climb, golf ball hit, and weight lift. While the components of the robot are still being finalized, our team has continued to iterate our design such that it addresses all of the imperative criteria for the competition determined by the team to be mobility, power, stability, size, durability, and safety. In the future, the team is looking forward to ordering and machining the remainder of the components and starting the assembly process so that testing with the actual unit can begin.

ACKNOWLEDGMENTS

Team 23 would like to thank Dr. Camilo Ordonez and Mr. Keith Larson for their expert technical advice on the structure and many of the mechanisms to be employed by our robot. Additionally, team 23 would also like to thank the FAMU-FSU College of Engineering for funding this endeavor and as well as the ASME for organizing this competition.

1. Competition Overview

There are some strict requirements set by the competition which all robots must satisfy. The first, and arguably the most limiting, is that the robot must be able to fit within a 50 cm x 50 cm x 50 cm sizing box. This includes not only the robot itself, but the controller, any spare batteries, any spare parts, and even the weight which will be used in Event 2. This is especially limiting as the more weight which we would like to lift, the smaller the robot itself will have to be in order to accommodate the extra weight.

Also, each robot is only permitted to use conservable forms of energy. Therefore uncontrolled chemical reactions like gasoline or gunpowder are not permitted and rechargeable batteries of any kind are the only allowable core power source. Other conservable energy sources such as springs or compressed air are permitted so long as the energy can be restored to its initial state by the robot at the end of each event.

1.1: The Sprint

The first event in the competition is rather straightforward. Each robot must complete a straight-line sprint down a ten-yard long track and return. The event is scored based on the fastest time with penalties for each time the robot touches the sideline. The team is taking a rather unorthodox approach to this event. Early on in the competition, the event organizers responded to a question from another team and in doing so, revealed that during any event, a robot is allowed to segment itself into smaller pieces as long as those pieces stay attached the entire time. Team 23 intends on taking advantage of this caveat by employing the use of a small extending shaft, or projectile which would fire out in front of the robot as it left the starting box, make contact with the wall, and return to its initial configuration as the robot moves back into the starting box. Powered by a small DC motor, the team believes that a design such as this has the ability to net a much faster event time than a conventional approach could.

1.2: The Lift

The next event of the competition requires the robot to lift a weight of the team's choosing as high as possible. This event is scored according to the product of the mass lifted and the height lifted. However, a flat 50 cm is subtracted from any measured height which the robot can lift the weight. This forces the team to attempt to start the lift at as high of a height as possible in order to minimize the score lost. The weight being lifted must be in the form of a rectangular prism with no gripping or holding features whatsoever.

While preparing for this event, the team is taking the approach of lifting a very heavy weight a short to medium distance. In order to maximize the amount of weight the robot will be lifting, the team will be filling rectangular containers with fine, lead shot, typically used in shotgun shells. This will allow a maximization of empty space as each rectangular prism can be of arbitrary size and filled to capacity with lead such that virtually all of the unused space in the robot is filled with lead.

To perform the lift itself, the selected method is using a device known as an air jack. These are pneumatically-powered devices capable of exerting very large lifting forces at a very low operating psi. The particular jack that is under consideration for buying is capable of lifting 1.5 tons to a height of about

75 cm. It takes about 45 seconds to inflate completely and 5 seconds to deflate. Because the weight is initially starting at a height just under 50 cm, the team is expecting a very respectable score for this event.

1.3: The Throw

Event number three is straightforward as well. The robot is required to launch a tennis ball as far as possible. The means by which it does this is up to the discretion of the team. Distance for this event is measured on a fixed axis and if the ball falls off center, the distance it traveled *along that axis* is taken as the score, not the total Euclidean distance. The distance the ball bounces after its initial landing is also included in the score.

The team's approach for this event is to utilize what is essentially a glorified potato cannon. Employing the same pneumatic system used to inflate the air jack, the robot will pressurize a small reservoir with compressed air and release it into the barrel at pressures approaching 200 psi. Testing and individual personal experiences lead us to believe that this approach will allow for us to launch the ball a significant distance.

1.4: The Climb

This event is markedly more challenging than the ones preceding it. In this timed event, the robot is tasked with climbing up, and then back down, a set of three steps. The fastest recorded time for the robot to do this wins the event and a team is disqualified if their robot falls off of the stairs during the attempt. Each step will be between 8 and 15 cm tall with a landing of *at least* 50 cm between each step. This means that the robot will be able to completely fit on each step while remaining perfectly level. This gives us a very low overall angle of approach to overcome; the maximum angle is approximately 17 degrees.

In order to succeed in the climb, the team decided to design a robot mimicking the "chaos" frame design. Robots with this frame behave very similar to a skid-steered tank, except that instead of two-static tracks, there are four individual tracks which can each rotate a full 360 degrees about their own axis independent of each other. This frame has a high degree of dexterity and has been proven to be able to overcome virtually any obstacle, including stairs.

The design adopted by Team 23 is slightly modified from this framework in order to save costs. Instead of each leg rotating independently of one another, the fore and aft legs are powered by the same motor, and thus, paired to rotate at the same angular velocity. Similarly, the tracks on the right and left side of the robot are paired as well such that the robot maintains a differential drive characteristic. The ingenuity of the design lies in the fact that no matter what orientation the legs are in, there is always track contact with the ground. This means that no matter what position the legs are in, the robot will drive and control virtually the same.

This choice of frame offers many other passive advantages which can be utilized in many other events. For example, during the Event 3: The Throw, the front arms can be rotated such that the robot pitches a controlled amount. This will give us control over the exit angle of the ball from our cannon. The arms will also allow us to “stand” during the lift, given that the structure is strong enough, to gain additional height.

Figure 1: A robot built using the chaos frame design

1.5: The Hit

Arguably the most difficult event, The Hit requires the robot to “hit” a golf ball from the ground as far and as straight as possible. The scoring for this event is similar for the hit except now, the distance which the ball lands from the measuring line is subtracted from the distance traveled along the measurement axis, placing a significantly higher emphasis on accuracy. The ball is only allowed to have a small clearance above the ground, a maximum of 0.2 cm. Additionally, the score distance is taken from the first contact of the ball with the ground, as opposed to the bounce distance taken from the throw.

Team 23 had initially planned to use a pneumatic rotary vane actuator to rotate a shaft attached to a sawed-off golf club in order to strike the ball. However, recent discoveries have revealed that this approach would not result in a distance that could be deemed acceptable for the team. After reviewing the fruits of earlier brainstorming sessions, the team determined that a spinning wheel approach could net in a better score, though much of the robot would have to be redesigned around this change.

The spinning wheel approach is very similar to that of a pitching machine one might see on a baseball field or tennis court. This device works by forcing a ball into contact with one or two wheels spinning at a high velocity. The wheels compress the ball and impart some of their energy onto it. Preliminary calculations for this approach resulted in ball exit velocities of approximately 20 m/s using attainable wheel speeds, which is an improvement over the vane actuator design by a factor of three or four.

To implement this approach, the robot would utilize the chaos frame design yet again. The robot will “stand” over the ball and lower the wheel assembly downwards so that is “sucks up” the ball. The ball would be launched vertically and roll up a ramp which is designed to reorient the ball velocity in the forward direction while simultaneously adding a certain level of backspin.

In adopting this approach, there are certain elements which have to be added to the current design. Firstly, it would be prudent to install a laser-alignment tool onto the base of the robot so that it can be made certain that the wheels, and not some other part of the assembly, will make the initial contact with the ball every time. There will also need to be two additional motors specced and an additional assembly has yet to be designed to lower the wheel system down onto the ball. Currently, it is Team 23's highest priority to fully design and analyze this new system so that the lag imparted on our project timeline is minimal.

2. Component Selection and Analysis

2.1 Control

To control our robot, Team 23 needs a microcontroller capable of taking input from a controller. A suitable microcontroller for our robot is the Arduino Uno with USB shield to allow us to connect a bluetooth hub to our device for connection to a controller with bltooth capabilities. The controller that will be used for our device is an xbox one controller since it's easier to sync with our robot due to microsoft's built in library with all of their devices. This will alleviate many of the programming issues which would arise if Team 23 were to use a third party controller such as one from Sony or any other company.

2.2 Drivetrain

In order to drive the system with full authority, a total of four motors would be required. Two of the motors will be used to power the rotation of the arms, and the other two will be used to power the tracks. The front and rear arms will operate independently, as will the left and right tracks. This gives a differential steer capability, while reducing the number of required motors. The primary motors will be responsible for driving the tracks. For these, we have selected the RS775 Motor and Encoder (am-2923) gear motor with an attached 27:1 planetary gearbox from AndyMark. These motors will be able to provide a constant output torque of approximately 1500 oz-in at 45 rpm and will be able to drive a 50lb robot at approximately 3 m/s with an additional gear ratio of 6:1. Our secondary motors will be used for controlling the motion of the arms. For these, we have selected the RS775 gear motor and Encoder with a 188:1 planetary gearbox also from AndyMark. This motor is ideal for our purposes due to its high cost to torque ratio and will be able to provide sufficient torque to our legs with an additional gear ratio of approximately 12.5:1. We plan on operating both of these motors at their nominal operating points to avoid any possibility of damaging or destroying them during our months of testing the system.

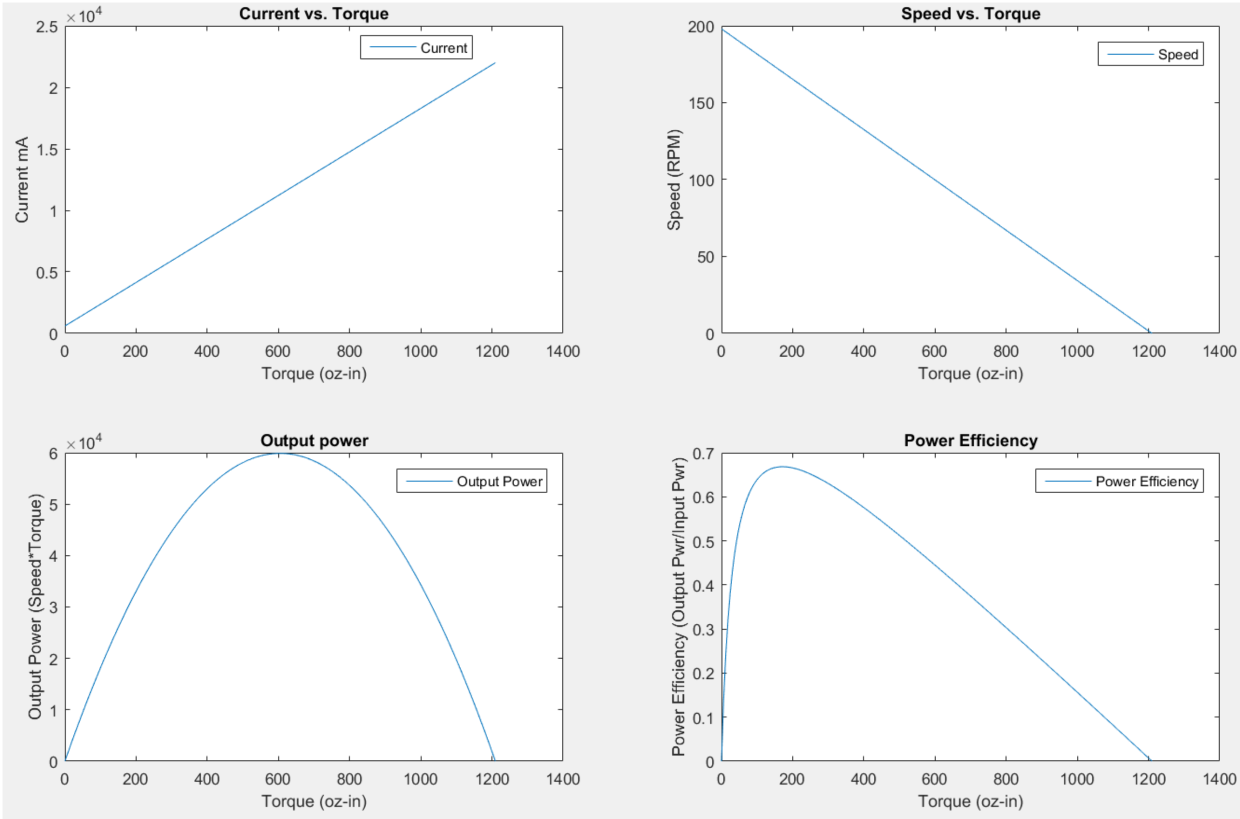

Figure 2: Torque-Speed Curves calculated for the primary motors. These motors will be run at their nominal operating point at about 300 - 400 oz-in of torque and 135 – 150 rpm. These motors will be geared down additionally by another gear ratio of approximately 3:1

Figure 3: The primary motor being used on the robot. An AndyMark AM9015 motor with a PG27 Planetary gearbox

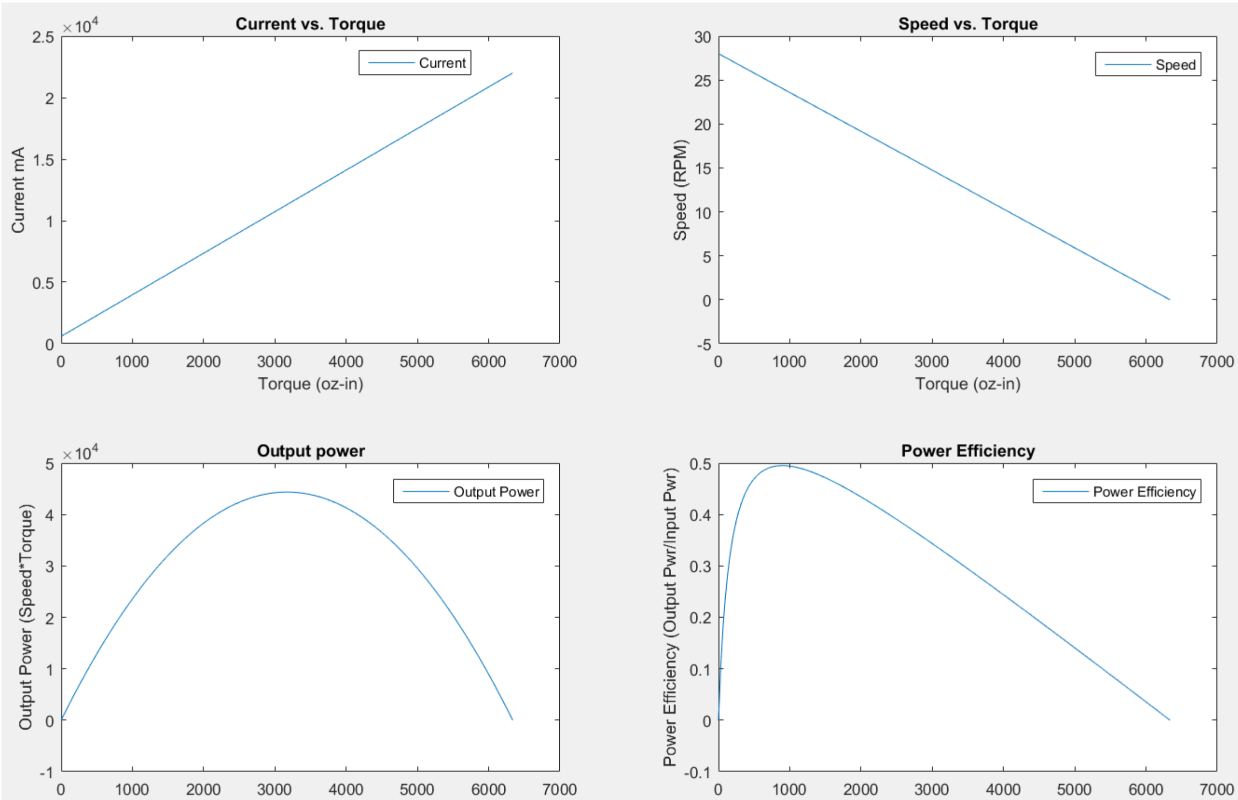

Figure 4: The torque-speed curves for the secondary motors on the robot. The motors will be run at their nominal operating point between1500 – 2000 oz-in of torque and 17.5 – 20 rpm. These motors will be subjected to an additional outside gear ratio of approximately 12:1.

Figure 5: The secondary motor being used on the robot is an AM9015 motor attached to a PG188 gearbox from AndyMark

2.3 Pneumatic System

2.3.1 Core

At the core of the pneumatic system lies the air compressor and air tank array. The idea is to use a standard paintball gun compressed air tanks to store the air of and power out pneumatic system. These tanks will work great for this design because of their relatively high volume capacity and exceptional psi rating. The air tanks used on the robot will be aligned in a parallel such that the air storage capacity of the robot can be increased dramatically. The current configuration is utilizes a two-tank, 0.5 gal system. However, expansion of this array into a four-tank 1.0 gal system may become possible in the future. The main limiting factor in this approach is the physical space that each tank consumes.

The air compressor being used is a model rated for 200 psi from the manufacturer VIAir. This model has the ability to fill a 2.5 gal tank to 150 psi in approximately 3 minutes. This fill time is much too long to be viable in this competition, however a significantly smaller tank will be used on the competing robot. It was calculated that this compressor would be able to fill a 0.5 gal tank to just shy of 200 psi in 58 seconds. This is perfectly suited to the competition and it is for this reason that the VIAir 480C compressor will be used on the robot.

Figure 6: The 480C air compressor from VIAir is a 12-V air compressor with the highest fill rate in its class.

2.3.2 Air Jacks

Air jacks are lightweight devices which use relatively low pressures to lift very heavy objects. They are generally used to lift overturned freight trucks and to lift a car off its axle in order to change a tire. For the lift event, the *Bushranger Air jack* will be placed in between two plates on the top of the robot. This particular air jack is used to lift a car in order to change a tire by inflating it through the car's exhaust pipe. It lifts 75 cm, hard to puncture, and is designed to lift 1.5 tons. This will be particularly useful during the competition because it will allow the team to lift a weight a relatively high distance in comparison to the weight's heaviness. Since the *Bushranger* is a tough material and designed for rough terrain, it is quite durable and will survive much wear and tear during testing and the competition.

One thing to consider is the inflation of the air jack when the weight is placed on top of it. Hopefully, the two plates that the bag is placed in will add the necessary stability so that the weight is not being lifted at an angle causing the weight to slide off the robot. Any additional support systems for the jack will be determined during testing.

Figure 7: A real-life demonstration of the *Bushranger* air jack's ability to lift objects to a respectable height

2.3.3 Air Cannon

An air cannon is the most promising design to launch the tennis ball. This cannon will use a release of pressure from the pneumatic system in order to propel the tennis ball accurately along the target axis. It is a relatively simple and straightforward design. The compressor would function to fill the lower chamber in Figure 8. Pressure would be released by opening an electrical valve which would then release the pressure into the chamber, launching the tennis ball.

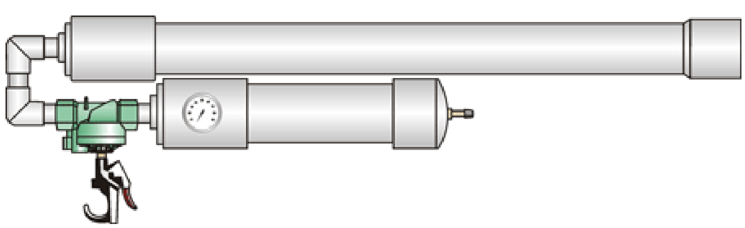

Figure 8: An example schematic of a simple air cannon system

2.4 Electrical Systems

Motor Relay Circuit

The circuit design for the motor relay circuit will be used for movement and control. This will allow the robot to climb stairs, move in any direction, and set up the arms of the tracks to place itself in different positions for each event. The Motor Relay circuit will operate on a 8-18V Battery Source (shown in Appendix A). This will act as an effective switching mechanism that uses low power signals for control. Switching efficiency is important because it will be able to catch any input faults or incorrect commands during specific tasks. Digital switches will be used for switching between individual motors for different task functions.

Controller

The controller used for the robot will be a Playstation 3 sixaxis controller. The PS Home button in the center of the controller will be used to toggle between the different events. For each event that the controller is toggled to, an LED on the back of the controller as well as an LED on the robot will light up to represent which event the controller's buttons will be mapped to. This is beneficial because it allows the user to select a specific task so if there is any misclick or incorrect input command during the task, the robot doesn't act based on incorrect user input. Both the relay circuit and the controller will be designed so eliminate any possible incorrect commands that may cost the robot any additional loss of power by triggering anything that should be off during the competition or throughout the testing process of this project.

Microcontroller

The microcontroller is going to be the robot's brain and will be helpful in reducing any input error. Developing circuits and products based on microcontrollers is simpler and cost effective due to few additional hardware components required. The commands for the competition are going to be fairly simple and do not require complex computing. Therefore, a simple micro controller is the way to go rather than using a more complex microprocessing unit.

Batteries

Lithium ion/polymer batteries are the best option for powering the robot. They have small dimensions, can be recharged quickly, and have a high energy density. These batteries are typically used in robotics for controlling and require less to power the electric motors. It is in the best interest for this competition to use multiple batteries in parallel. This will allow further design manipulation regarding space and when it comes to possible task assignment. There are disadvantages to using multiple batteries: multiple batteries to recharge and multiple parts of the robot will stop working at different times. However, the way the competition is laid out, it is possible to program the robot so that everything that is not to be working during the task being performed can be turned off using the relay circuit. Everything the robot is designed to do is not going to be running simultaneously, so that eliminates the second concern mentioned for the use of multiple batteries.

3. Design Challenges

Though designing for every event has been challenging in its own right, creating effective solutions to the hit and lift problems has provided significantly more design challenges tan any of the other events.

For the hit, a major design challenge was getting enough force applied to the ball at the appropriate angle. The size constraints and placement of the other features on the robot prevented the team from using an appropriate length shaft for the club, which would've increased distance exponentially. Due to these challenges, the team was forced to revamp the approach to the event. While the pitching wheel concept should yield more favorable results there is still the challenge of fitting the subsystem onto the robot as well as designing a system that will raise and lower the device without much additional cost and complexity.

The design for the lift also experienced hardships. Complexity in the original design led to more points of possible failure as well as a higher cost due to the use of multiple pneumatic cylinders. Continuing with the pneumatic design, the idea of Air Jacks were discussed. The *Winbag* was the initial concept for the air jack design. There would have been multiple bags stacked together as to increase the lifting height (an individual *Winbag* expands only about 2 inches). This proved too expensive and unstable to use, so the *Bushranger* became the most viable option. Stability will be an issue with this but the location where the pneumatic pistons were previously will now contain four extending supports that will lock at the maximum height, in order to hold the weight at a constant height for the judges to measure.

The mobility of the robot has also been extremely challenging due to the budget constraints. The robot archetype that the team is following uses a total of 8 motors for locomotion, though the size and budget constraints prevented that exact approach. As was mentioned earlier, the clever use of drive shafts cut the number of motors from eight to four, though the independent motion of each leg was sacrificed. The use of drive shafts provided another challenge, the layout of the robot had to be reorganized in order to make space for the shafts running across the entire width of the robot, as well as the chain along the length of the robot that will drive the tracks. This issue was remedied by creating a space between the baseplate and the floor plate in which to place all of the motors and drive shafts.

4. Conclusion

Large strides have been made in this project since the midterm report. Component selection has been finalized for a majority of the vital parts and the selection pool for the remaining components has been narrowed significantly. Specifically, many options for the air compressor and rotary actuators have been eliminated so that there is a good understanding of what will be used in the final product.

The next primary goals for this project are finalizing the component selection, performing Failure and effects analysis on the structure of our robot, and creating event-specific prototypes for the throw and hit events. The plan is to optimize the performance for these events using these prototypes off of the robot and then install them onto the bot when their performance meets the team’s standards. Finalizing the selection of the components is one of the most important aspects of designing the robot and is a necessary step in finalizing the CAD models. Once the CAD models are updated according to the components selected, a failure analysis will be performed in order to assess if mechanical failure will occur, and if not, where the design is at risk of failing. If high-risk areas are discovered, the CAD models will be updated accordingly until the design is at a low risk of failure. Once the CAD models have been finalized, the machining process as well as the ordering of components can begin.

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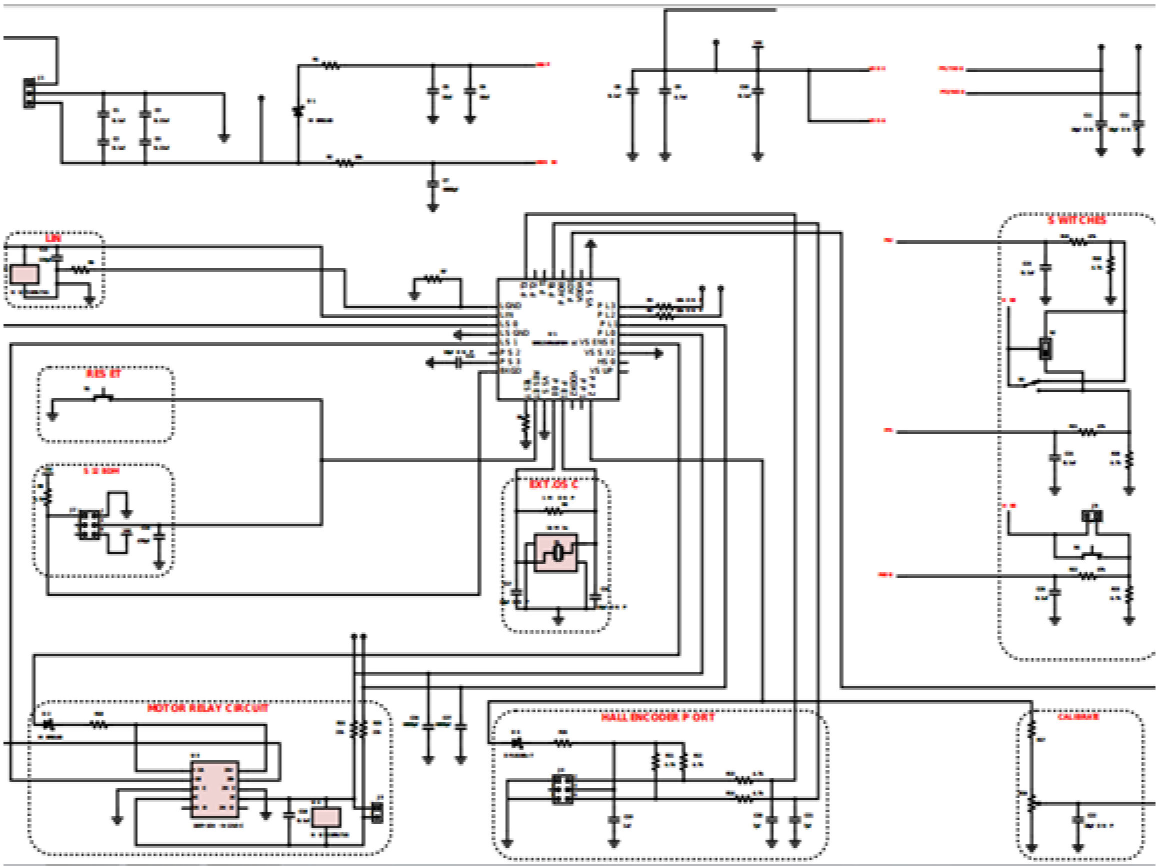
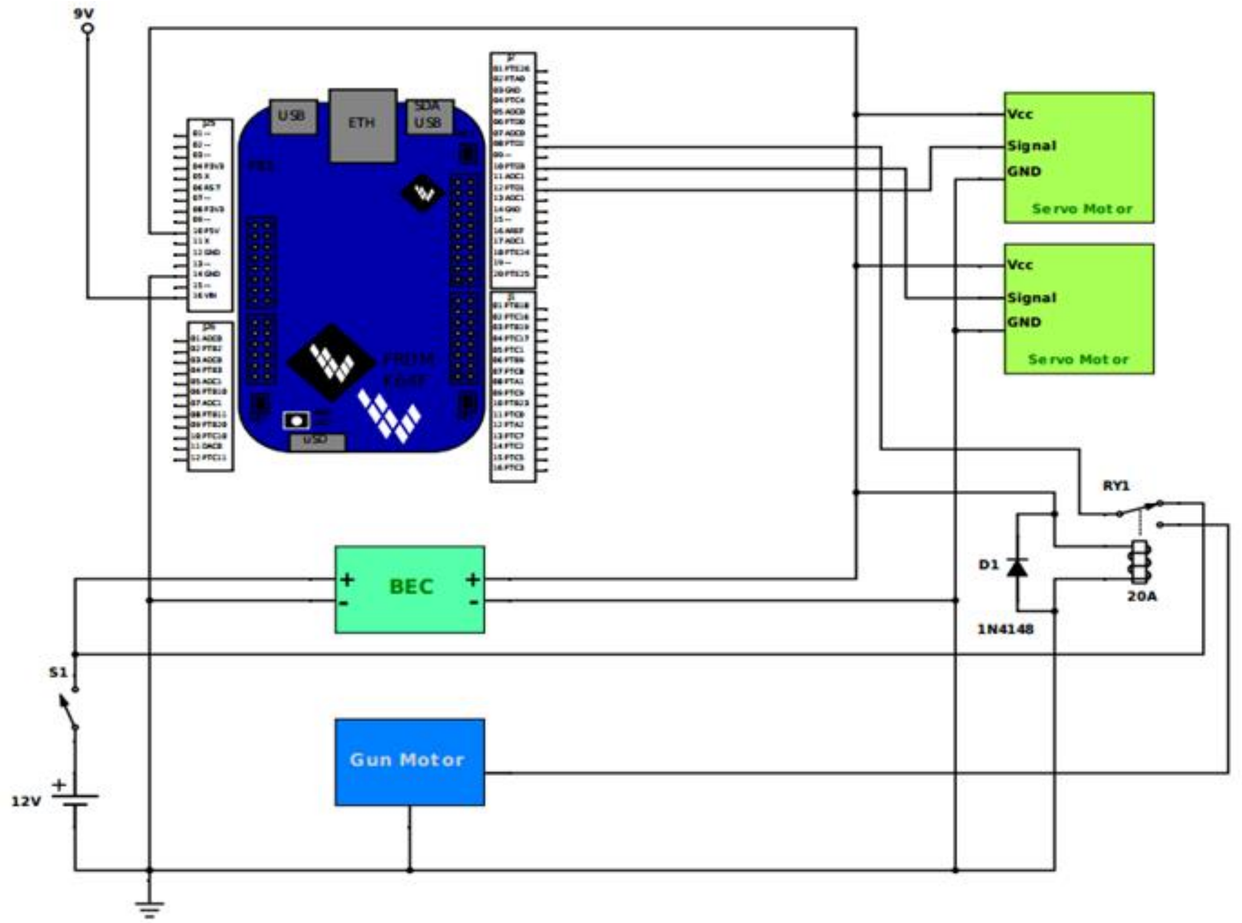
Appendix A

This is a design which features the S9S12VR64AF0MLC microcontroller (MCU), under the S12 MagniV MCU family from Freescale. In this design, advantages of the S12 MagniV 16-bit MCU are showcased for the relay-based DC motor control application. The circuit is simple with low amount of external components but has a high voltage capability. The operating voltage range for the circuit is from 8V - 18V.



Appendix B

This circuit showcases the FRDMK64F MCU used to control an electrical nerf dart shooter. The circuit contains a motor to shoot the dart and a Battery Eliminator Circuit (BEC) to eliminate the need for a receiver This component will operate on a 12V source..



Biography

Abdur-Rasheed Muhammed is a Senior Computer Engineering student from Jacksonville, FL currently enrolled at FAMU. He is overseeing the programming aspects of the robot competing in the robot pentathlon under ASME.

Ben Edwards is a Senior Mechanical Engineering student at Florida State University from Tampa, FL. He is currently overseeing the feasibility calculations for each of the systems.

Natalia Cabal is a Senior Electrical Engineering student from Cali, Colombia currently enrolled at Florida State University. She is currently overseeing the circuit design and power aspects of the robot.

Troy Marshall is a senior in the Department of Mechanical Engineering at Florida State University from Panama City, Florida. Troy is the Webmaster responsible for designing and managing the Team 23 website.

Michael Jones is a senior in the Department of Mechanical Engineering at Florida Agricultural & Mechanical University from Ft. Lauderdale, Florida. Michael is the Financial Advisor and is currently overseeing the design of the pitching machine for the “Golf Ball Hit” competition.

Ryan Alicea is a senior in the Department of Mechanical Engineering at Florida State University from West Palm Beach, Florida and is the project lead. Currently, he is reworking the structure of the robot to accommodate the new wheel system.