Midterm I Report

Team 23

Design of a Multi-functional Mobile Robot

Members:

Abdur-Rasheed Muhammed - abdurrasheed1.muhammed@famu.edu

Ben Edwards - bje12b@my.fsu.edu

Michael Jones - michael5.jones@famu.edu

Natalia Cabal -nc11b@my.fsu.edu

Troy Marshall - tam14d@my.fsu.edu

Ryan Alicea - rla11h@my.fsu.edu

Faculty Advisor

Dr. Camilo Ordonez

Instructors

Dr. Chiang Shih

Dr. Nikhil Gupta

10/21/16

Table of Contents

Table of Figures

Table of Equations

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 still in the component selection and analysis phase,our team has selected a preliminary design that addresses all of the imperative criteria for the competition including mobility, power, stability, size, durability, and safety. Future works are to include prototyping, design analysis, and prototype refinement. The short-term goal as determined by the team is to have a working platform by mid-December to allow for system integration testing and continuation of design refinement.

ACKNOWLEDGMENTS

Team 23 would like to gratuitously 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. We 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. Project Statement

The goal of this project is to compete and win the 2017 ASME SPDC Student Design Competition. The competition requires the team to build a robot capable of competing in five different events: sprint, lift, throw, hit, and climb. The current short-term goals are to finalize the component selection and CAD modeling. Once the CAD modeling is completed, machining and water-jetting the necessary components will begin, as well as placing orders on all other components. The primary goal for this semester is to have a functioning robot platform by December. This will include both motor pairs and the base body of the machine.

2. Background Research

1.1 2.1 The Lift

The lift portion of the competition is scored based on the weight and the height lifted. This scoring system offers two approaches to the event: lift a small mass a high height, or a heavy mass for a low height. Both approaches can achieve the same score, however it will be more achievable and valuable to design a robust robot which can lift a large weight only a short height. The score for this event is calculated using the formula:

$$Score = (Height - Maximum\ Height) * Mass \qquad \text{Eqn. 1}$$

There were three main considerations for the lifting event: scissor lift, pneumatic pistons, and inflatable air jacks. The scissor lift was eliminated from future consideration due to the high amount of movement within the system and the significant amount of added weight to the robot. Scissor lifts are effective in achieving the best weight to height ratio, but the forces required to initiate the motion are large compared to the other approaches considered. The pneumatic piston-cylinder design will deliver a driving force to a lifting platform. Though the use of pneumatics would require an additional power-source-- namely an air compressor-- the addition of this power system would be able to produce the significant forces to lift the heavy weights desired. An on-board pneumatic system would also allow further exploration of other options in other events as well. The third design considered involves small air jacks in addition to or instead of the pneumatics pistons. The air jacks would serve the same function as the pistons except these would be much lighter in weight and more economic. The air jacks are made from flexible material which will possibly require additional support structures as they inflate. The additional structures would ensure the lifting platform remains level throughout the task. The air jack currently being considered is manufactured by the company Winbag and is 7 inches by 7 inches (Length/ width). The bag is capable of lifting up to 300 pounds 2 inches in height. The bag comes with a one handed release valve and a hand pump that can easily be removed and connected to the pneumatic system to eliminate the necessity of manual inflation. In order to improve the score in light of the competition, it is possible to incorporate multiple bags on top of each other to increase the height of the weight being lifted. Using multiple bags to increase the height increases the necessity of an additional support system for the bags.

2.2 The Sprint

The rules of the sprint state that the robot must leave the starting box completely, touch a wall 10 meters away, and return to the box. These rules leave a glaring loophole, in that the robot is allowed to expand from its original configuration throughout the course of the event. The robot design will exploit this by using a projectile on a retractable tether in order to contact the wall and quickly return to the initial position. The robot will only need to move about half a meter forwards and back, and the projectile can reach the wall virtually instantly. The scoring system of the sprint is not explicitly specified other than that it will be calculated solely off of the time it takes the robot to complete the event.

2.3 The Stair Climb

This portion of the competition requires the robot to climb up and down a set of three stairs within a period of two minutes. Although the actual step heights are not known, it is stated in the rules that each landing height will be no less than 8 cm and no greater than 15 cm. There is also a possibility that each successive landing may be of the same or a different height of the landing that precedes it. Additionally, it is stated that each step landing will be a minimum of 50 cm in length, which is also the maximum allowable length of the robot. Another caveat of this event is that the landing finish is unknown, meaning that the stairs may be rough or smooth, painted or unpainted. All that is certain is that the stairs will be made of wood. The competition allows two attempts to climb the stairs in under two minutes.

The plan for this event is to utilize well researched locomotion techniques, such as tracks, that will allow for traversing the possible range of stair heights. This provides a sufficient level of friction as to not slip when attempting the climb in the event a landing does happen to be smooth. One proposed method of this is to use articulated track which would be mounted on four independently rotating arms as seen in Figure 1.

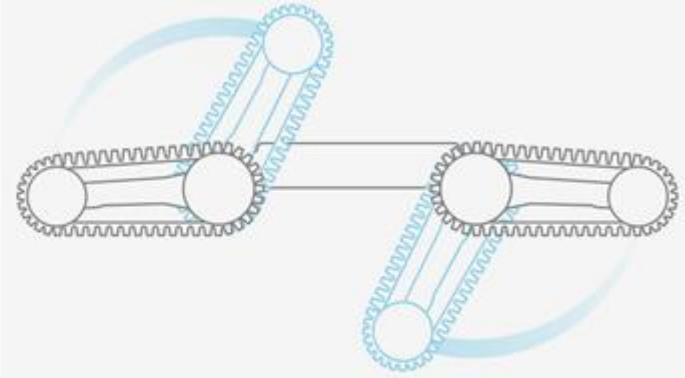


Figure 1: Example of the tracked-arm design showing full 360° of rotation

2.4 The Throw

The rules of this category require the robot to throw a standard tennis ball as far as possible in a specified direction. Once the tennis ball comes to a complete stop the total distance traveled is taken into account. However, only the distance in the specified direction is counted. This means that the distance score is equal to the product of the total distance of the ball and the cosine of the angle of the error ($\mathcal{E}$).

$$D_{score} = D_{total} + cos(\varepsilon) \qquad \text{Eqn. 2}$$

The approach for this event is to minimize the error angle as much as possible while maximizing the distance of the ball. The rules of this event state that the ball must be "thrown", though they do not state that the ball cannot be "launched". The plan is to implement a compressed air cannon to launch the ball directly forward with as little error as possible. The ball will travel virtually *exactly* where desired, while allowing the freedom to add backspin and orient its initial velocity at the optimum angle of attack.

The trajectory range of the ball can be found by solving the equations of motion where α is the angle of attack and is the earth's gravity. These were solved to be:

$$D = {v^2}_0 * sin(2 * \alpha)/g \qquad \text{Eqn. 3}$$

This is a simplified version of the actual system and does not account for lift and drag. The optimum angle of attack is actually somewhere between 35 and 40 degrees [1] and future planning will determine this angle experimentally.

2.5 The Golf Shot

This event requires the robot to hit a stationary ball off of the ground as far as possible. In this event, the ball must also travel along a specified path but distance after a bounce is not included in the score. The penalty for angular error is far greater than in the "Throw" event. In this event, the distance the ball travels *away* from the specified direction is subtracted from the straight-line distance of the ball. This means that the score is calculated using the equation:

$$D_{score} = D_{total} * cos(\varepsilon) - D_{total} * sin(\varepsilon) \qquad \text{Eqn. 4}$$

Because the score will be penalized for any angular error in the hit, precision is paramount on all components pertaining to this event. The plan is to use an actual golf club head to make contact with the ball. The reasoning behind this is that the engineering behind golf clubs has been refined over hundreds of years. Any golf club on the market today is undoubtedly superior to any available substitute.

The plan is to actuate the club with compressed air as well. Because the plan is to utilize a pneumatic system for other events, it is both resourceful and cost-effective to apply that infrastructure here. The type of club to be used is still to be determined. A test rig will be constructed with the pneumatic system in order to determine the optimum type of club and club pitch for this event.

3. Design Selection and Analysis

3.1 Constraints

Spatial and Energy

The design is subject to a series of strict requirements on the size of the robot and on the ways the robot consumes energy. Firstly, the system must fit within a 50 cm x 50 cm x 50 cm box. This includes the robot, controller, weight to be lifted, and all required batteries. The next major restriction is that the robot must be powered solely by rechargeable batteries. This can include anything from lithium-ion/polymer batteries to a standard lead-acid car battery. Replacement batteries are allowed, however, these must also fit within the 50 cm x 50 cm x 50 cm sizing box. The only exception to these battery rules is that if chosen to power the device through a remote control, the remote control may have its own batteries independent from the system. The third major constraint states that while it is allowed to utilize alternative energy storage devices such as springs or compressed air, these devices *must* be returned to their original state by the end of the event. It is also explicitly stated that flying devices are not allowed in the competition.

The Sprint

Touching the sideline of the 1 m wide course will result in a five-second time penalty per touch. Fully crossing the sideline will result in disqualification and a last-place score. There is a maximum time of one minute to complete the event.

The Lift

The weight must remain stationary at the apex of the lift for sufficient time to be measured. The weight *must* be in the shape of a rectangular prism. The weight must have smooth sides with no holding or gripping features. The score will be determined by multiplying the mass of our weight in kg by the height lifted in cm. The weight must be provided by the team, and must fit within the sizing box with our robot.

<u>The Throw</u>

The ball may be placed on the robot, and will be commanded throw using a remote control system. The tennis ball will be provided by the judges and must not be modified in any way. There is a one-minute time limit to complete this event.

<u>The Climb</u>

If the robot is touched by a team member or if the robot falls off of the staircase, the team is disqualified for that event and will receive a score of last place. The stairs will be between 8cm and 15cm in height per step, with a 50cm x 50cm landing between each step.

<u>The Hit</u>

The golf ball must initially rest on the ground with an allowable above-ground clearance of only 0.2 cm. The golf ball may not be modified in any way. The robot must remain in a fixed position during the attempt and be operated remotely to hit the ball.

3.2 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.

3.3 Pneumatic System

3.3.1 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 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 considered 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. Because the fill time of the robot cannot be matched with the manufacturer's specifications due to the smaller tank, the fill time of this compressor feeding into a 0.5 gal tank and a 1.0 gal tank is actively being looked into.

3.3.2 Air Jacks

Air jacks are lightweight devices which use relatively low pressures to lift very heavy objects. For example, they are frequently used to lift overturned freight trucks on the highway, or lift a car off of its axle in order to change a tire. There are many different approaches being considered in the air jack system but they all rely on the same concept; the airbags will be stacked onto each other in order to achieve a respectable height. This is mainly due to the very low gain in height that each individual airbag can achieve, given that the size of the airbags which we can fit on our robot are relatively small with an approximate size of 7” x 7” and an expanded height of 2”. There are many different ways which these can be configured, however. A promising approach is create successively smaller platform arrays of these devices which would lift successively smaller platforms. A potential issue with this design is that the air jacks are flexible.

3.3.3 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 2. Pressure would be released by opening an electrical valve which would then release the pressure into the chamber, launching the tennis ball.

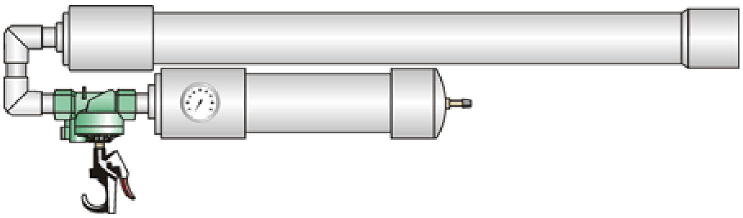


Figure 2: A simple model of how our air cannon will be designed.

3.3.4 Pneumatic Swing

The golf swing will also be actuated using compressed air. The conversion from pressure to rotational motion will be made using a pneumatic vane actuator. This actuator will rotate a shaft that is connected to a golf club. This actuator functions by using a small internal lever to receive the force of the pressurized air and rotate an output shaft. A cross-section of this type of actuator is shown in Figure 3. The center of the figure is the output shaft. This structure will rotate as the pressurized air acts on the lever. The design will utilize a pendulum attached to this shaft which will swing downwards and strike the golf ball. This type of actuator can also be easily reset by allowing pressurized air to flow in the opposite direction. The main approach for the hit event requires us to use both of our secondary motors to stand our robot up on end, then use the primary motors to position our robot over the ball, and finally, once the robot is in position, release the pressure stored in our tanks in order to strike the ball with the pendulum.

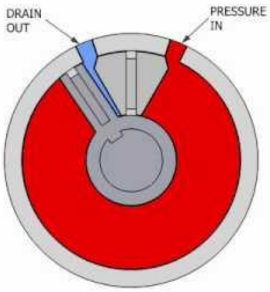


Figure 3: ***Cross section of a pneumatic vane actuator. The openings on the top of the image can be used to pump air into either side, actuating***

3.4 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 an 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.

Dart Shooter Circuit

The circuit design for the robot includes a circuit to shoot a dart for the Sprint event. There will be multiple batteries implemented into the design to make sure that enough power is going through the system for the component. 12V will be needed for the dart shooter (shown in Appendix B).

Controller

The controller used for the robot will be a Playstation 3 sixaxis^{TM} 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 user error 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 series. 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.

4. Scheduling and Resource Allocation

Because it is desired to have a functioning platform by December, it is imperative that a design is finalized quickly. The pool of design options has been narrowed dramatically during the last few weeks and much of the current work being done is focused on determining which components will work well within each design structure and how this will affect the overall cost. The total budget for this project consists of $2500.00. Options for expanding this are being looked into. Many manufacturers, especially smaller ones, are open to the idea of providing discounts on their products in exchange for advertising during the student design competition. This seems to be a viable option for maximizing the effectiveness of the budget.

5. Conclusion

Large strides have been made in this project since the needs assessment had been performed. Component selection for the motors has been finalized and the selection pool for many 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.

References

[1] ASME, "Engineering competitions: Student design competition," in *American Society of Mechanical Engineers*, 2017. [Online]. Available: https://www.asme.org/events/competitions/student-design-competition. Accessed: Sep. 13, 2016.

[2] B. Webb, "Phonotaxis in Crickets and Robots," in *University of Edinburgh School of Informatics*, School of Informatics, The University of Edinburgh. [Online]. Available: http://homepages.inf.ed.ac.uk/bwebb/. Accessed: Sep. 20, 2016.

[3] B. UL, "Wheg," in *Robotics Portal*. [Online]. Available: http://www.roboticsportal.it/en/wheg. Accessed: Sep. 20, 2016.

[4] D. Mihai, "Wheeled mobile robot development platforms," in *Build Robots*, Smashing Robotics, 2012. [Online]. Available: https://www.smashingrobotics.com/wheeled-mobile-robot-development-platforms-from-budget-to-full-featured/. Accessed: Sep. 21, 2016.

[5] A. S. Inc, "Chaos high mobility robot | ASI," in *ASI Robots*, ASI, 2016. [Online]. Available: https://www.asirobots.com/platforms/chaos/. Accessed: Sep. 25, 2016.

[6] "Scissor lift – battery powered working height 8 meters extended platform 6 meters minimum height 2000 meters width 760mm weight 1000 Kg supplied on trailer total weight 1540 Kg. Price: Full day only $180.00," in *Picton Hire*. [Online]. Available: http://pictonhire.com/product/scissor-lift/. Accessed: Oct. 06, 2016.

[7] A. Hitchcox, "Checklist for matching air cylinders to load requirements," in*Hydraulics & Pneumatics*, 2013. [Online]. Available: http://hydraulicspneumatics.com/cylinders-amp-actuators/checklist-matching-air-cylinders-load-requirements. Accessed: Oct. 01, 2016.

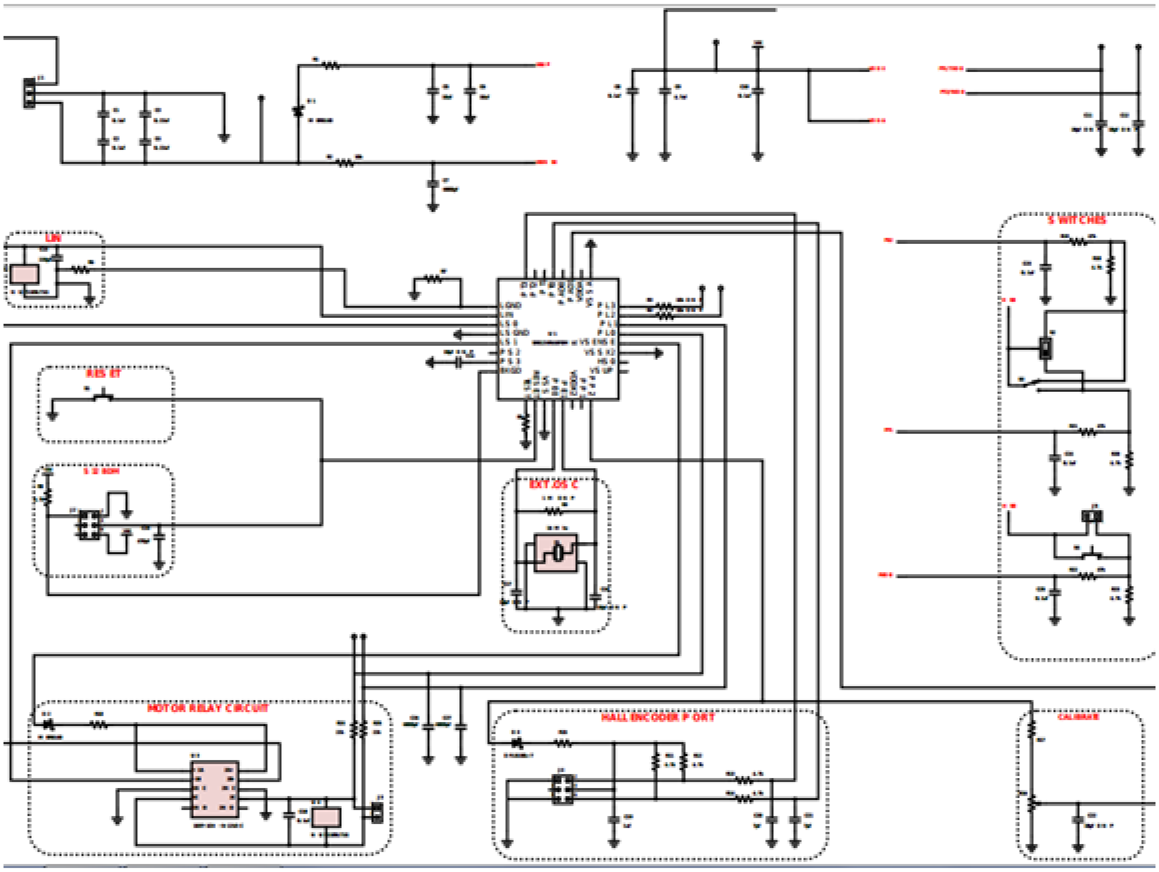
[8] "About Winbag," in *Winbag USA*. [Online]. Available: http://winbagusa.com/. Accessed: Oct. 08, 2016.

[9] B. Carter, "Robo-Pitcher Throwing in Detroit has 100MPH Fastball," in *WIRED*, WIRED, 2012. [Online]. Available: https://www.wired.com/2012/08/cy-ber-young-baseball-robot/. Accessed: Sep. 29, 2016.

[10] D. Tutelman, "What Happens at Impact," in *The Tutelman Site*, 2015. [Online]. Available: http://www.tutelman.com/golf/design/swing2.php. Accessed: Sep. 31, 2016.

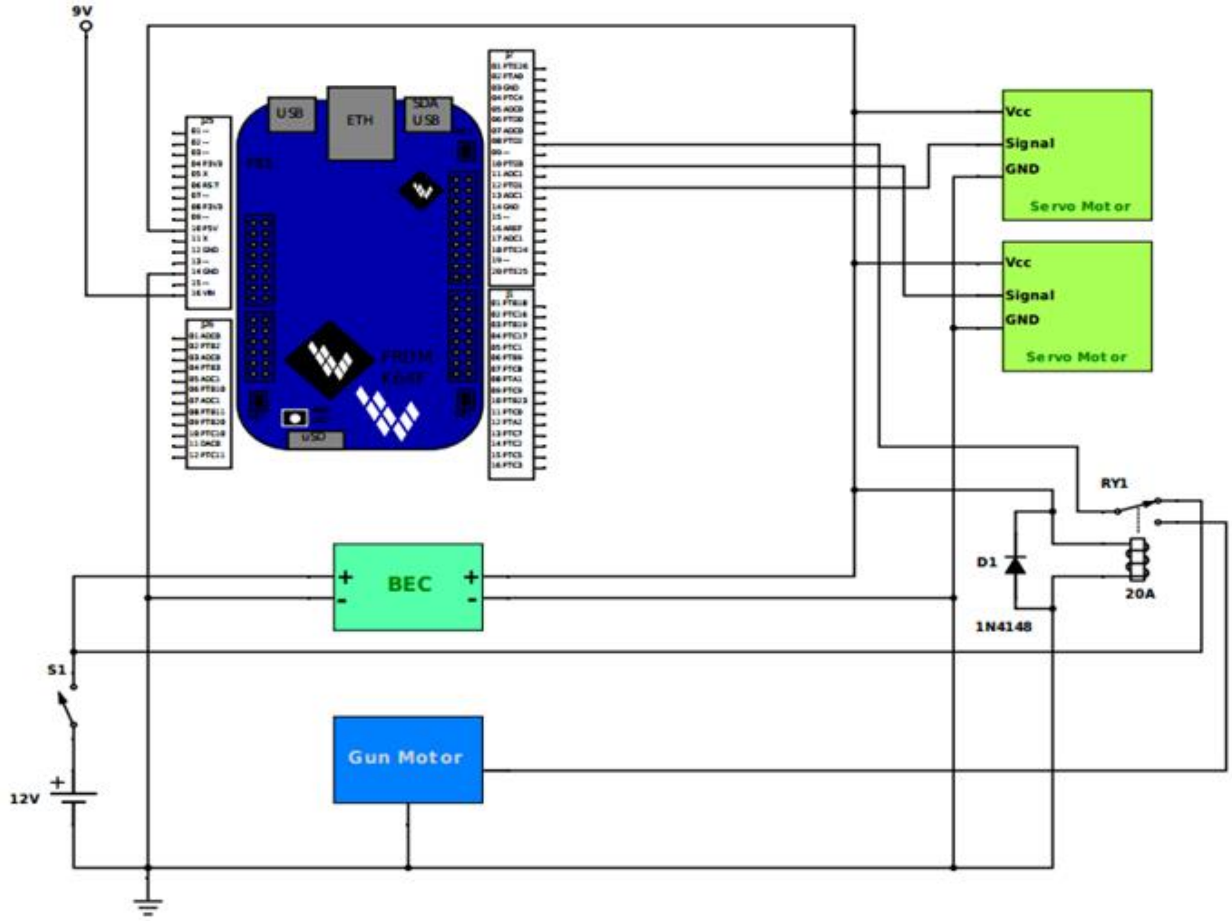
Appendix A

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 the lead mechanical engineer for the project and is currently overseeing the creation of CAD Models for the design of the robot.

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 pneumatics circuit.

Ryan Alicea is a senior in the Department of Mechanical Engineering at Florida State University from West Palm Beach, Florida. Ryan is the project lead and is currently performing specification analysis of necessary components and FEM analysis of the structure.