Final Project Report

Team M3F1

Engineering Design VI - ME 322

Group Number LB2

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I pledge my honor that I have abided by the Stevens Honor System

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Introduction

The team will develop an interactive toy which serves as an artificial pet, targeted for users with busy and hectic schedules. The “pet” will be small in size, fitting within a 12”x12”x12” box. It will be able to automatically move around, will react to being “fed”, will respond to “affection” from users, will have a playful mode where it can perform tricks or act happy, and will favor ambient warmth and disfavor extreme hot or extreme cold environments. The team will design the product using PD approach. This approach will involve planning, concept development, system level design, detail design, testing and refinement and production ramp up. Following this systematic PD approach will allow the team to make decisions as a unit, will allow structure behind the process to ensure that it is done rigorously and in a well documented manner and will ensure that the final product meets customer and stakeholder needs.

Individuals with very hectic schedules simply do not have the time to care for household pets due to outside constraints, including work, school or other family obligations. These people are missing out on the benefits that owning and caring for a pet can bring to their life. Developing an artificial, interactive pet will the target customers, high-tech toy enthusiasts and adults with busy lifestyles, the benefits of having a pet without the responsibility of caring and cleaning up after one.

The team will consider various constraints during the Product Development Process. The production-scale device must cost the customer less than $100.00. The product must be user customizable, safe to operate and must endure several years of use. The product should satisfy the primary market including high-tech toy enthusiasts as well as adults with busy live, and the secondary market of college students. Some of the general constraints dictating the development of an alpha prototype include a cost to the user less than $100, fits inside of a 12”x12”x12” box, moves without human interaction, and reacts to environmental inputs.

To satisfy the needs, specifications, and constraints overviewed above, Team M3F1 proposes the M3F1 robot as a viable product to sell to consumers. The M3F1 is inspired by the R2D2 character from the *Star Wars* franchise. The likeness to a well known character improves the marketability of a final product. The M3F1 robot can move with a wheel in each side leg and a ball bearing acting as a pivot, emit audible beeps through a speaker, blink an LED with different colors, measure temperature, and react to user interaction. A more in depth description and analysis of the product is conducted later in the report.

State of the Art Review

This next section of the report seeks to review three existing products on market that fall under the category of high tech toy pets that are mobile and interactive with the user. The team first reviewed the problem statement to attain an understanding of possible products and to guide the research in evaluating existing products. Examining existing products already in market is a valuable resource to a product design team to building their own product. This research seeks to establish features of other products, and how they can help in the design of the team's product. The interactive capabilities of the toy pet are a major requirement and the research into how existing products interact with users helps to shape the features included in the team's design. The three existing products evaluated by the team include an interactive therapeutic robot seal named PARO, a Joy for All Companion Pet dog from Hasbro, and a BB-8 app enabled droid. The team outlined the relevant specifications of each product for easy comparison to the requirements outlined in the problem statement of the project.

PARO

PARO, shown in Figure 1, is an interactive therapeutic robot which is mostly distributed in environments such as retirement homes and hospitals in place of a therapy pet. PARO has been found to reduce stress for patients and improve relaxation, social skills and motivation for those that interact with it. PARO is manufactured in Japan by Intelligent System, Co.. Figure 1 below shows a picture of PARO, the interactive therapeutic robot.

Figure 1: PARO Interactive Therapeutic Robot

A link to the company website with product information: http://www.parorobots.com/index.asp

- Technical Specs:
    - Power: AC100V, 50-60Hz, 1.3-0.7A
    - Internal rechargeable battery
    - Length: 57cm (22.4")
    - Weight: about 2.7kg (95.2 oz)

- Price:
    - $5,000
- Awards:
    - World's Most Therapeutic Robot certified by Guinness World Records
- Sensors:

    - Tactile
        - For sensing when the user is physically interacting with the system such as a stroke from a hand or if the user is disciplining the system.
    - Light
        - To sense if it is night or day
    - Auditory
        - To recognize when it being called and identify the direction of the sound
    - Posture
        - To be able to sense when the system is being picked up, or being hugged
    - Temperature
- Robotic movements:
    - Head moves in multi-directionally
    - Flippers move up and down
    - The systems eyes blink open and closed

<u>Joy for All Companion Pets</u>

Hasbro has created an artificial pet to act as a companion for elderly people who lack companionship in environments such as retirement homes or hospitals, shown in Figure 2 below. The pet come in two species, cat and dog. The companion pet incorporates Hasbro's real time feedback technology so that the pet can react to its environment and users actions, and has real feel fur to mimic that of an actual cat or dog. The Joy for All Companion Pet is manufactured by Hasbro and has the model number B9108. Figure 2 below shows an image of the Joy for All Companion Pet from the Hasbro website.

Figure 2: Hasbro Joy for All Companion Pets

A link to the company website with product information: http://joyforall.hasbro.com/en-us

- Sensors
    - Tactile
        - For sensing when the user is petting the system so that it can react accordingly
    - Auditory
        - So that the pet can sense when it is being spoken to

- Robotic movements:
    - Multi-directional head
    - Eyelids that open and close
    - Mouth that opens and closes
    - Vibrating system that mimics a heartbeat
- Technical Specs:
    - Dimensions: 4.4 x 8.4 x 9 inches
    - Weight: 4 pounds
    - Power: 4 C batteries
- Price:
    - $116.05 on Amazon

<u>BB-8 App Enabled Droid</u>

From the creators of the star wars series, comes the BB-8 App controlled robot, shown in Figure 3. The robot is a model of the BB8 model droid featured in *Star Wars: The Force Awakens*. The droid can travel up to 7 ft/s and can be controlled with either a wrist mounted “Force Band” device or a smartphone. The BB-8 droid is manufactured by Sphero. Figure 3 below shows an image of the BB-8 droid and the optional force band for user control.

Figure 3: BB-8 App Enabled Droid

A link to the company website with product information:
https://www.amazon.com/Sphero-Star-Wars-Controlled-Robot/dp/B0107H5FJ6

- Sensors
    - Bluetooth compatible
        - Allows for “Force Band” control
    - Autonomous Behavior
        - Droid can sense objects and interact with surroundings autonomously
- Robotic movements:

    - Multi-directional head
    - Eyes and head to mimic visual sensors
    - Moves in all four directions
    - Can project holographic message
- Technical Specs:
    - Dimensions: 11.4 cm height, 7.3 cm wide
    - Weight: 200 Grams
    - Power: rechargeable battery lasting 60 minutes
- Price:
    - $129.95 at Amazon

The research done on existing products allowed for the team to develop a better understanding of what features existing high tech toys have and how they implement them. It also allowed the team to learn about different types of technologies which exist in the electronics and mechanisms area of engineering. With this product research the team discovered the capabilities of a toy and how it is restricted by price. The three evaluated products all cost above the set budget of $100 so the team realized the robot must be significantly simpler than existing products. The previous products companies would have conducted market research with consumers to build the most appealing and marketable product. Based off this knowledge, the team took into account the features of other products to try to incorporate them into the products design. The team identified the major advantages and disadvantages of each existing product to shape the team's design in order to avoid disadvantages and try to incorporate advantages. Overall, existing product research helped guide the development and design features included in the team's product design.

Some of the complex functionality that the team identified as impractical for a product that can be brought to market for under $100 include a multi-directional head, control through a mobile app, and eyelids and mouths that can open and close. The BB-8 droid and Hasbro pet dog fit within the size constraints alerting the team that the toy can have high functionality in a compact design. The three evaluated products all can interact with users in a complex manner in several different ways. The team is limited in resources and technical knowledge, and realized the designed products interaction with users must be simpler and not overly complex. The team discovered several ways for the user to interact with toy pets such as touching it in certain locations, speaking, and remote controlled app. The team concluded human touch on a sensor is the best option for the proposed product. Part of the requirements is the high tech toy pet must react to sensor inputs. The studied products below react to objects in the way, ambient temperature, and sound commands. With the supplied equipment the team can use a combination of movement with motors, LEDs, or a speaker to react to inputs. The teams toy pet must be mobile, however only one of the reviewed products can move. The BB-8 droid can roll in any direction, but uses complex motion. The team realized a simpler approach with wheels and straight line motion is the best option.

Design Selection

The team was to develop an interactive toy that acts as an artificial pet for the user that invites human interaction from the user, and is capable of reacting to environmental changes based on sensor input. The primary target markets for a high-tech toy pet are adults with busy lifestyles that can not provide full time for an animal, and high-tech toy enthusiasts. A secondary market for a high-tech toy pet are college students that can receive a form of companionship and responsibility without the responsibility of caring and providing for an animal such as a dog or cat. The primary stakeholders for a product such as this are the users as well as the students and staff of the ME 322 class. Secondary stakeholders for a high-tech toy pet include retailers, production staff, service staff, legal department, and many other organizations.

A high-tech toy pet addresses a market of individuals who want a pet but cannot due to other applications. Owning and caring for a pet has been proven to improve quality of life for individuals, However, individuals with busy schedules often cannot provide adequate care for a house pet due to time constraints and obligations that take priority. A high-tech toy pet can provide the benefits of owning a live pet without the burdens involved with a living creature such as feeding, cleaning, and exercising. To address this benefit proposition the team was given needs and specifications for a final product satisfying this scenario to be introduced to market. The final product design must fit within a 12”x12”x12” cube. The artificial pet must exhibit several personality traits. The artificial pet must be able to move around its environment without direct human intervention. The product must request or crave “feeding” in some form, and then must respond positively to the user when it is “fed”. The toy pet must also respond favorably to “attention” or “care” from users in some manner. A playful mode where the toy pet can perform tricks or act happy towards the user is also required. The toy pet must also favor ambient warmth and disfavor extreme temperatures, either hot or cold.

The final version of the high tech must also offer several benefits to the end user. The production version of the high-tech toy pet must cost less than $100 to the customer. The toy should be configurable to the user, operate safely, and endure several years of use by the user. These design needs and specifications provide a framework for the team to follow in order to bring a viable alpha prototype of a high-tech toy pet to fruition for review.

The team created a summary of stakeholders needs and desired metrics for the high tech toy product. These criteria were separated into 6 categories: Durability, Safety, Traits, Demonstration, Features, Business, Prototype and ME-322. The criteria was used in order to determine which design would best fulfill the customer’s needs. Each criterion was ranked between 1 and 10 (1 being most important to the product and 10 being least important to the product). The most important criteria include being able to fits inside a 12"x12"x12" cube, be able to operate normally for several years, have Configurable parts that can be easily replaced by user, and can operate normally with minimal maintenance. A full list of the criterion can be found in Appendix A1-1.

The stakeholder needs were then tabulated in terms of the critical specifications, which are quantifiable criterion. This needs are vital for customer satisfaction and are shown below in Table 2.

Specification Number	**Need Number**	**Specification**	**Units**	**Value**
1	5	Low cost to User	US$	< 100
2	1,8	Size range of product	inches	12" X 12" X 12"
3	6, 10	Temperature sensitivity	°Fahrenheit	68 < x < 77
4	2, 3, 5	Material Selection	in^2 in^3	Cardboard: 31.35 ABS Plastic: 3.5

Table 2: Critical Specifications

Based on the needs, metrics and specifications discussed above, the team came up with 3 product concepts to fulfill all requirements. A general overview of each concept is included below. Detailed design descriptions and concept combination tables of each concept can be found in Appendix A1.

Proposed Design 1: Giraffe

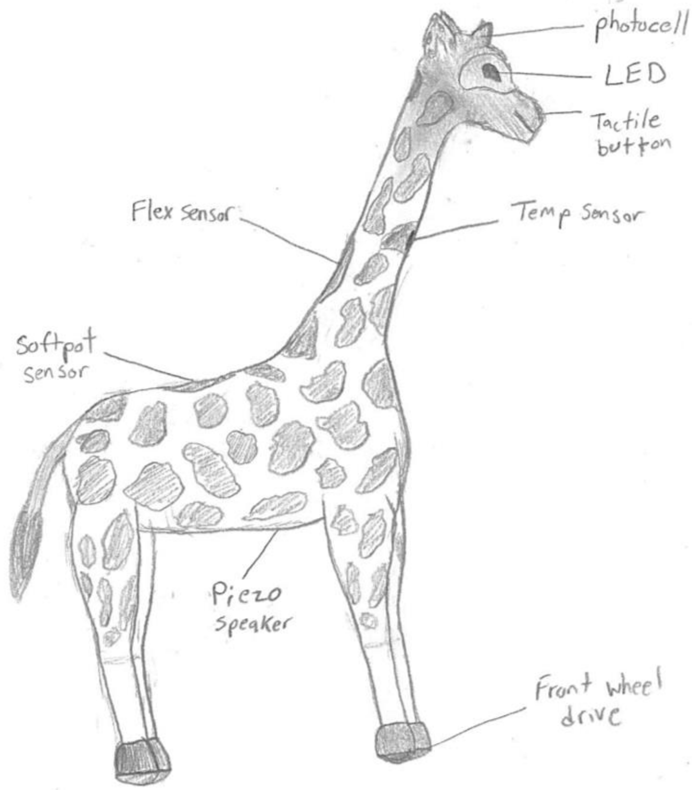

Figure 4: Giraffe Concept Illustration

The first concept design is a based off of the Toys R us Mascot - a Giraffe. A concept illustration of the giraffe is shown in Figure 4. This type of animal is recognized by many in our market demographic as a symbol of fun and happiness. This concept has been designed according to our customer primary needs and specifications. The system shall respond to its habitat by sensing various elements of its environment. The system shall communicate to its owner via LEDs and speaker, with a variety of preprogrammed combinations to convey emotions. The next requirement if for the system to respond to hunger, the giraffe would communicate with red LEDs and stomach rumbling noise to simulate hunger. The giraffe will favor an ambient temperature which is defined in the range of 68 - 77 °F. In addition to sensing its environment, the system will react to human interactions such as petting. In order to move around autonomously, the giraffe shall have a front wheel drive located in the front legs of the system. Lastly the system will perform tricks, such as running away from light by sensing light sensitivity through a photocell placed on its head.

Proposed Design 2: Turtle

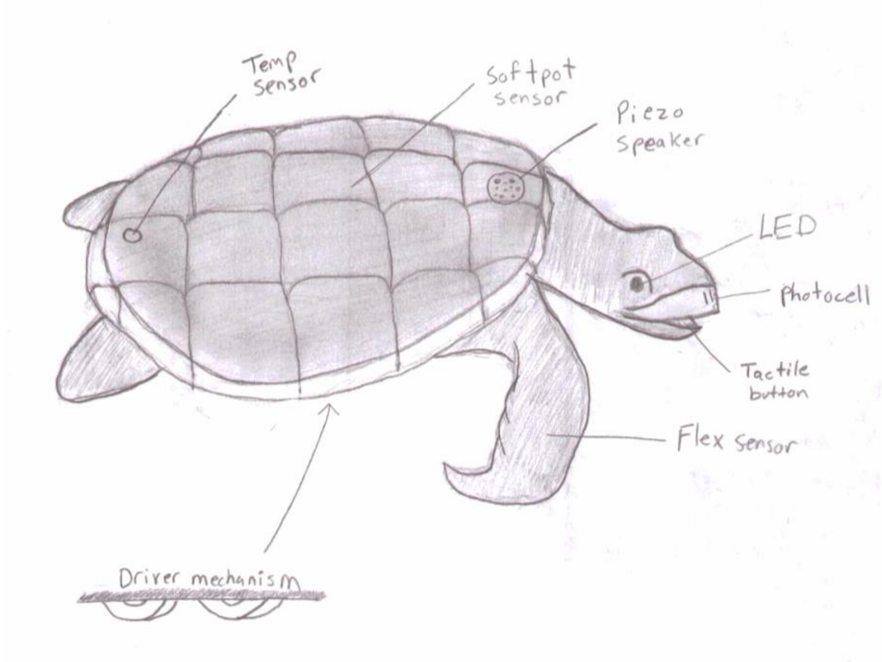

Figure 6: Turtle Concept Illustration

The second concept design is a based off of a sea turtle, such as the ones made famous by Finding Nemo character, Crush . This concept has been designed according to our customer primary needs and specifications. An illustration of the turtle is shown above in Figure 6. The system shall respond to its habitat by sensing various elements of its environment. The system shall communicate to its owner via LEDs and speaker, with a variety of preprogrammed combinations to convey emotions. The next requirement is for the system to respond to hunger, the turtle would communicate with Green LEDs and groaning noise to simulate hunger. In order to feed the turtle, the team has incorporated a tactile button into its mouth. that once pushed the system will simulate the feeding process. The turtle will favor an ambient temperature which is defined in the range of 68 - 77 °F. In addition to sensing its environment, the system will react to human interactions such as petting. In order to move around autonomously, the turtle shall have a four wheel drive located on the bottom of its body. There will be a preprogrammed motion sequence to have the system move autonomously without human intervention. Lastly the system will perform tricks, such as triggering a random dance by bending the flex sensor in the turtles fin to activate the motions.

Proposed Design 3: M3F1

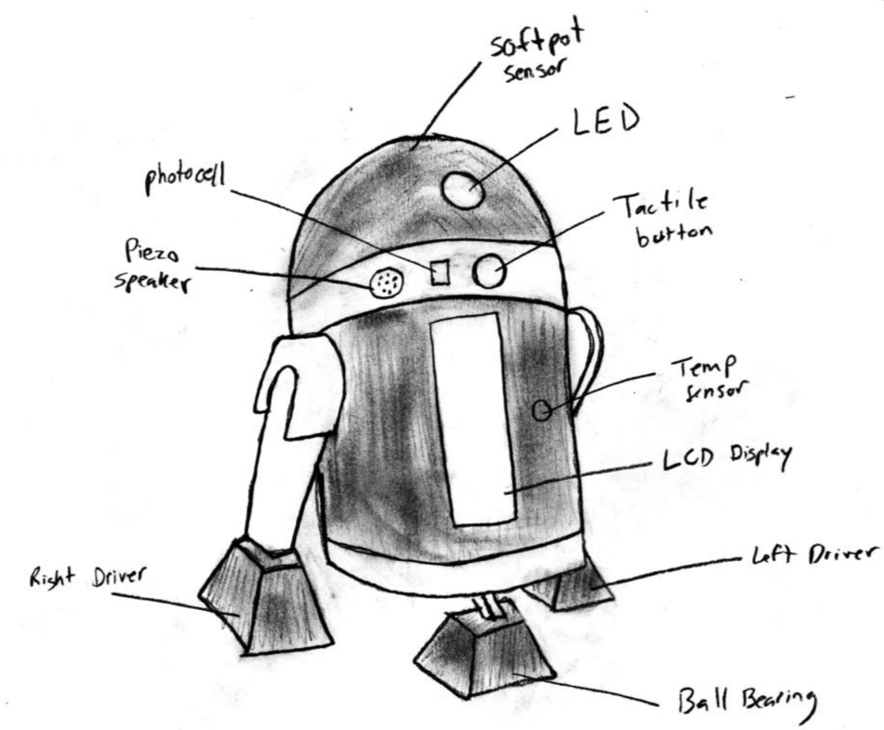

Figure 8: M3F1 Concept Illustration

The third and final design concept design is a based off of a famous astromech droid named R2D2, from the infamous Star Wars Saga. This movie is extremely popular among the geek community, and seeing that our stakeholders are composed of mostly engineers, the team thought this design would resonate well with the stakeholders. In addition, Star Wars has gained popularity in the public majority, and we believe that they to would be interested in this design. This concept, named M3F1, has been designed according to our customer primary needs and specifications. An illustration of M3F1 is shown above in Figure 8. The system shall respond to its habitat by sensing various elements of its environment. The system shall communicate to its owner via LEDs, speaker, a push button, temperature sensor and a soft potentiometer, with a variety of preprogrammed combinations to convey emotions. The next requirement is for the system to respond to hunger, the droid will communicate with LEDs and machine noises. In order to feed the system we have incorporated a tactile button into its mouth-mid chassis area. Once pushed, the system will simulate the feeding process. The droid will favor an ambient temperature which is defined in the range of 68 - 77 °F. In addition to sensing its environment, the system will react to human interactions such as petting. In order to move around autonomously, the droid shall have a drive system with independent rotation speeds and directions. The wheels are on the sides of the system (Left and Right as seen above) and have their own motors assigned to them. There will be a preprogrammed motion sequence to have the system move autonomously without human intervention.

After developing three viable product concepts, the team had to select a single concept to pursue as the final concept. The first step was to create a high-level concept screening decision matrix to identify any designs significantly lacking compared to others. The team ranked with a system +, -, 0 system. This method allowed the team to the giraffe concept as an unsatisfactory design concept. The team was left with two designs to chose between: the Turtle and M3F1. Appendix Table A1-2 shows a completed concept screening decision matrix.

The team was able to select the design concept that best matched the proposed design requirements and specifications in the problem statement with use of the Concept Selection Matrix, shown below in Table 5. The compared the final two concepts, including the giraffe and a robot named M3F1. This table weighs different selection criteria that all add up to 100%. Each product is rated on a scale of 1 to 5 that is then weighted based on the selection criteria. The total weighted score is calculated for each design concept. The team discovered the M3F1 design concept to be the best choice by best matching the design requirements and specifications from the problem statement. The key categories that guided the team to select the M3F1 include the following categories: user configurable, low cost and interactive with user. The M3F1 outranked the turtle in the user configurable category because once the toy is on the market, there will be customizable skins that the user can buy to customize the outer body of the toy. The overall design of the M3F1 includes simpler geometric attributes as compared to the turtle, since the turtle shell would be more complex to manufacture, which ultimately would increase the cost of the turtle. Choosing the M3F1 allowed the team to find use for the speaker, to add another dimension of interaction with the user, since it is logical for a robot-esque toy pet to make beeping noises. Appendix Table A1-3 shows the completed full concept selection matrix.

Design Overview

The M3F1 product will communicate with its owner via LEDs and a piezo speaker, which receive information from the temperature sensor, soft potentiometer, and tactile button. The owner can communicate with M3F1 via a push button located on the front part of the main body and by touching the soft potentiometer on the top of the dome simulating petting. A figure showing the sensor locations on M3F1 is shown in Figure 9 below. The multicolor LED will be used to notify the owner when M3F1 is hungry, fed, hot, cold and in response to touch. The piezo speaker will be used to respond to touch from the owner as well as the temperature of the ambient environment becomes too hot or cold. The temperature sensor will be used to send data to the LED when the temperature of the product is out of the preferred range, in order to notify the owner when M3F1 is cold or hot. M3F1 will respond by reversing away from the source of the extreme temperature. The soft potentiometer will be used to detect if the owner is touching the product. The M3F1 will be able to move on its own, as the two motors will work in conjunction with the wheels and ball bearing. The ball bearing creates a pivot point for M3F1 giving it excellent maneuverability. Details for understanding the M3F1 product, its main subsystems and how it will be constructed will be explained more thoroughly in this section of the report.

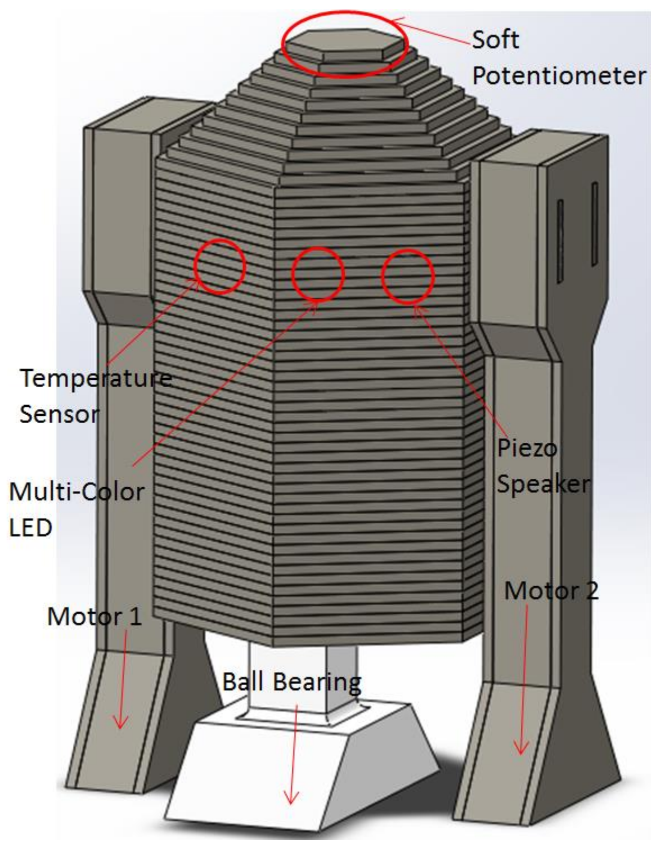

Figure 9: Sensor Locations on M3F1 Design

There are 3 inputs to the system: the temperature sensor, the soft potentiometer sensor and the tactile button. Each of these inputs will send data to the arduino board, which will then be processed and will trigger a response to either the motors, LED or the piezoelectric speaker. The purpose of the system/subsystem diagram is to display the overall data flow and the responses to the system to show that the product design fulfills the customer's needs and requirements. A complete Major Systems/Subsystems Diagram can be found in Appendix Figure A3-9.

The structure of M3F1 consists of several major components including the main body, dome, two side legs, and the front foot. The current dimensions of M3F1 are 6" wide, 5.62" deep, and 9.12" tall. All of the main components of M3F1 have standard geometry with no overly complex shapes of curves causing complexity in the manufacturing process. M3F1 fits well within the maximum dimensions of 12"x12"x12". Drawings of all major structural components of M3F1 are found in Appendix 3.

M3F1 is controlled through an Arduino controller with attached Ardumoto. Some of the components include a multicolor LED, temperature sensor, piezo speaker, tactile button, soft potentiometer, two DC motors, and several resistors. The Arduino circuit is powered by a single 9V battery. The circuit board includes all of the necessary sensors and is compact enough to fit inside the body of M3F1. A Fritzing electrical diagram and technical diagram of the circuit are shown in the Appendix in Figure A3-7 and Figure A3-8.

The software for M3F1 controls the Arduino and all of the sensors and outputs. The team started by creating a software flow chart to assist in visualising what the code must accomplish and how different sections are connected. With an outline or flow of the software writing the code becomes significantly simpler. The flowchart for M3F1's software is found in the Appendix in Figure A3-10 and A3-11. The code had to capture the inputs from three sensors including the tactile button, soft potentiometer, and temperature sensor. The values from these sensors was monitored and the team used IF statements to create a reaction if one of the input values exceed a set limit. For example, if the value of the soft potentiometer goes above 200, M3F1 will emit a series of auditory beeps similar to RD2 and then spin in a complete sensor. To achieve this the team had to set speed and direction for both motors, as well as create the notes and pitch of the noises to emulate the noises a robot may make. Through the software M3F1 is able to accomplish the specifications outlined including mobility, interactive with user, has a playful mode, and does not require direct human interaction.

The major complex system of the design is the wheel or driving mechanism of both side legs. Each motor is mounted inside the main body of M3F1 and its driving shaft is positioned inside each of the side legs. The shaft is connected to a timing belt pulley. At the bottom of the leg there is a freely rotating axle connected to another timing belt pulley. Both pulleys are then connected with a timing belt. With this mechanism the rotational speed of the top pulley is equal to the rotational speed of the bottom pulley. This mechanism is illustrated below in Figure 10.

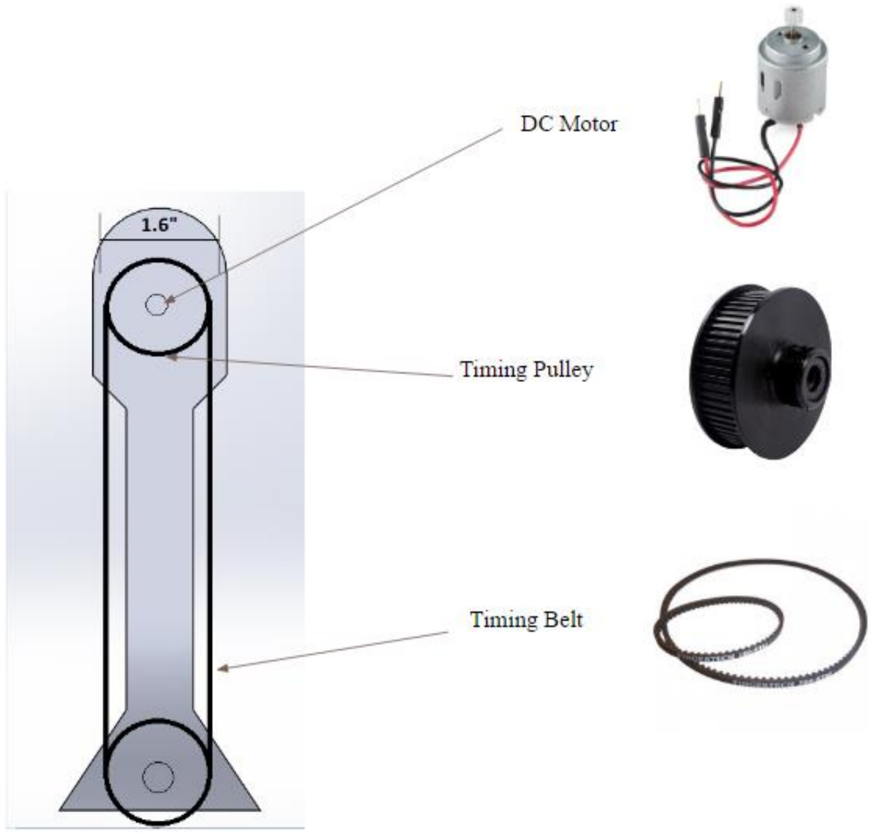

Figure 10: Motor and Wheel Mechanism

Table 6 shown below depicts how the team's proposed product will fit the customer's needs. M3F1 will be under 12" x 12" x 12" as it will be 10.45" x 6" x 5.61". All the circuitry will be contained within the chassis, to prevent any electrical accidents and to keep the product safe. The customer will be able to configure the design of the product as there will be various skins for visually appealing exterior design. The M3F1 design will be inexpensive with a cost to the customer of $73.99. The cost to the user will be broken down in more detail in the production plan section. The product will be interactive with the user. The touch sensor data will trigger the piezo speaker to emit sound when the user is petting or touching the product. The data collected from the temperature sensor will be used to trigger the LED to flash red and the piezo speaker to emit sound if the temperature of the product is not within the range of 68 to 77 degrees Fahrenheit. The robot will be mobile; the motor will be included in the side legs and the pivot front foot will include a ball bearing for easing pivoting. Table 6 below outlines the driving needs of the project and how M3F1 satisfies each one of them.

Driving Needs:	How will it be fulfilled?
Compact Size	M3F1 will be 10.45" x 6" x 5.61'
Durability	Stacked cardboard for increased strength
Safety	All circuitry will be contained within the chassis.
User Configurable	Will have various available skins for exterior color schemes
Low Cost	Material Cost $71.97
Interactive with User	Piezo Speaker will emit audio beeps as reaction to petting/care from user according to touch sensor data
Mobility	Motor included in the side legs; pivot front foot includes ball bearing for easy rolling
Aesthetically Pleasing	Will be colored to resemble a typical 'robot'
Can be Fed	Color changing LED which changes from red to green, based on hungry level (Red meaning hungry, green meaning satisfied)
Sensitivity to temperature	Will complain via red flashing LED and piezo speaker emitting sound if the temperature is not within 68-77 degrees Fahrenheit using data from temperature setting

Table 6: Driving Needs Fulfillment

Production Plan

Since only an alpha prototype was created, there are significant items on M3F1 that will differ from the initial prototype. One major different is the exposed circuit board on M3F1 will no longer be present on the finished model. The circuit board will be manufactured in China for significantly cheaper and also will not use an arduino. Instead of an arduino, a much cheaper, more generic microcontroller will be used. Additionally, the team will be allowed to solder in the final product which will allow the soft potentiometer to be mounted on the head. In addition, the chassis will not be made of strips of cardboard but will be injected molded. The specifications of the injection modeling is listed below in Table 7. In the Alpha Prototype, the motors were mounted outside of the arms. In the final product, the team will likely utilized the proposed gear train idea initially proposed in Figure 10. Finally, the team will color the model to mimic the colors of the original R2D2.

Part	Manufacturing Process	Material
Body	Injection Molding	Polypropylene
Legs (2)	Injection Molding	Polypropylene
Dome	Injection Molding	Polypropylene
Front Foot	Injection Molding	Polypropylene
Battery	Outsource Supplier	-
Wheels (2)	Outsource Supplier	-
Motors	Outsource Supplier	-
Circuitry Board	Outsource Supplier	-
Front Foot - Ball Bearing	Outsource Supplier	Stainless steel

Table 7: Manufacturing Plan for Main Components

In terms of production, the team is intending to initially produce about 6,000 M3F1 models. The team decided on 6,000 products after considering the popularity of the StarWars franchise. The team suspects that M3F1 will be very appealing to the Star Wars fans. The team researched the current market and found data supporting significant growth in the consumer robotic market. In 2016 consumer robotics sales reached 11.5 million units. This data was gathered from Figure 11 below. This market capacity helped the team estimate the production volume of M3F1.

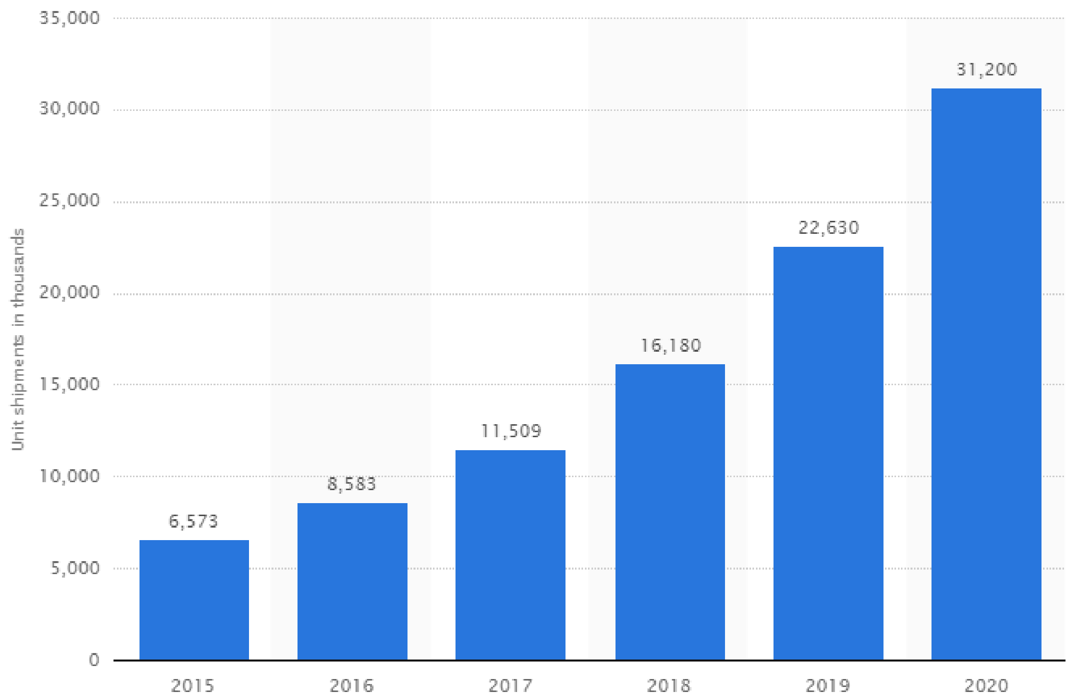

Figure 11 : Consumer Robotics Market Capacity

In order to determine a selling price of M3F1, the team first found bulk pricing information of all necessary components and raw material essential in building M3F1. The raw material cost was found to be $40.18. Next, the team researched the cost of injection molding as the main structural components of M3F1 will be injection molded with polypropylene. The team found a mold cost $14,000. With a total production run of 60,000 units, the per unit cost of injection molding was found to be $0.23. Transportation cost is another major factor in the final cost of a product. The team researched shipping cost finding the cost per mile to be $1.93 and estimating total travel distance as well as the number of units that can fit in a truck. The team found the transportation cost to be $1.50 per unit. Next, the team estimated the overall labor cost to be $5.00 per unit. Because of the similarities between M3F1 and R2D2 from *Star Wars*, the team plans on licensing M3F1 through Disney. While licensing is expensive the product will receive significantly more exposure in the market. The estimated licensing cost per unit is $10.00. Considering all of these factors the total cost per unit is $56.91. This leaves the team significantly below the required maximum price point of $100. The team plans on selling M3F1 at a 30% margin for a cost to the consumer of $73.99.

Engineering Analysis

This section outlines the initial modeling, calculations, and assumptions the team must consider while moving through the design process. In the team's preliminary model, the system incorporated a temperature sensor and tactile sensor to create a real time feedback operations system. With the temperature sensor, the system will have a preference of ambient warmth, indicating that it does not like excessive heat or cold. Ambient temperature is 65-77 °F with too cold being below 65°F and too warm being above 77°F. The tactile sensor will be a touch potentiometer to sense when the system is being petted and cared for, responding in a positive manner with LED lights and sound from the piezo speaker. The size of the product will be within the specified dimensions of 12x12x12 inches.

The team will need to utilize equations to calculate different values for the high-tech toy pet. Some of the equations the team will consider using during the project are listed below.

The team must make several engineering assumptions before designing a product based on the outlined stakeholder needs. Some of the major engineering assumptions are listed below.

- Power source will be a 9V battery
- Temperature range of environment will be between 30-100°F
- The system will not experience over 50 lbs of force
- The robot will move on flat and level surfaces only

<u>Mechanical</u>

______For the mechanical analysis, the team first conducted several SolidWorks simulations. The first analysis shown in figure 12 features one of the teams finite element analysis. The analysis was done before the physical creation of M3F1 to ensure there were no glaring structural weaknesses. The second and third study (as seen in figure 12 and 13) are stress and strain analysis, respectively. Similar to the displacement study, the team used these to help better predict the behavior of the model. To do this study, the team made the three wheels rolling supports and added a 1 newton surface load applied to the inner chassis. This was to simulate the breadboard. The team also selected the material closest to cardboard and applied a constant for gravity.

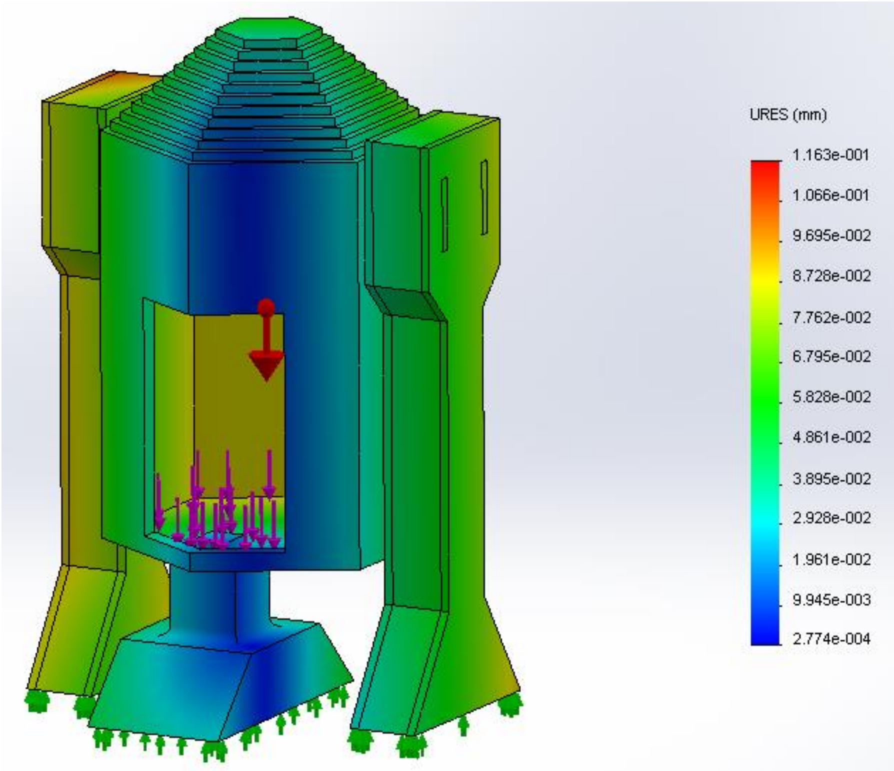

Figure 12: Displacement FEA

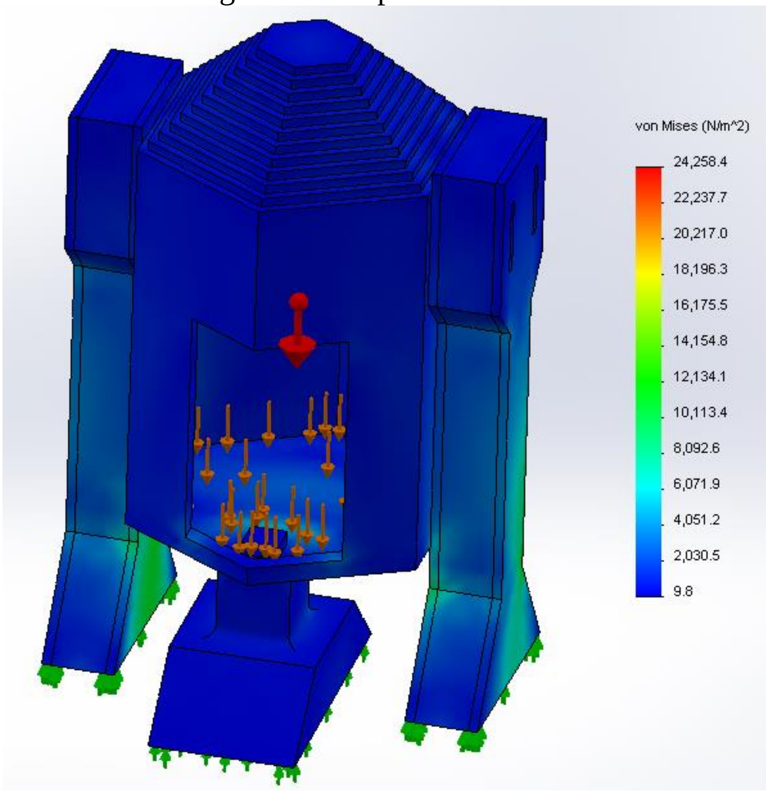

Figure 13: Stress FEA

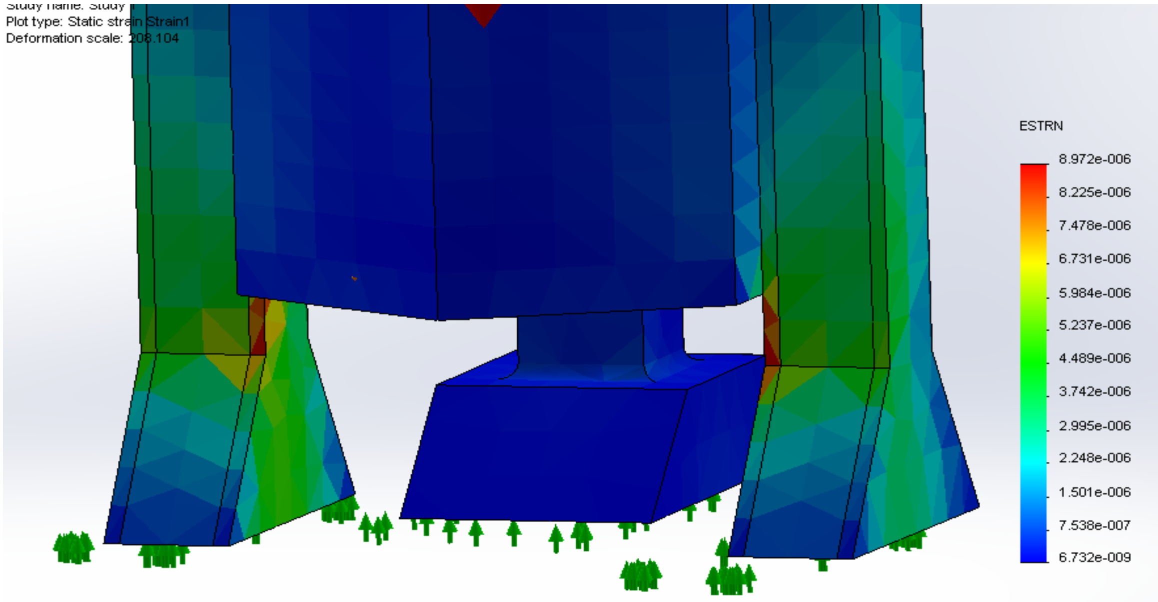

Figure 14: Strain FEA

The team expressed concerns about the center of gravity of the robot and if it would be at risk of tipping over. In SolidWorks the main body, top dome, and both side legs were given the material properties of corrugated paper. The front leg was set as ABS plastic.

The new and improved M3F1, which takes a much more realistic approach to manufacturing. The team was also able to update the mass properties of the robot and make them much more accurate to what the robot will end up being. In addition, the team redesigned M3F1 so that the body now stands upright, instead of at an angle. This was done to minimize the complexity of the design. The team then dove into the numerical analysis of the robot.

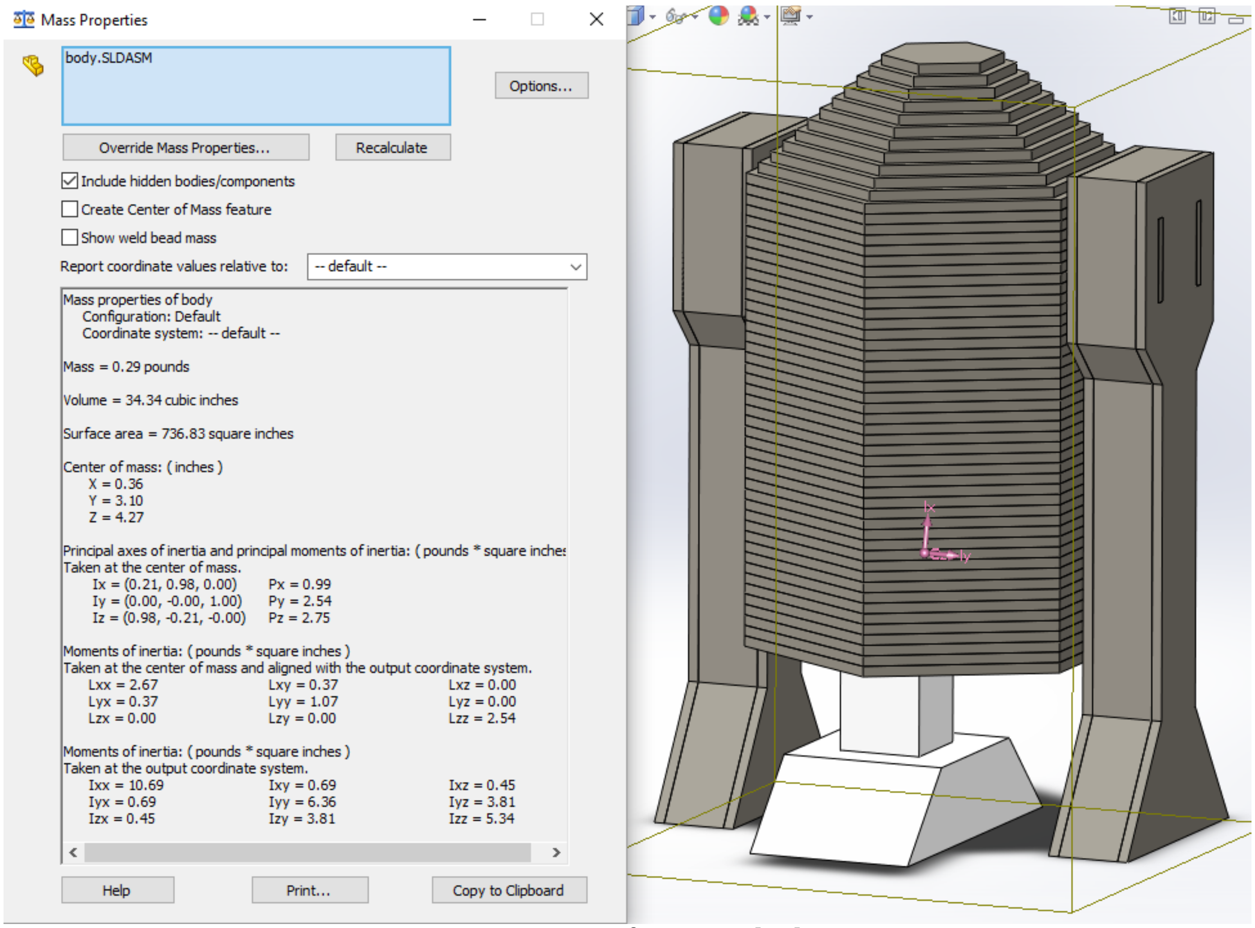

Figure 15: Center of Mass Calculations

The first calculation the team did was an estimation of the movement speed of the robot
Velocity calculations:
65 rpm x 60min/h = 3900 rph
65 rev/min * 60 min/hr x 8.375 in/1 rev x 1 ft/12 in x 1 mile/5280 ft = .078 mph (movement speed)

The team predicted, that the robot would be able to move .078 mph as it's max speed. This calculation made the team initially question that M3F1 would be able to perform pivots at it's max speed. Therefore, the team lowered the value, in the code, for power during turns from 255 to 200.

The team then assessed the approximate weight of the robot
Weight = .29 lbs + 1.5 lbs (for breadboard and other components) = 1.79 lbs

The team used the weight value to inform their finite element analysis and to ensure that the results from the finite element were not unreasonable.

Additionally, the team determined the force required to make the robot overcome the force of friction and move. Research on the internet lead the team to arrive at the value of .65 which is the coefficient of friction on wood. The team figured that the robot would most likely be used in a home where there would be wood floors.
F=weight*μ
1.79*.65 = 1.1635 lbf

These calculations as well as the finite element analysis lead us to realize that M3F1 must be reinforced - especially at the ankle area (red areas on Figure 14). The team was also limited by the strength of cardboard.

Electrical

In the electrical design, the team used the Fritzing software to create a simulated bread board and schematic, shown in Appendix A-3. The schematic shows the Sparkfun motor shield attached to an arduino. Although this does not show the arduino in the fritzing diagram, it is implied that it is connected it. The 9V is the main power source. There are also 2 DC motors attached to the shield, one in the A port and one in the B port. Additionally, there are connections for the temperature sensor, Potentiometer, the RGB LED, and Piezo speaker. The schematic still reflects the correct concept. A photo of the prototype electrical system is shown in Figure 16.

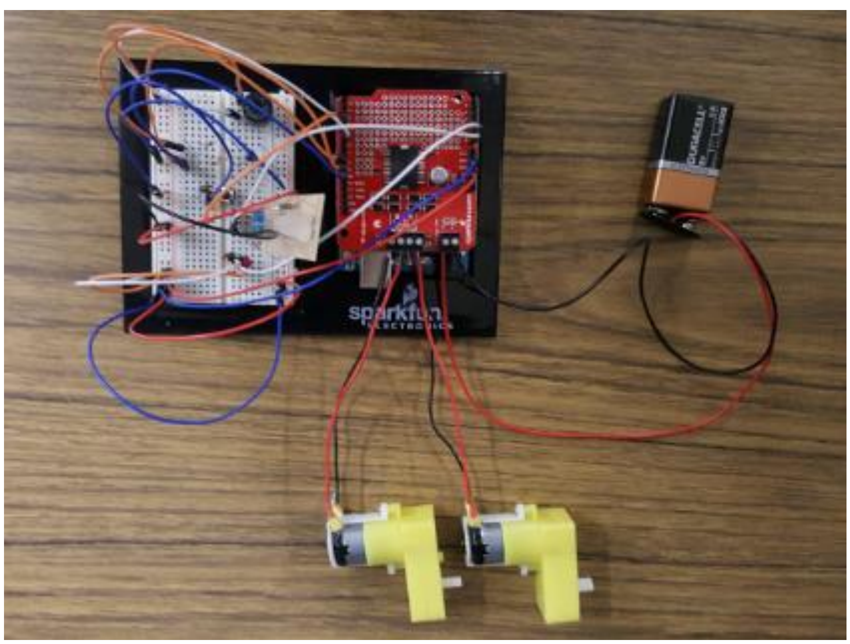

Figure 16: Assembled Electrical Circuit

Power Source: 9V battery
Electrical Power over time: 500 mAh

$I_{circuit}$ = 5.45 mA + 240 mA + 240 mA + 71.4 mA + 0.05 mA = 556.9 mA

500 mAh / 556.9 mA = 0.898 h ~ 54 minutes

This tells the team the approximate battery life of the 9V battery with all components operating.

Voltage of each component on circuit board:

- DC Motor (1): 9 V
- DC Motor (2): 9 V
- Soft Potentiometer: 100Ω - 10kΩ
- Piezo Speaker: 3-5 V
- Temperature Sensor: 2.7 - 5.5 V
- Multicolor LED: 2-3.2 V
- Battery: 9 V

RGB LED:
V_{RGB}= 5V-3.2V = 1.8V
I= V/R = 1.8V/330Ω = 5.45mA
P=VI = 5V * 5.45 mA = 27.25 mW

Motors (using stall current):
P=IV = .24A * 3V = .72W

Piezo Speaker:
V= 5V - 3V = 2V
I=V/R= 3V/42Ω= 71.4mA
P=VI=5V*71.4mA= 0.357W

Temperature sensor:
V=5V-2.7V=2.3V
I=.05mA (current draw)
P=VI= 2.3V*.05mA = .115mW

Total:
P_{total} = 1.12 W

The total power consumed by the toy pet is 1.12 W. An important note is the majority of the power is consumed by the motors. The team should attempt to limit the usage of the motors where possible to extend the operating life of the toy pet on a single battery.

Experimental Test Results

In order to prove product functionality, the team will have to test various aspects of the prototype. This alpha prototype testing helps to bring the most robust product to market. The team was concerned about a high center of gravity and decided to set up an experiment to characterize the stability of the M3F1 prototype. The team used Solidworks to determine the center of mass of the product. The results showed a higher than optimal center of gravity but was not overly concerning to the team. The team made note to limit the speed of the motor to prevent too much torque tipping the robot over. The team was unsure on the capabilities of the piezo speaker in regards to its volume, pitch and frequency. The team researched heavily online the functionality of the speaker and found code for different sounds to test. While testing the team discovered that the speaker lacked volume. When the motors were running, the speaker could not be heard, and as a result the team decided only the speaker or motors could operate at one time, and not both simultaneously. In addition some fine tuning was necessary for the speaker sounds. The team tried to simulate the desired “emotion” of M3F1, such as hunger or feeling cold depending on the sensor input so the noise made sense based on the input.

The majority of testing occurred in fine tuning the motor speeds and delays to achieve the desired result. The first task for the team was finding the optimal speed for the motors. In the Arduino code there is a value range of 0-255 that can be set for the motors. The team started with the motors set at 255. The team quickly realized this was too fast and decreased the values incrementally. The team eventually settled with motor speeds of 90. At this speed M3F1 moves quick enough where it doesn’t seem overly slow, but not too fast to be at risk of tipping. Next, the team had to fine tune the delays for M3F1 to complete a full rotation. The team set one motor at half the speed of the other motor and had both turn in the same direction. Then the team adjusted the delay until M3F1 completed a 360 degree rotation. Setting the low and high temperature limits also required testing. Similar to the motors the temperature is represented on a scale of 0-255. The team monitored the serial monitor of the temperature value in several different indoor locations to find a nominal temperature or value that represents ambient conditions. The team then set upper and lower limit values that would register if there is a significant change in temperature but not alert to false positives.

Design Evaluation

The final design of the device was created to satisfy the the following customer requirements. The product should satisfy the primary market including high-tech toy enthusiasts as well as adults with busy live, and the secondary market of college students. Our design is modeled after the famous R2D2 from Disney's Star Wars Saga, we chose this design since it resonates with most engineering students and is currently popular with the new movies rolling out. The requirements derived from the driver needs included the system being a compact size within 12" x 12" x 12" and the design of M3F1 was designed to be 10.45" x 6" x 5.61", meeting the requirement. The system needed to be durable and to meet the need, the team designed the product using stacked cardboard to improve rigidity. Another driving need was low cost, the final design s estimated to cost $71.97 in materials, allowing us to price the product well under the $100.00 prefered price point.

M3F1 was designed to be interactive with the user, so the team incorporated Piezo speakers to emit beeps as reactions to petting and caring, in addition to the speaker the team incorporated a RGB LED to use color to convey emotions. Additionally, the system has programmed moves to convey a "happy dance" to show that it's happy. The best example of being user interactive is when the system is petted, by triggering the Softpot, the system reacts by beeping, flashing a green light, and moving in a circle.

The system also responds to temperature sensitivity and hunger. The system uses a combination of a temperature sensor, RGB LED, Piezo speaker, and motors to convey when the robot is not in ambient temperature. When the system is cold, it will play a tune of "Let it go" from Disney's Frozen and flash a Blue LED while moving backwards with its wheels. If the system is hot, the tune of a "whistle" will play and the LED will flash red while the system drives backwards. The system reacts to hunger by using a count, the more you play with system the hungrier it gets. M3F1 will ask to be feed by beeping and flashing a red light, and the system can be fed by pushing a tactile button. We believe that our design accomplishes all the driver needs and requirements by being interactive and peaking the interest of our desired stakeholders.

Intellectual Property

Intellectual property, or IP, includes all legally protectable ideas, concepts, names, designs and properties. IP includes several patent types, trademarks, trade secrets and copyrights. Intellectual property is an intangible, but extremely valuable asset to major companies. Filing the appropriate paperwork to cover aspects of a design is important to ensure the sole use of the property and secure the financial security of the design. The physical design of the body of M3F1 is a unique feature and can be considered intellectual property. This aspect of the product would need a design patent. Although it is costly and time consuming to file a patent, it would be a vital part of the team's business plan to ensure originality and security on the market. A cost benefit analysis would be used to prove the necessity of this type of patent. Additionally, the name "M3F1" would need to be trademarked in order to give the team the exclusive right to "own" this word for branding and marketing purposes. It would be in the team's best interest to develop a symbol to coincide with the name M3F1, which would also be trademarked. The team would file an additional design patent for the custom skin wraps for the body and legs of M3F1. These skins would be similar to those used on electronics such as smartphones and laptops where users can select custom colors and patterns to purchase separately. This offers a unique custom feature to customers that isn't found in other toys on the market. Because of the similarities between M3F1 and R2D2 from *Star Wars*, the team plans on licensing M3F1 through Disney.

Ethical Implications

The team took all ethical implications into account for both the design and manufacturing execution of the M3F1. As per the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers, as well as all other engineering ethical codes, engineers should hold the safety, health and welfare of the public to the utmost importance. The team included a metal casing for the battery compartment shielding, in order to prevent the user from a leaking battery. Additionally, the team will require a choking hazard to be included in the retail product due to the small parts included in the assembly of the M3F1. This will note that this product is not intended for use by children, as per "ANSI Standard ISO/TR 8124-8:2016, Safety of toys - Part 8: Age determination guidelines". All retail production will be done within the US in order to ensure workplace safety for employees. The team will require any manufacturing partners to participate in an ethical screening before signing contracts to ensure that the company's ethical standards align with that of the teams'. This coincides directly with the fourth Rule of Practice standard in NSPE's Code of Ethics for Engineers.

The entire body of the M3F1 will be manufactured by injection molding of polypropylene. Polypropylene is a low density plastic, which reduces its negative environmental impact. Additionally, this plastic is 100 percent recyclable. The team conducted a Design for Engineering Analysis in Solidworks to investigate the impact of material and manufacturing location. The initial baseline inputs in the DFE include material choice of ABS plastic for the body, dome, side legs, and front foot. Other inputs include a manufacturing location in Asia, and water based paint. The team changed the material to PP Copolymer plastic and changed the manufacturing location to North America. Figure 17 below shows the results of the DFE study. All four categories including carbon, energy, air, and water were reduced significantly by anywhere from 18 to 53%. By changing material and manufacturing location the team saw a significant reduction in the environmental impact of the product.

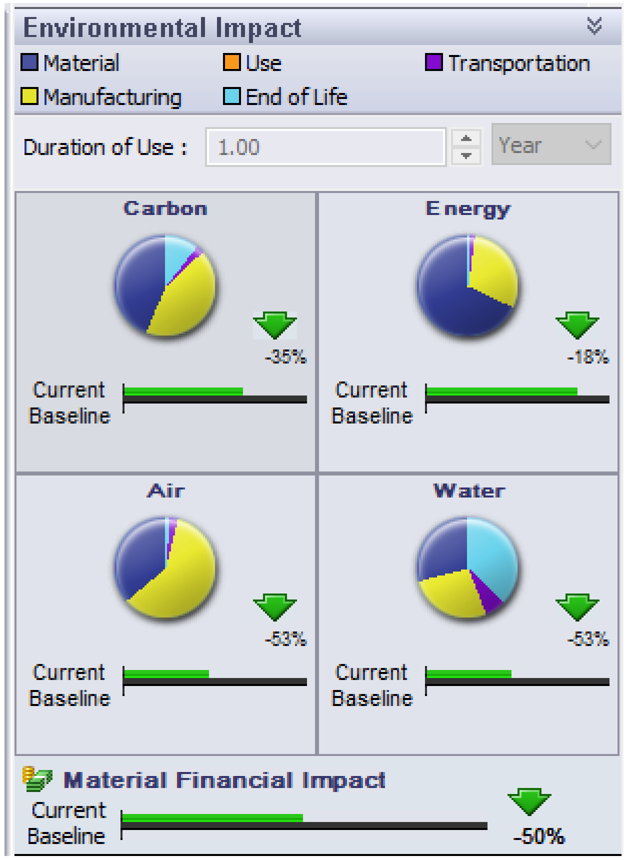

Figure 17: SolidWorks DFE Analysis Results

Lessons Learned

The Design 6 course at Stevens is the first time students are exposed to the full product development process. The team learned the detail that goes into each stage, from the concept selection to the designing and building of the prototype. Additionally, the team learned about engineering ethics and the standards to which products need to be built by, as well as the environmental impact of product components. There was a great deal of exposure to modeling software and programming as well. The team successfully designed their prototype using Solidworks and programmed the product using Arduino software. Additionally, the team learned about the capabilities of 3D printing and the protocol in using this lab at Stevens. This course provided the team with an overview to what a mechanical engineer does in the industry and allowed them to develop an appreciation for the process.

The greatest difficulty the team encountered was in time management. Each member of the team is a fourth year co-op student and are in various other mechanical engineering courses. Balancing this project, which is driven by a smaller number of deadlines, with other courses where assignments are due more frequently, challenged the team. This issue was handled by utilizing the team Groupme chat to discuss deliverables according to the Gantt Chart. The team set internal deadlines, which were earlier than those set by the course instructors. This allowed the team to have time to go through the deliverables to ensure that all aspects of the project were completed to a high standard. Additionally, the team was challenged by the technical modeling of simulation involved in prototyping. No team members have a strong electrical background which made it difficult to wire and to differentiate between the various electrical components provided in the kit. Additionally, the team had to conduct a lot of research to mathematically determine the power consumption of individual components as well as the overall circuit, and battery usage.

If the team was to redo the project, they would have conducted the technical analysis aspect of the product earlier. Additionally, the team would reach out for help from the Teaching Assistants and Professors to seek guidance. From a project management aspect, the team would have adhered more closed to their internal deadlines to ensure that progress was made more gradually and to minimize the rush to meet deadlines.

Project Management

At the start of the term project, the team discussed each other's strengths and weaknesses in order to assign various tasks to one another. Greg had a great deal of experience with Solidworks, so he was in charge of the modeling of and FEM simulation of the design. Nicole and Luis were responsible for designing the Arduino circuit and Fritzing diagrams. Dylan was in charge of the assembly. All other aspects of the project, including the testing of the prototype and the technical calculations, were done as a team. The team continuously worked together and completed most of their work together in a collaborative environment. Each team member successfully fulfilled their responsibilities and worked well together.

The team relied heavily on Groupme in order to remain on constant communication and hit each deadline for this project, outlined on the updated Gantt Chart, shown below in Figure 18. The team used this group message in order to plan all in-person meetings. The team used the Stevens library as their designated meeting space. It was essentially for the team to meet outside of the allotted lab time in order to design, build and test the M3F1. The team found it beneficial to meet in person rather than remotely in order to hold one another responsible for the tasks which needed to be completed.

	Task Name	Duratic	Start	Finish	Pre	Resource Names
1	Determine needs/specs	7 days	Sun 2/19/17	Sat 2/25/17		
2	Perform Market Research	7 days	Sun 2/26/17	Sat 3/4/17	1	Nicole,Luis,Greg
3	Prelim Report Compilation	7 days	Sun 3/5/17	Sat 3/11/17	1,2,4	Dylan,Greg,Luis,
4	Prelim modeling/ calcs	2 days	Sun 2/26/17	Mon 2/27/17	1	Dylan,Greg
5	Design Concept Generation	3 days	Sun 2/26/17	Tue 2/28/17	1	Dylan,Greg,Luis,
6	Concept Selection	1 day	Fri 3/3/17	Fri 3/3/17	5	Luis,Nicole
7	Selected Concept Modeling	4 days	Sat 3/4/17	Tue 3/7/17	6	Dylan,Greg
8	Preliminary Teechnical Design Analysis	4 days	Sat 3/4/17	Tue 3/7/17	6	Dylan,Greg
9	Proposal Presentation Compilation	7 days	Fri 3/3/17	Thu 3/9/17	5	Luis,Nicole
10	Aquire Sparkfun.com materials (Vendor Order)	10 days	Wed 3/8/17	Fri 3/17/17	8	Dylan,Greg,Luis,
11	Aquire Home Depot Materials (Vendor Order)	1 day	Sun 2/26/17	Sun 2/26/17	1	Dylan,Greg,Luis,
12	Aquire robotshop.com materials (Vendor Order)	20 days	Sun 4/2/17	Fri 4/21/17	8	Dylan,Greg,Luis,
13	Building of Prototype	4 days	Fri 4/21/17	Mon 4/24/17	12	Dylan,Greg,Luis,
14	Refine Technical Design Analysis	4 days	Mon 4/24/17	Thu 4/27/17	12	Dylan,Greg
15	Theoretical Analysis of Functionality	4 days	Thu 4/27/17	Sun 4/30/17	14	Luis,Nicole
16	Physical Testing of Prototype	5 days	Sun 4/30/17	Thu 5/4/17	13	Dylan,Greg,Luis,
17	Final Presentation Compilation	8 days	Wed 5/3/17	Wed 5/10/17	13	Dylan,Greg,Luis,
18	Final Report Compilation	15 days	Fri 4/28/17	Fri 5/12/17	13	Dylan,Greg,Luis,

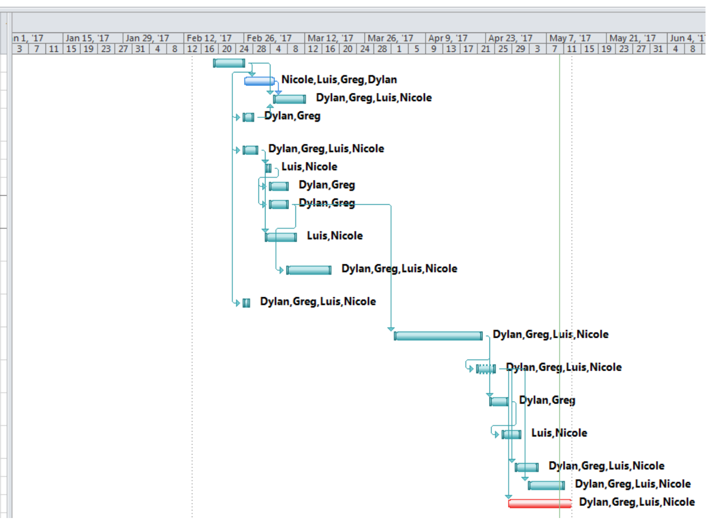

Figure 18: Gantt Chart

Project Feedback

While this project was successful, we did learn valuable lessons and have feedback on how to improve our design. In the future we would position the system sensors in the correct positions, since during the prototyping phase we were not able to correctly place the sensors on the system and instead displayed them all on the breadboard positioned in the front of the M3F1 body. We would also like to see this product be prototyped using the manufacturing process, to see the viability of the plan, and whether polypropylene will be a viable material. The team would also use better sensors to improve the retrieval of data input, bettering the system responsiveness. In addition our cost analysis is only an estimate, we would in the future actually do a trial run of the manufacturing process to get a better estimate of how much the cost for production and distribution would be. Lastly we would incorporate more functions/reactions in the system code, so that the interactivity of the system would increase and overall make the customer feel more involved and closer to the robot.

Appendices

A1: Concept Development and Selection

<u>Stakeholder Needs and Target Metrics</u>

Category	Designation	Priority	Description
Durability	Dur1	9	Operates normally for several years
Durability	Dur2	9	Configurable parts that can be easily replaced by user
Durability	Dur3	9	Operates normally with minimal maintenance
Safety	Saf1	7	Potential for injury during normal operation is negligible
Safety	Saf2	7	Product must pass all Federal safety standards
Safety	Saf3	7	Materials in product are safe for user handling
Traits	Tra1	6	Seeks or requests "feeding" in some manner
Traits	Tra2	6	Reacts positively when "fed" and becomes "hungry" again
Traits	Tra3	1	Responds favorably to affection, attention, or care from user
Traits	Tra4	1	Can perform tricks
Traits	Tra5	1	Displays "happiness" in an interactive manner
Traits	Tra6	5	Favors ambient warmth
Traits	Tra7	5	Disfavors excessive heat or cold
Demonstration	Dem1	2	Present design to primary stockholders demonstrating form and functionality
Features	Fea1	10	Fits inside a 12"x12"x12" cube
Features	Fea2	3	Is mobile and can move around its environment without direct human intervention
Business	Bus1	4	Production device costs less than $100 to customer
Prototype	Pro1	1	A functioning alpha prototype in presentable form and working as well as possible
ME322	ME1	1	Demonstrates abilities of ME 322 team

Table A1-1: Stakeholder Needs and Target Metrics

Outline of early concepts, with figures

Proposed Design 1: Giraffe

The first concept design is a based off of the Toys R us Mascot - a Giraffe. This type of animal is recognized by many in our market demographic as a symbol of fun and happiness. This concept has been designed according to our customer primary needs and specifications. The system shall respond to its habitat by sensing various elements of its environment. The system shall communicate to its owner via LEDs and speaker, with a variety of preprogrammed combinations to convey emotions. These LED’s will be located in the systems eye sockets and the speaker shall be placed in the underbelly of the system. The next requirement if for the system to respond to hunger, the giraffe would communicate with red LEDs and stomach rumbling noise to simulate hunger. In order to feed the giraffe, the team has incorporated a tactile button that once pushed the system will simulate the feeding process. The giraffe will favor an ambient temperature which is defined in the range of 68 - 77 °F, the giraffe will sense the temperature with a temperature sensor incorporated in its neck. In addition to sensing its environment, the system will react to human interactions such as petting. This will be done by embedding a soft potentiometer in the back of the giraffe; it will react to the different pressures a human can apply when petting the system. In order to move around autonomously, the giraffe shall have a front wheel drive located in the front legs of the system. There will be a preprogrammed motion sequence to have the system move autonomously without human intervention. Lastly the system will perform tricks, such as running away from light by sensing light sensitivity through a photocell placed on its head. A concept combination table is a helpful tool to a design team to consider combinations of solution fragments systematically. A concept combination table for the giraffe concept is shown in Figure A1-1 below. This table includes some but not all of the major subsystems of the design. A concept combination table is designed to be brief and not complicated nor intricate.

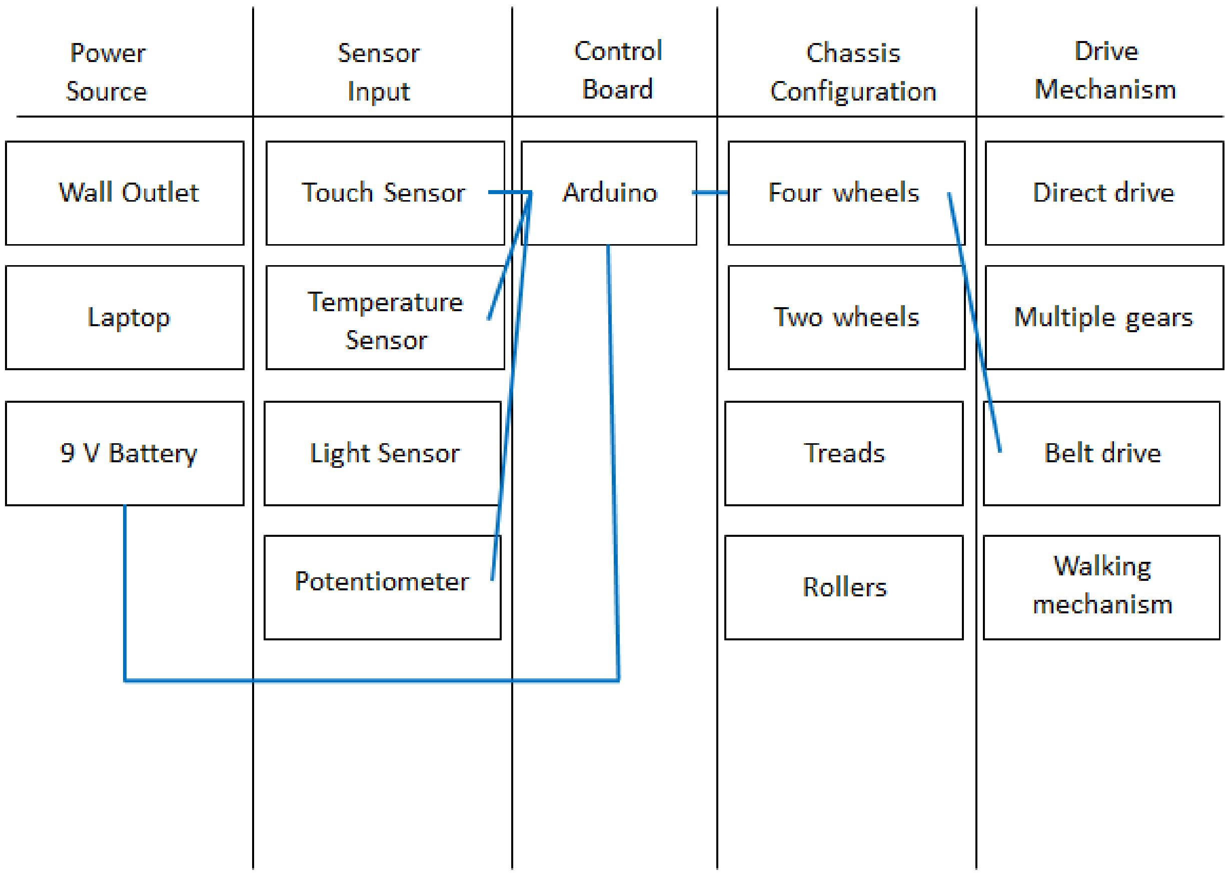

Figure A1-1: Giraffe Concept Combination Table

Proposed Design 2: Turtle

The second concept design is a based off of a sea turtle, such as the ones made famous by Finding Nemo character, Crush . This concept has been designed according to our customer primary needs and specifications. The system shall respond to its habitat by sensing various elements of its environment. The system shall communicate to its owner via LEDs and speaker, with a variety of preprogrammed combinations to convey emotions. These LED's will be located in the systems eye sockets and the speaker shall be placed in the head region of the shell of the turtle. The next requirement is for the system to respond to hunger, the turtle would communicate with Green LEDs and groaning noise to simulate hunger. In order to feed the turtle, the team has incorporated a tactile button into its mouth. that once pushed the system will simulate the feeding process. The turtle will favor an ambient temperature which is defined in the range of 68 - 77 °F, the giraffe will sense the temperature with a temperature sensor incorporated in the rear of its shell. In addition to sensing its environment, the system will react to human interactions such as petting. This will be done by embedding a soft potentiometer in the middle of the shell, where it will react to the pressure of a human petting the system. In order to move around autonomously, the turtle shall have a four wheel drive located on the bottom of its body. There will be a preprogrammed motion sequence to have the system move autonomously without human intervention. Lastly the system will perform tricks, such as triggering a random dance by bending the flex sensor in the turtles fin to activate the motions. A concept combination table of the turtle design concept is included below in Figure A1-2.

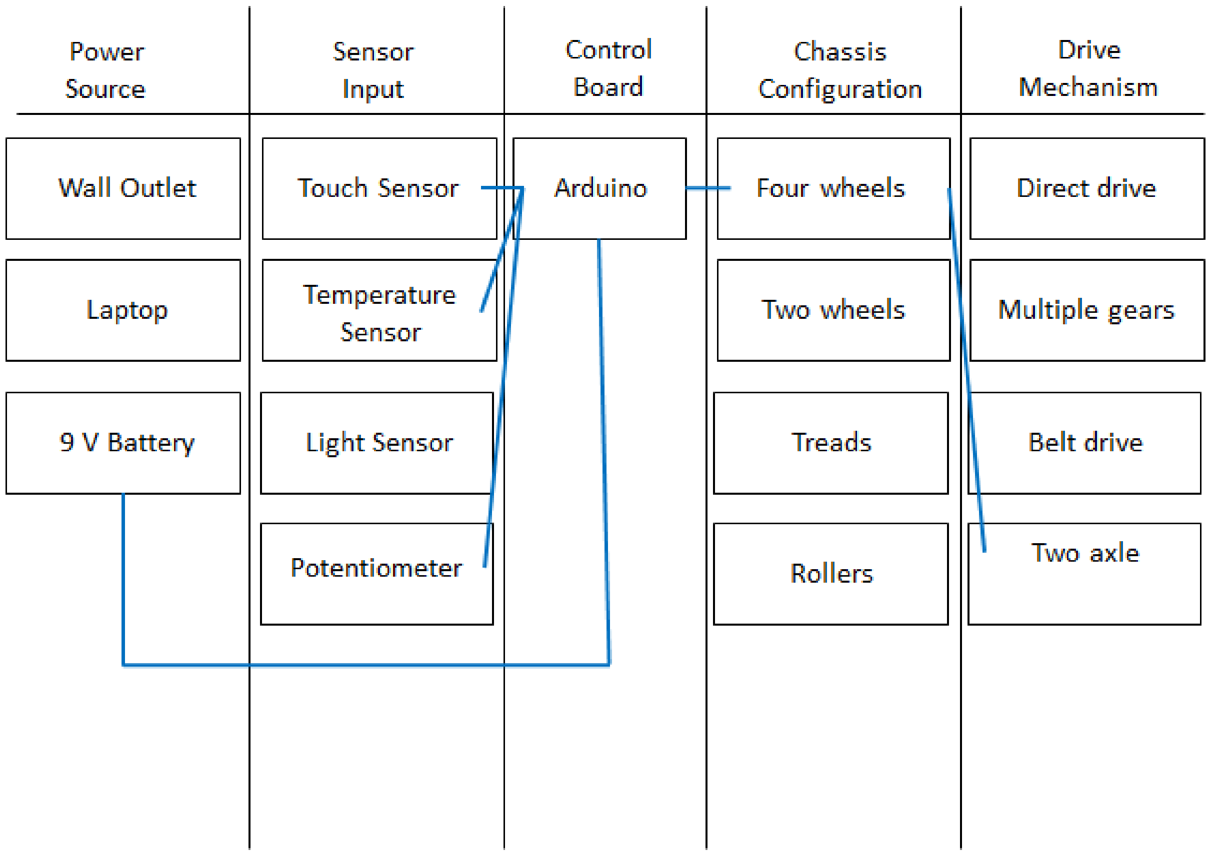

Figure A1-2: Turtle Concept Combination Table

Proposed Design 3: M3F1

The third and final design concept design is a based off of a famous astromech droid named R2D2, from the infamous Star Wars Saga. This movie is extremely popular among the geek community, and seeing that our stakeholders are composed of mostly engineers, we thought this design would resonate well with the stakeholders. In addition, Star Wars has gained popularity in the public majority, and we believe that they to would be interested in this design. This concept , named M3F1, has been designed according to our customer primary needs and specifications. The system shall respond to its habitat by sensing various elements of its environment. The system shall communicate to its owner via LEDs, speaker, a push button, temperature sensor and a soft potentiometer, with a variety of preprogrammed combinations to convey emotions. These LED’s will be located in the systems head, the speaker shall be placed in the mid region of the droids body and the push button in the mouth. The next requirement is for the system to respond to hunger, the droid will communicate with LEDs and machine noises. In order to feed the system we have incorporated a tactile button into its mouth-mid chassis area. Once pushed, the system will simulate the feeding process. The droid will favor an ambient temperature which is defined in the range of 68 - 77 °F, the system will sense the temperature with a temperature sensor incorporated in the lower region of the chassis. In addition to sensing its environment, the system will react to human interactions such as petting. This will be done by embedding a soft potentiometer in the middle the systems hemisphere head, where it will react to the pressure of a human petting the system. In order to move around autonomously, the droid shall have a drive system with independent rotation speeds and directions. The wheels are on the sides of the system (Left and Right as seen above) and have their own motors assigned to them. There will be a preprogrammed motion sequence to have the system move autonomously without human intervention. A concept combination table of the M3F1 design concept is included below in Figure A1-3.

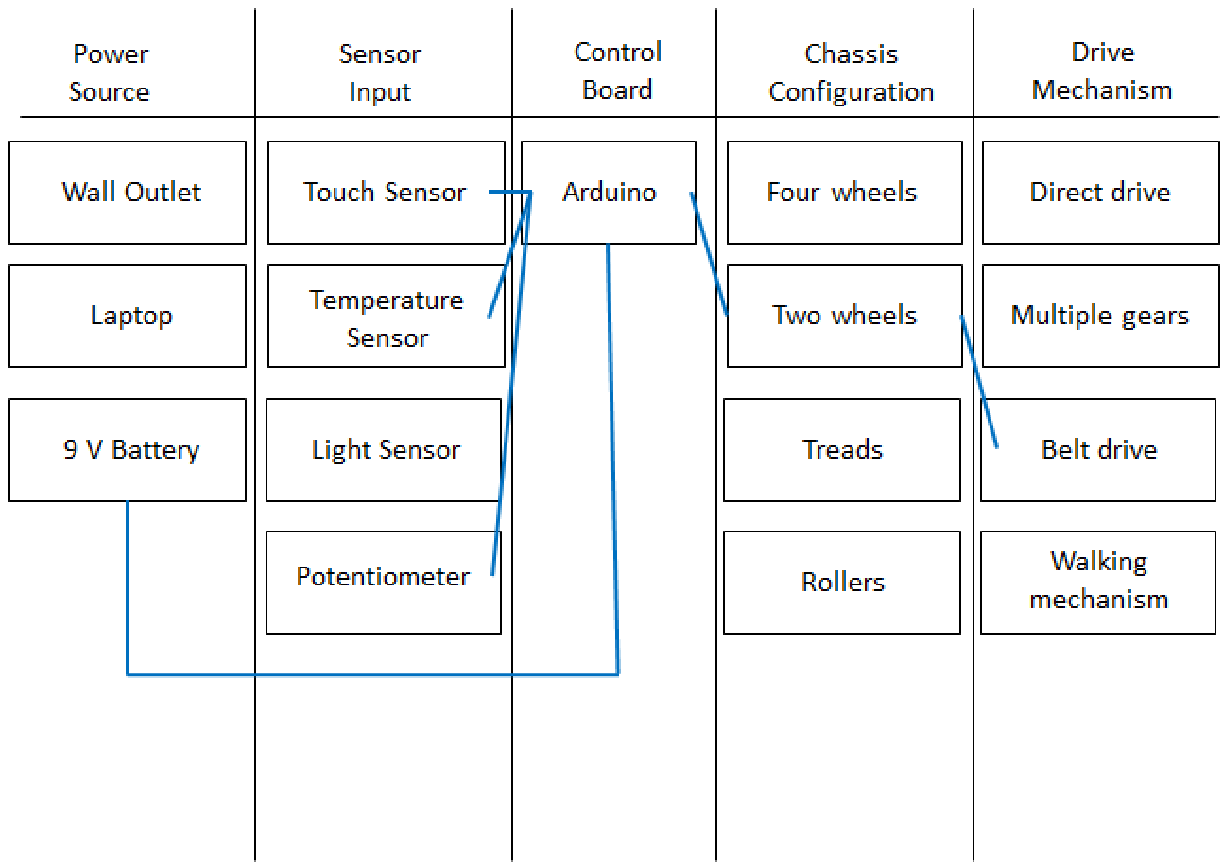

Figure A1-3: M3F1 Robot Concept Combination Table

Full Decision Matrices

Designs:	Giraffe	Turtle	M3F1
Compact Size	-	+	+
Durability	0	+	+
Safety	+	+	+
User Configurable	-	-	+
Low Cost	+	0	-
Interactive with User	0	0	+

Mobility	-	+	+
Aesthetically Pleasing	0	+	+
Can be Fed	0	+	0
Plus Total	2	6	7
Neutral Total	4	2	1
Minus Total	3	1	1
Net Score	-1	5	6
Rank	3	2	1
Continue?	No	Yes	Yes

Table A1-2: Concept Screening Decision Matrix

Concepts					
Design		**Turtle**		**M3F1**	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Compact Size	10%	3	0.3	3	0.3
Durability	10%	4	0.4	4	0.4
Safety	5%	3	0.15	3	0.15
User Configurable	5%	2	0.1	4	0.2
Low Cost	10%	3	0.3	5	0.5
Interactive with User	15%	3	0.45	4	0.6
Mobility	15%	4	0.6	4	0.6
Aesthetically Pleasing	20%	4	0.8	4	0.8
Can be Fed	10%	5	0.5	5	0.5
Total Score		3.6		4.05	
Rank		2		1	
Continue?		No		Yes	

Table A1-3: Concept Selection Matrix

A2: Bill of Materials

A vital part of any product is a complete bill of materials list that includes every component in the product, its quantity, as well as its cost. Figure A2-1 below is the complete bill of materials list for the M3F1 alpha prototype design. Included is the cost, quantity, and source of all components. The team calculated the total cost to construct the alpha prototype would be $57.17, which is less than the set limit of $100. The out of pocket cost of materials to the team is $4.36. Figure A2-2 lists all of the materials and the links to where the team gathered pricing and part numbers of the component.

Item	Description	Vendor	Vendor Part Number	Unit Cost	Quantity	Cost (actual)	Cost (unit_cost*qty)
9V Battery	Battery to power circuit board (600 mAh of usage)	amazon.com	MN1604	$2.20	1	$0.00	$2.20
Redboard	Sparkfun redboard programmed with Arduino	sparkfun.com	DEV - 13975	$10.95	1	$0.00	$10.95
Breadboard	Solderless circuit board to attach wires, sensors	sparkfun.com	PRT - 12002	$4.95	1	$0.00	$4.95
Temperature Sensor	TMP36 temperature sensor	sparkfun.com	SEN - 10988	$1.50	1	$0.00	$1.50
Tri Color LED	RGB clear three prong LED	sparkfun.com	COM - 00105	$1.95	1	$0.00	$1.95
Jumper wires	30 pack of 7" jumper wires (multiple colors)	sparkfun.com	PRT - 11026	$1.95	1	$0.00	$1.95
Piezo Speaker	PC Mount 12mm 2.048 kHz	sparkfun.com	COM - 07950	$1.95	1	$0.00	$1.95
Potentiometer	Trimpot 10k with knob	sparkfun.com	COM - 09806	$0.95	1	$0.00	$0.95
Push button	Pushbutton switch 12mm square	sparkfun.com	COM - 09190	$0.50	1	$0.00	$0.50
Resistor (330 ohm)	Resistor used in breadboard circuit	sparkfun.com	COM - 11057	$0.95	3	$0.00	$0.95
Resistor (10 kohm)	Resistor used in breadboard circuit	sparkfun.com	COM - 11508	$0.95	3	$0.00	$0.95
Cardboard	1/8"x18"x24" corrugated cardboard sheet	boxforless.com	CSS - 1824	$0.58	2	$0.00	$1.16
ABS Plastic	3-D printed material to form front foot of robot	Stevens	N/A	$15.00	3 in^3	$0.00	$15.00
Elmers Glue	Adhere cardboard layers (4 fl oz)	homedepot.com	E7010	$3.47	1	$3.47	$3.47
Ball Bearing	5/8" ball bearing attached to front foot for rotation	menards.com	9110	$0.89	1	$0.89	$0.89
Wheel	65 mm rubber tire wheel for mobility	sparkfun.com	ROB - 13259	$2.95	2	$0.00	$2.95
Motor	65 RPM (right angle) gear motor	sparkfun.com	ROB - 13258	$3.95	2	$0.00	$3.95
Trimpot	10k trimpot with knob	sparkfun.com	COM - 09806	$0.95	1	$0.00	$0.95
Total						$4.36	$57.17

Figure A2-1: Bill of Materials for M3F1 Alpha Prototype

Item	URL
9V Battery	https://www.amazon.com/s/ref=nb_sb_noss_1?url=search-alias%3Daps&field-keywords=9v+battery
Redboard	https://www.sparkfun.com/products/13975
Breadboard	https://www.sparkfun.com/products/12002
Temperature Sensor	https://www.sparkfun.com/products/10988
Tri Color LED	https://www.sparkfun.com/products/105
Jumper wires	https://www.sparkfun.com/products/11026
Piezo Speaker	https://www.sparkfun.com/products/7950
Potentiometer	https://www.sparkfun.com/products/9806
Push button	https://www.sparkfun.com/products/9190
Resistor (330 ohm)	https://www.sparkfun.com/products/11507
Resistor (10 kohm)	https://www.sparkfun.com/products/11508
Cardboard	https://www.boxforless.com/categories/Corrugated-Cardboard-Sheets/
ABS Plastic	N/A
Elmers Glue	http://www.homedepot.com/p/Elmer-s-8-oz-Carpenter-s-Wood-Glue-E7010/202819835
Ball Bearing	https://www.menards.com/main/tools-hardware/fasteners-fastener-accessories/specialty-fasteners/bearings/tool-shop-reg-5-8-roller-ball-bearing/p-1444421213207.htm
Wheel	https://www.sparkfun.com/products/13259
Motor	https://www.sparkfun.com/products/13258
Trimpot	https://www.sparkfun.com/products/9806

Figure A2-2: Links to all components in the alpha prototype

A3: Design Drawings

Technical Drawings

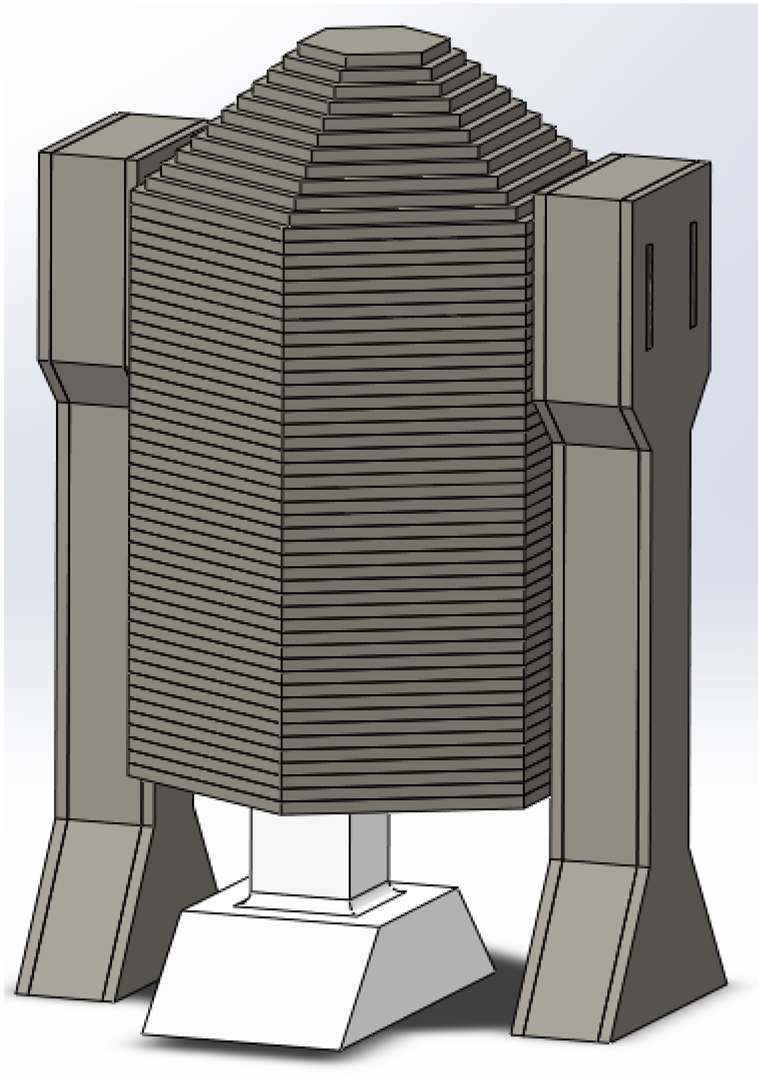

Figure A3-1: 3D Assembly of M3F1

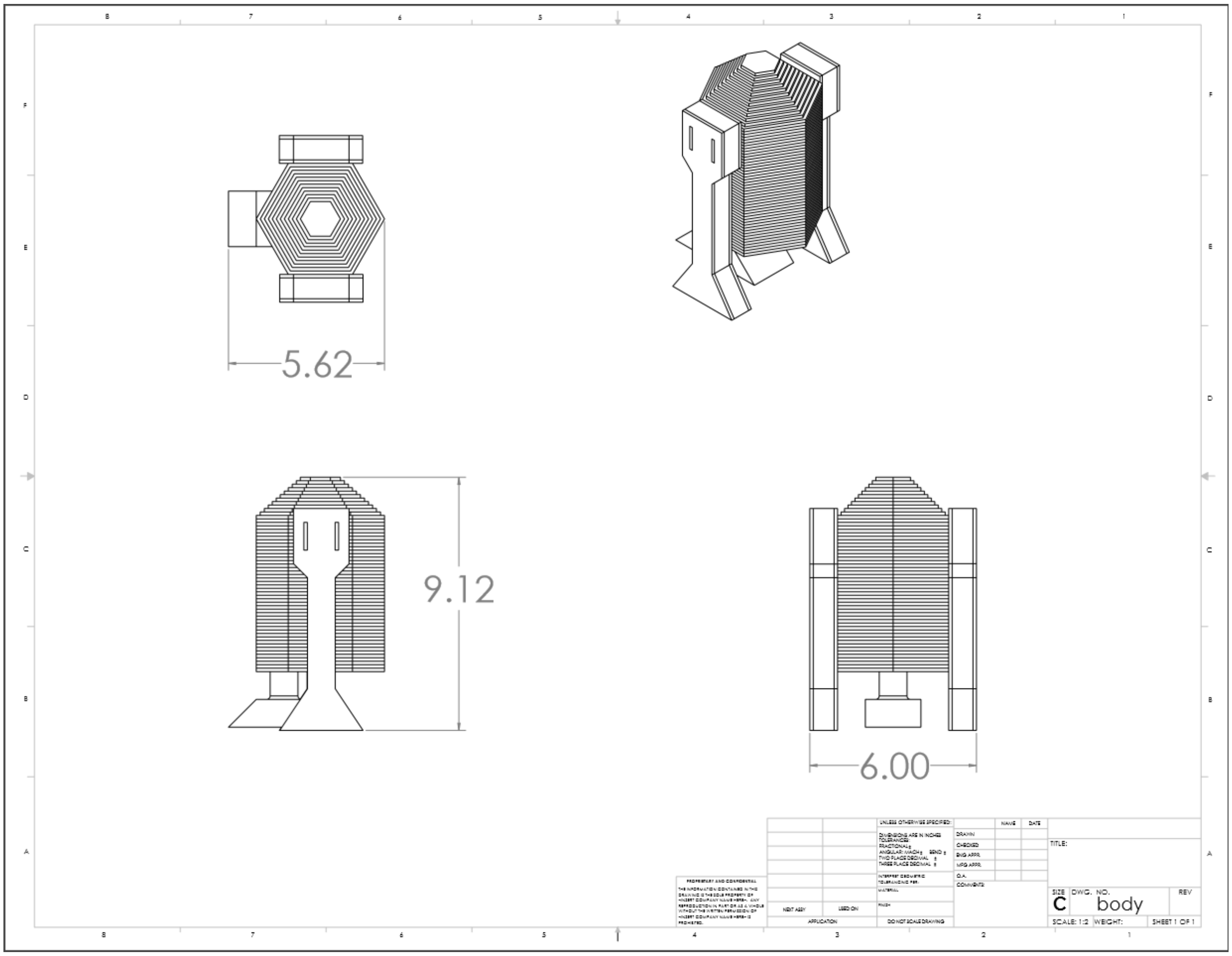

Figure A3-2: Drawing of assembled M3F1 with dimensions

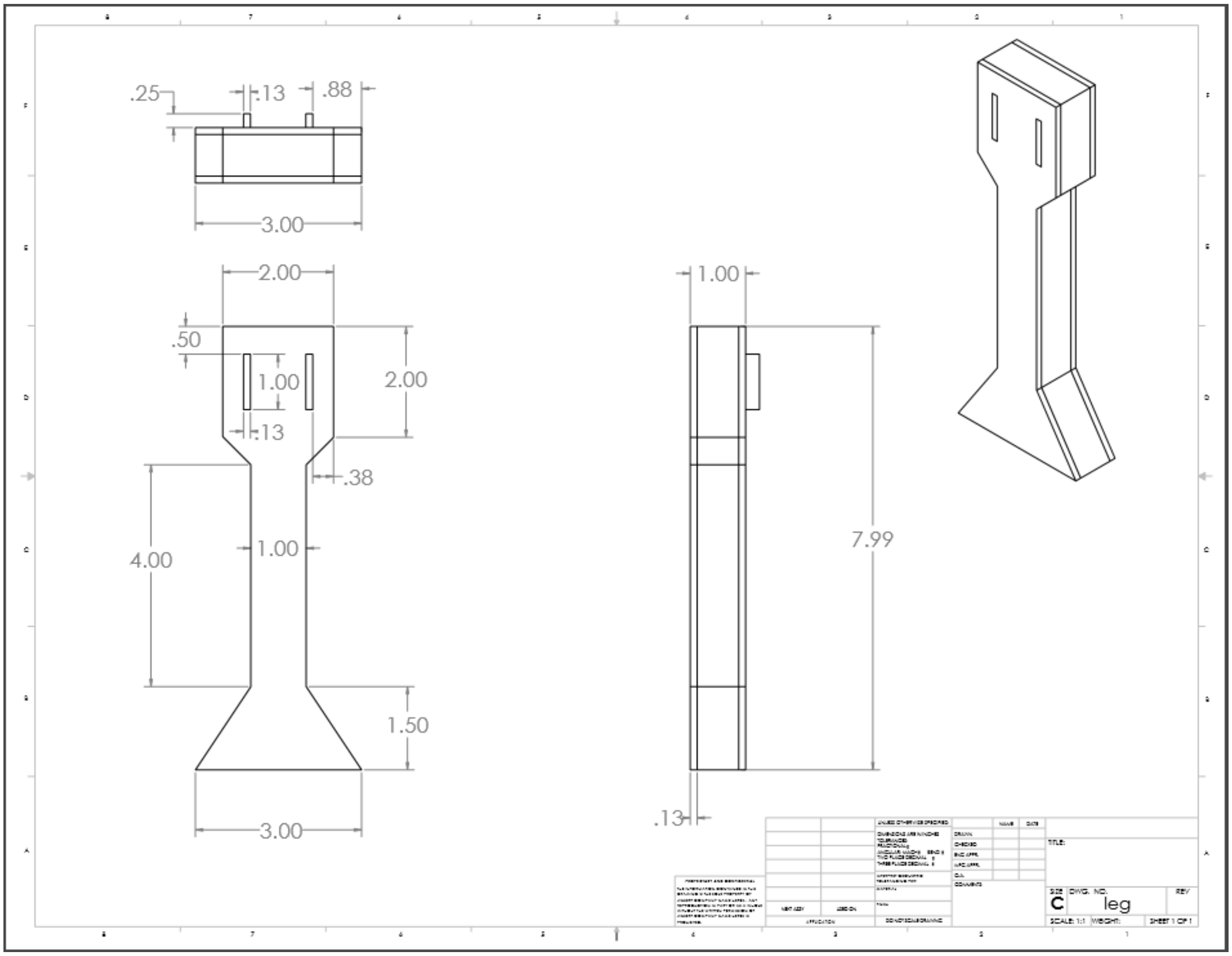

Figure A3-3: Side leg assembly of M3F1 robot

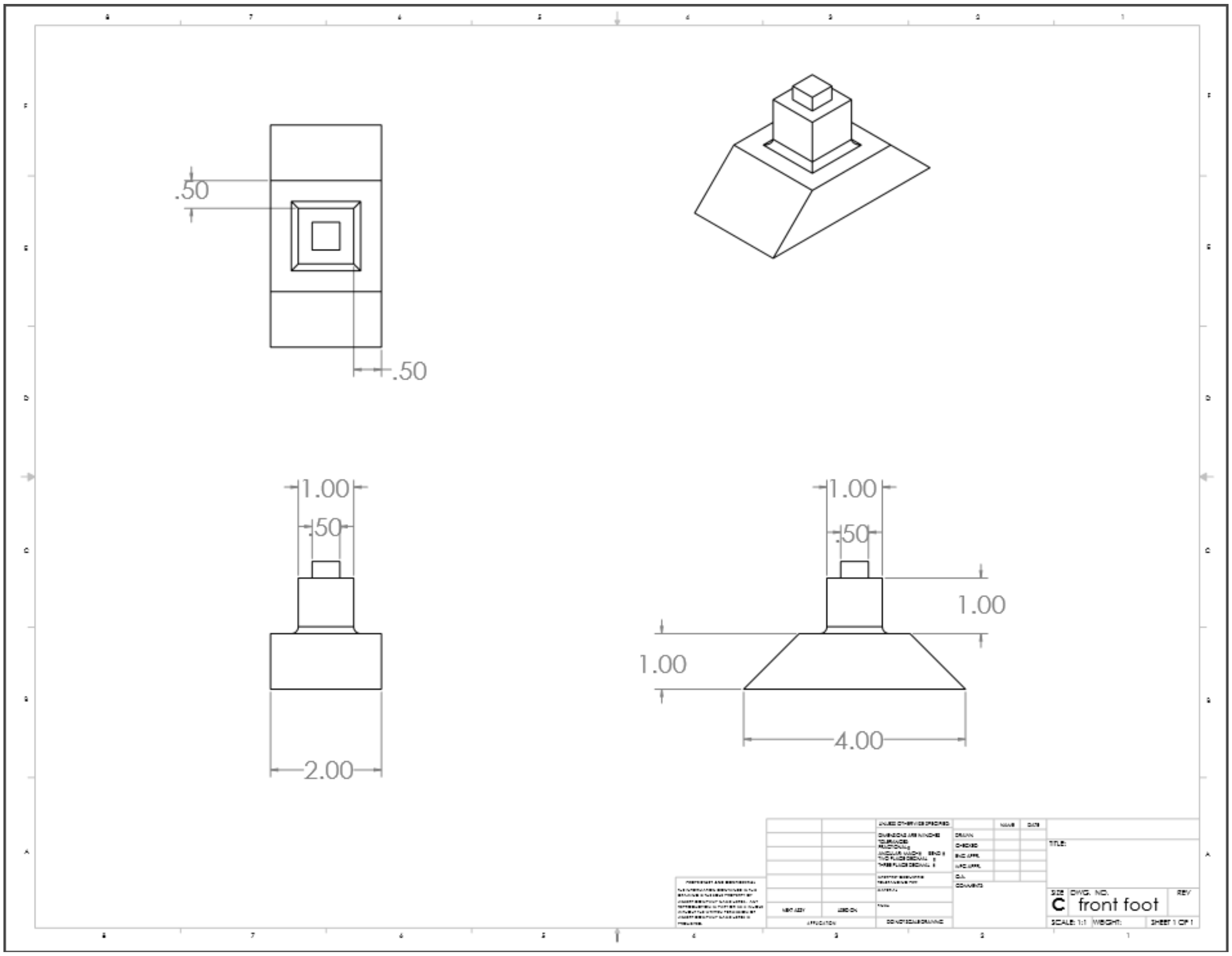

Figure A3-4: Front foot of M3F1 robot

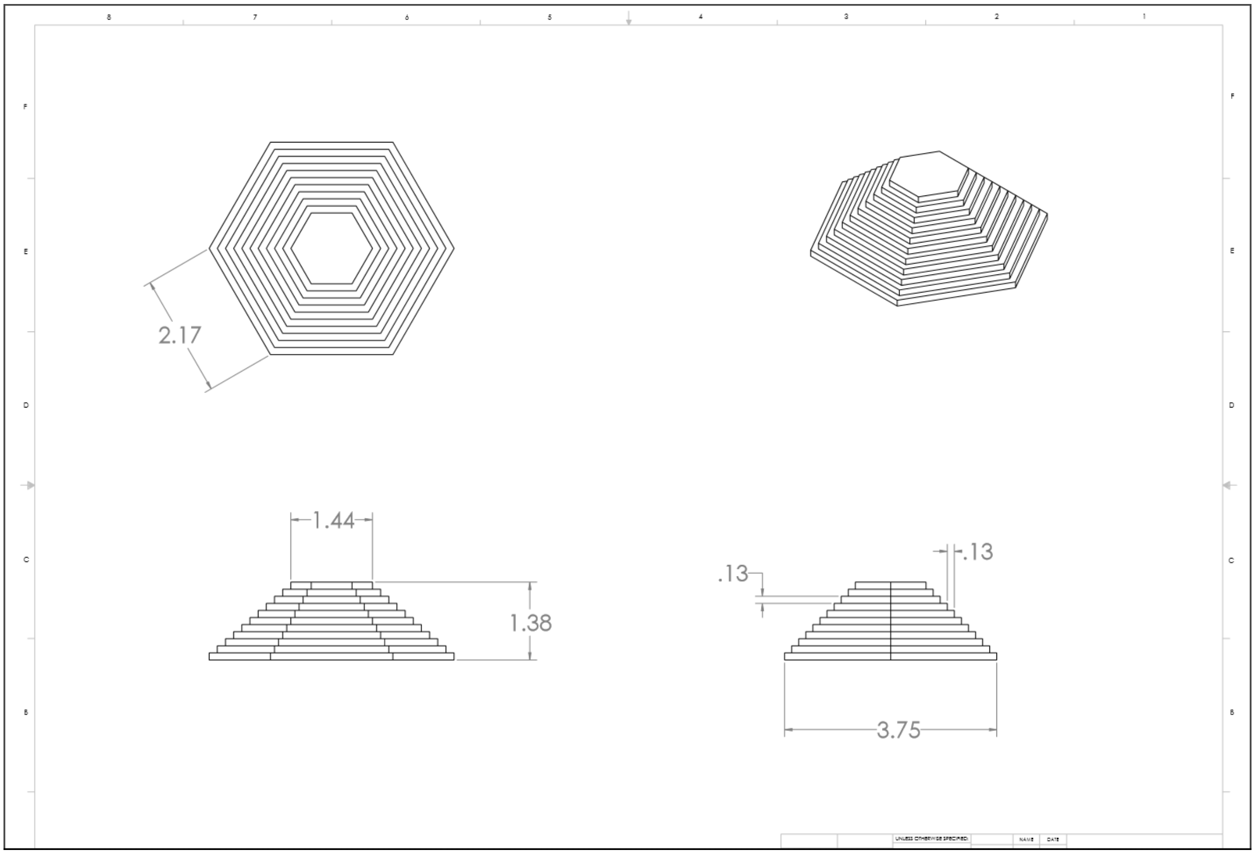

Figure A3-5: Top dome assembly of M3F1 robot

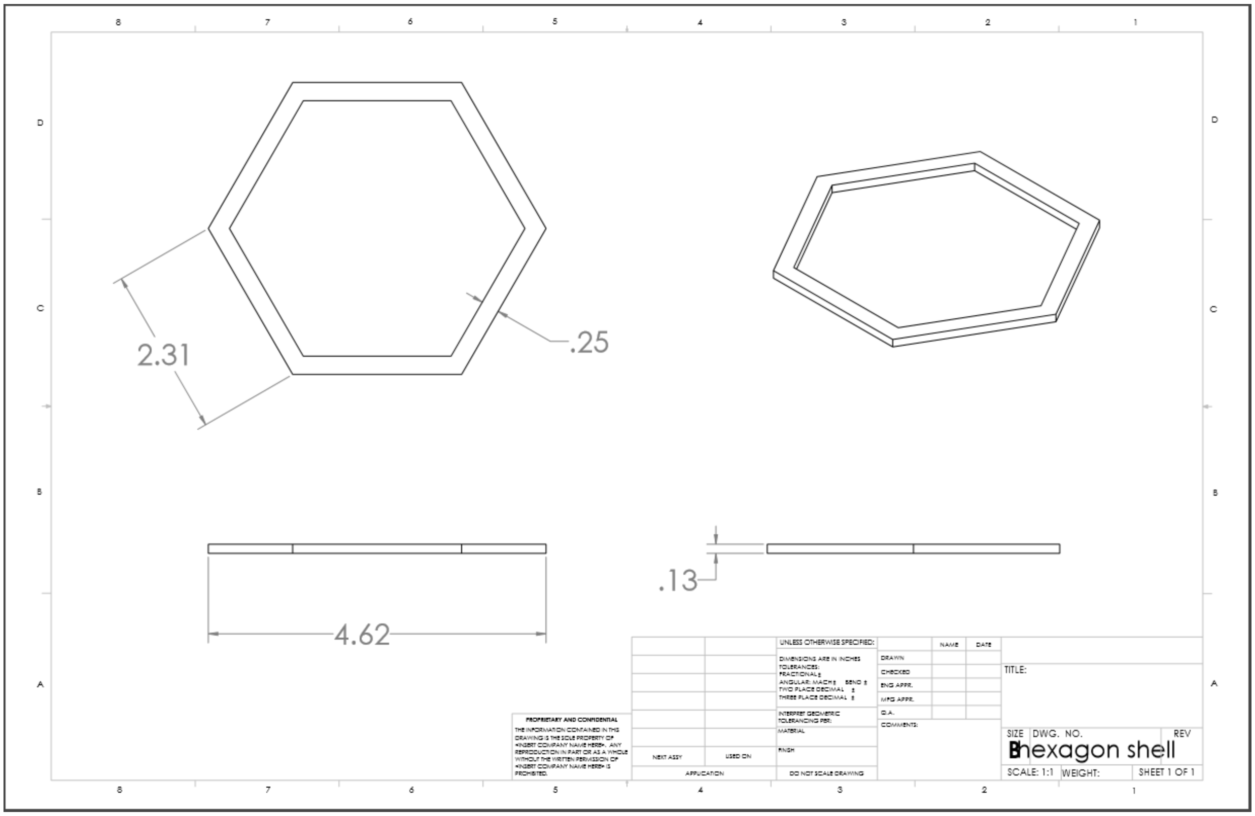

Figure A3-6: Hexagons stacked to create main body of M3F1

Fritzing Electrical Diagrams of Circuit

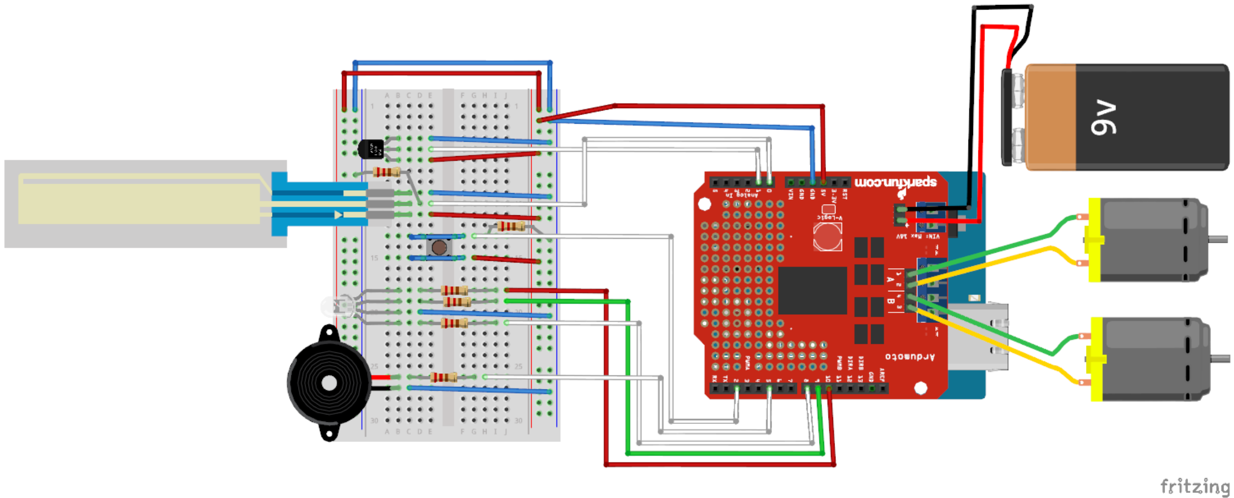

Figure A3-7: Fritzing Electrical Diagram

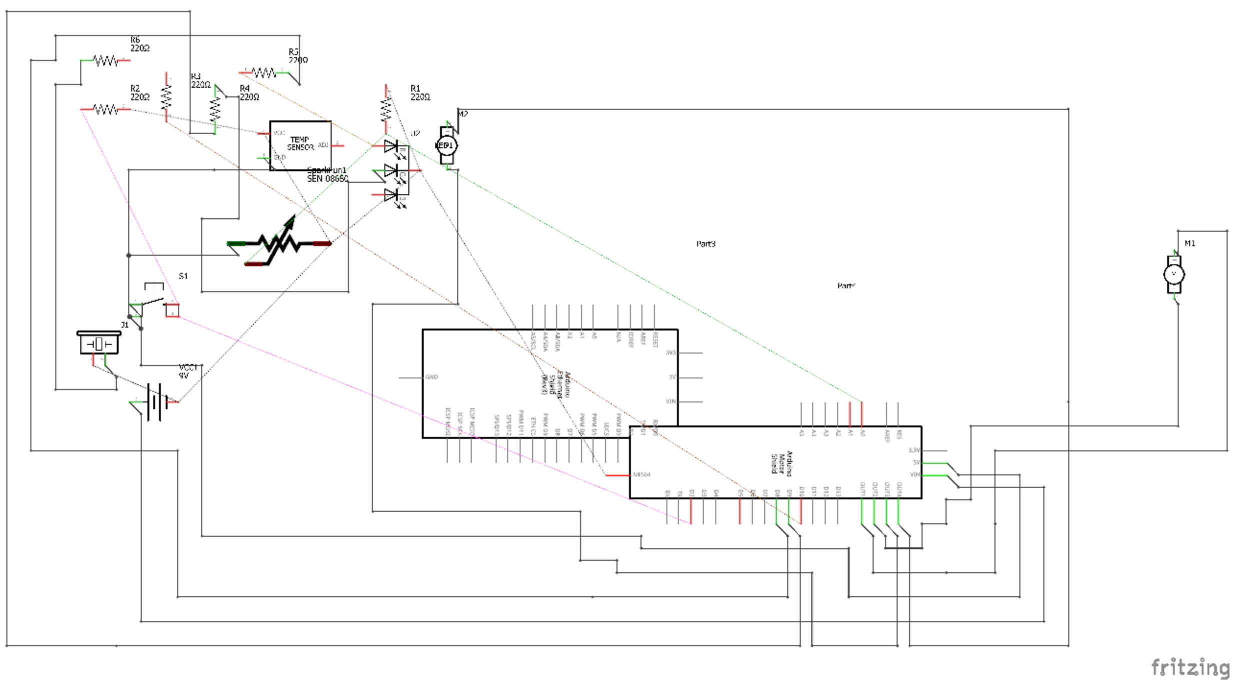

Figure A3-8: Fritzing Technical Diagram of Circuit

Major Systems/Subsystems Diagram

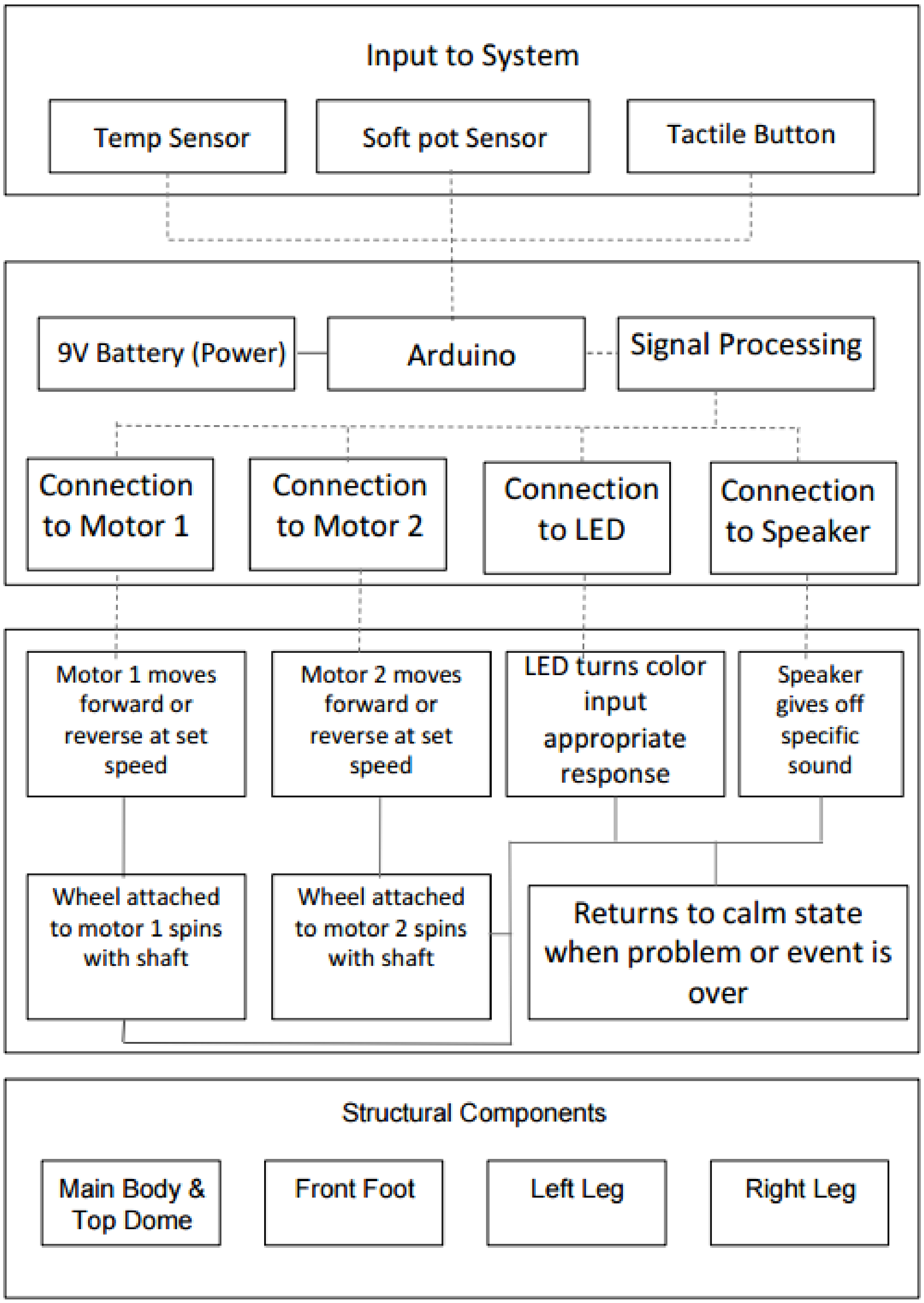

Figure A3-9 : Major Systems and Subsystems Diagram

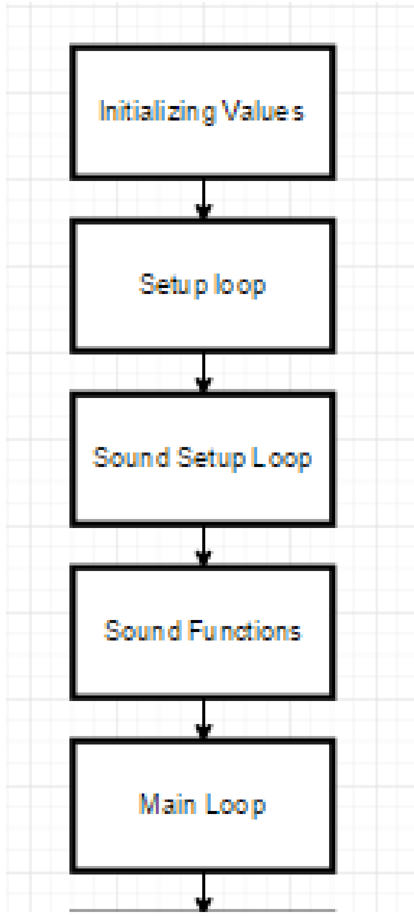

Figure A3-10: Initializing Process in Software

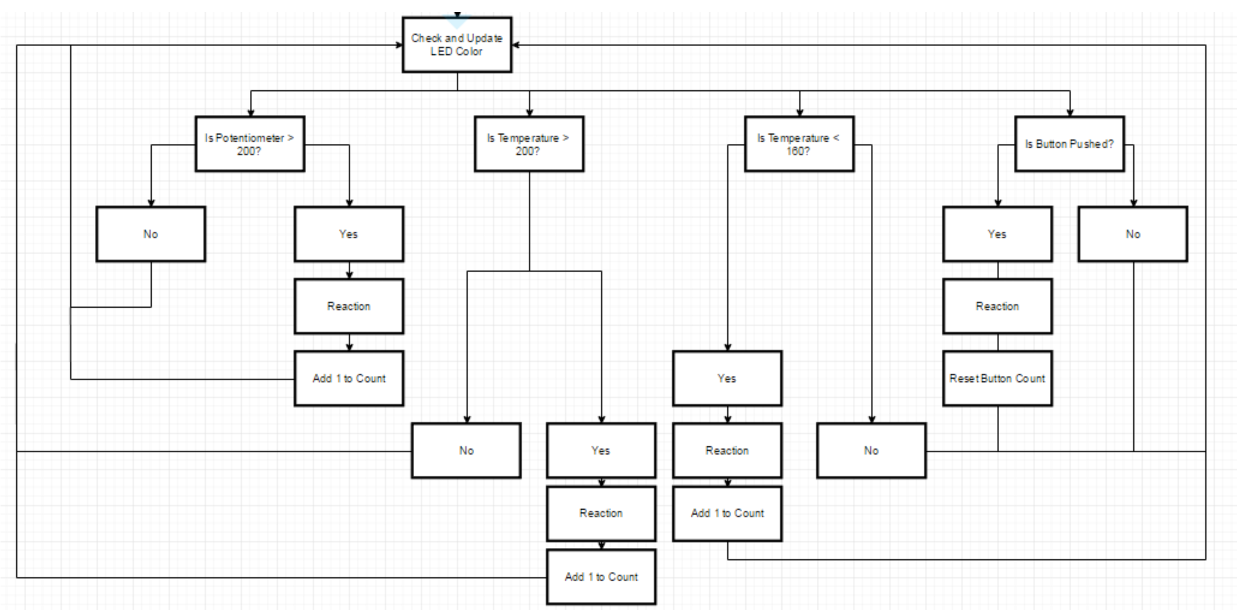

Figure A3-11 : Software Flow Chart

A4: Software

```
//Initialize pins

//Hunger Sensor
int count = 1;

//Creating notes for sounds for speaker
const float  note_C0 = 16.35;  //C0
const float  note_Db0 = 17.32;  //C#0/Db0
const float  note_D0 = 18.35;  //D0
const float  note_Eb0 = 19.45;  //D#0/Eb0
const float  note_E0 = 20.6;  //E0
const float  note_F0 = 21.83;  //F0
const float  note_Gb0 = 23.12;  //F#0/Gb0
const float  note_G0 = 24.5;  //G0
const float  note_Ab0 = 25.96;  //G#0/Ab0
const float  note_A0 = 27.5;  //A0
const float  note_Bb0 = 29.14;  //A#0/Bb0
const float  note_B0 = 30.87;  //B0
const float  note_C1 = 32.7;  //C1
const float  note_Db1 = 34.65;  //C#1/Db1
const float  note_D1 = 36.71;  //D1
const float  note_Eb1 = 38.89;  //D#1/Eb1
const float  note_E1 = 41.2;  //E1
const float  note_F1 = 43.65;  //F1
const float  note_Gb1 = 46.25;  //F#1/Gb1
const float  note_G1 = 49;  //G1
const float  note_Ab1 = 51.91;  //G#1/Ab1
const float  note_A1 = 55;  //A1
const float  note_Bb1 = 58.27;  //A#1/Bb1
const float  note_B1 = 61.74;  //B1
const float  note_C2 = 65.41;  //C2 (Middle C)
const float  note_Db2 = 69.3;  //C#2/Db2
const float  note_D2 = 73.42;  //D2
const float  note_Eb2 = 77.78;  //D#2/Eb2
const float  note_E2 = 82.41;  //E2
const float  note_F2 = 87.31;  //F2
const float  note_Gb2 = 92.5;  //F#2/Gb2
const float  note_G2 = 98;  //G2
const float  note_Ab2 = 103.83;  //G#2/Ab2
```

```
const float  note_A2 = 110;  //A2
const float  note_Bb2 = 116.54;  //A#2/Bb2
const float  note_B2 = 123.47;  //B2
const float  note_C3 = 130.81;  //C3
const float  note_Db3 = 138.59;  //C#3/Db3
const float  note_D3 = 146.83;  //D3
const float  note_Eb3 = 155.56;  //D#3/Eb3
const float  note_E3 = 164.81;  //E3
const float  note_F3 = 174.61;  //F3
const float  note_Gb3 = 185;  //F#3/Gb3
const float  note_G3 = 196;  //G3
const float  note_Ab3 = 207.65;  //G#3/Ab3
const float  note_A3 = 220;  //A3
const float  note_Bb3 = 233.08;  //A#3/Bb3
const float  note_B3 = 246.94;  //B3
const float  note_C4 = 261.63;  //C4
const float  note_Db4 = 277.18;  //C#4/Db4
const float  note_D4 = 293.66;  //D4
const float  note_Eb4 = 311.13;  //D#4/Eb4
const float  note_E4 = 329.63;  //E4
const float  note_F4 = 349.23;  //F4
const float  note_Gb4 = 369.99;  //F#4/Gb4
const float  note_G4 = 392;  //G4
const float  note_Ab4 = 415.3;  //G#4/Ab4
const float  note_A4 = 440;  //A4
const float  note_Bb4 = 466.16;  //A#4/Bb4
const float  note_B4 = 493.88;  //B4
const float  note_C5 = 523.25;  //C5
const float  note_Db5 = 554.37;  //C#5/Db5
const float  note_D5 = 587.33;  //D5
const float  note_Eb5 = 622.25;  //D#5/Eb5
const float  note_E5 = 659.26;  //E5
const float  note_F5 = 698.46;  //F5
const float  note_Gb5 = 739.99;  //F#5/Gb5
const float  note_G5 = 783.99;  //G5
const float  note_Ab5 = 830.61;  //G#5/Ab5
const float  note_A5 = 880;  //A5
const float  note_Bb5 = 932.33;  //A#5/Bb5
const float  note_B5 = 987.77;  //B5
const float  note_C6 = 1046.5;  //C6
```

```
const float  note_Db6 = 1108.73;  //C#6/Db6
const float  note_D6 = 1174.66;  //D6
const float  note_Eb6 = 1244.51;  //D#6/Eb6
const float  note_E6 = 1318.51;  //E6
const float  note_F6 = 1396.91;  //F6
const float  note_Gb6 = 1479.98;  //F#6/Gb6
const float  note_G6 = 1567.98;  //G6
const float  note_Ab6 = 1661.22;  //G#6/Ab6
const float  note_A6 = 1760;  //A6
const float  note_Bb6 = 1864.66;  //A#6/Bb6
const float  note_B6 = 1975.53;  //B6
const float  note_C7 = 2093;  //C7
const float  note_Db7 = 2217.46;  //C#7/Db7
const float  note_D7 = 2349.32;  //D7
const float  note_Eb7 = 2489.02;  //D#7/Eb7
const float  note_E7 = 2637.02;  //E7
const float  note_F7 = 2793.83;  //F7
const float  note_Gb7 = 2959.96;  //F#7/Gb7
const float  note_G7 = 3135.96;  //G7
const float  note_Ab7 = 3322.44;  //G#7/Ab7
const float  note_A7 = 3520;  //A7
const float  note_Bb7 = 3729.31;  //A#7/Bb7
const float  note_B7 = 3951.07;  //B7
const float  note_C8 = 4186.01;  //C8
const float  note_Db8 = 4434.92;  //C#8/Db8
const float  note_D8 = 4698.64;  //D8
const float  note_Eb8 = 4978.03;  //D#8/Eb8


//Define Speaker
int speakerPin = 5;

// Define Button
int buttonpin = 2;
int buttonstate = LOW;


//Define Multi Color LED
int redPin = 8;
int greenPin = 9;
```

```
int bluePin = 10;

// Define Potentiometer
int potpin = A0;
int potvalue = 0;

// Define Temperature Sensor
int temppin = A1;
int tempvalue = 0;

//Motors
// Clockwise and counterclockwise definitions.
// Depending on how you wired your motors, you may need to swap.
#define CW 0
#define CCW 1
// Motor definitions to make life easier:
#define MOTOR_A 1
#define MOTOR_B 0
// Pin Assignments //
// Don't change these! These pins are statically defined by shield
// layout
const byte PWMA = 3; // PWM control (speed) for motor A
const byte PWMB = 11; // PWM control (speed) for motor B
const byte DIRA = 12; // Direction control for motor A
const byte DIRB = 13; // Direction control for motor B

void setup ()
{ pinMode (redPin, OUTPUT);
  pinMode (greenPin, OUTPUT);
  pinMode (bluePin, OUTPUT);
  Serial.begin (115200);

  // All pins should be setup as outputs:
pinMode(PWMA, OUTPUT);
pinMode(PWMB, OUTPUT);
pinMode(DIRA, OUTPUT);
pinMode(DIRB, OUTPUT);
// Initialize all pins as low:
digitalWrite(PWMA, LOW);
digitalWrite(PWMB, LOW);
```

```
digitalWrite(DIRA, LOW);
digitalWrite(DIRB, LOW);
pinMode(speakerPin, OUTPUT);
}

void beep (int speakerPin, float noteFrequency, long noteDuration)
{
  int x;
  // Convert the frequency to microseconds
  float microsecondsPerWave = 1000000/noteFrequency;
  // Calculate how many HIGH/LOW cycles there are per millisecond
  float millisecondsPerCycle = 1000/(microsecondsPerWave * 2);
  // Multiply noteDuration * number or cycles per millisecond
  float loopTime = noteDuration * millisecondsPerCycle;
  // Play the note for the calculated loopTime.
  for (x=0;x<loopTime;x++)
        {
            digitalWrite(speakerPin,HIGH);
            delayMicroseconds(microsecondsPerWave);
            digitalWrite(speakerPin,LOW);
            delayMicroseconds(microsecondsPerWave);
        }
}
//Set up for one of the noises
void closeEncounters() {
        beep(speakerPin, note_Bb5,300); //B b
        delay(50);
        beep(speakerPin, note_C6,300); //C
        delay(50);
        beep(speakerPin, note_Ab5,300); //A b
        delay(50);
        beep(speakerPin, note_Ab4,300); //A b
        delay(50);
        beep(speakerPin, note_Eb5,500); //E b
        delay(500);

        beep(speakerPin, note_Bb4,300); //B b
        delay(100);
        beep(speakerPin, note_C5,300); //C
        delay(100);
```

```
        beep(speakerPin, note_Ab4,300); //A b
        delay(100);
        beep(speakerPin, note_Ab3,300); //A b
        delay(100);
        beep(speakerPin, note_Eb4,500); //E b
        delay(500);

        beep(speakerPin, note_Bb3,300); //B b
        delay(200);
        beep(speakerPin, note_C4,300); //C
        delay(200);
        beep(speakerPin, note_Ab3,300); //A b
        delay(500);
        beep(speakerPin, note_Ab2,300); //A b
        delay(550);
        beep(speakerPin, note_Eb3,500); //E b
}
// Set up for one of the noises
void catcall() {
  for (int i=1000; i<5000; i=i*1.05) {
    beep(speakerPin,i,10);
  }
 delay(300);

  for (int i=1000; i<3000; i=i*1.03) {
    beep(speakerPin,i,10);
  }
  for (int i=3000; i>1000; i=i*.97) {
    beep(speakerPin,i,10);
  }
}
// Set up for one of the noises
void letitgo() {
        beep(speakerPin, note_G4,300); //G
        beep(speakerPin, note_Gb4,300); //F#
        beep(speakerPin, note_G4,900); //G
        beep(speakerPin, note_D4,300); //D
        beep(speakerPin, note_B4,300); //B
        beep(speakerPin, note_A4,900); //A
        beep(speakerPin, note_G4,600); //G
```

```
	beep(speakerPin, note_E4,300); //E
	beep(speakerPin, note_E4,300); //E
	beep(speakerPin, note_E4,600); //E
	beep(speakerPin, note_E4,600); //E
	beep(speakerPin, note_Gb4,600); //F#
	beep(speakerPin, note_G4,900); //G
	beep(speakerPin, note_E4,300); //E
	beep(speakerPin, note_Gb4,300); //F#
	beep(speakerPin, note_G4,900); //G
	beep(speakerPin, note_D4,300); //D
	beep(speakerPin, note_B4,300); //B
	beep(speakerPin, note_A4,900); //A
	beep(speakerPin, note_G4,300); //G
	beep(speakerPin, note_A4,300); //A
	beep(speakerPin, note_B4,900); //B
	beep(speakerPin, note_C5,900); //C5
	beep(speakerPin, note_B4,900); //B
	beep(speakerPin, note_A4,900); //A
	beep(speakerPin, note_G4,1200); //G
}
//Set up for one of the noises
void r2D2(){
	beep(speakerPin, note_A7,100); //A
	beep(speakerPin, note_G7,100); //G
	beep(speakerPin, note_E7,100); //E
	beep(speakerPin, note_C7,100); //C
	beep(speakerPin, note_D7,100); //D
	beep(speakerPin, note_B7,100); //B
	beep(speakerPin, note_F7,100); //F
	beep(speakerPin, note_C8,100); //C
	beep(speakerPin, note_A7,100); //A
	beep(speakerPin, note_G7,100); //G
	beep(speakerPin, note_E7,100); //E
	beep(speakerPin, note_C7,100); //C
	beep(speakerPin, note_D7,100); //D
	beep(speakerPin, note_B7,100); //B
	beep(speakerPin, note_F7,100); //F
	beep(speakerPin, note_C8,100); //C
}
```

```
void loop ()
{

  potvalue = analogRead(potpin);
  Serial.print ("Potentiometer = ");
  Serial.print (potvalue);

  tempvalue = analogRead(temppin);
  Serial.print ("        Temperature = ");
  Serial.print (tempvalue);

  Serial.print ("        Count = ");
  Serial.print (count);


  buttonstate = digitalRead(buttonpin);
  Serial.print ("       Button Status = ");
  Serial.print (buttonstate);
  Serial.print("\n");
// Each color channel can range from 0 to 255.
// Values for multiple channels generate color blends.

//Display LED color based on count of sensors used. Turns red
if (count == 3)
{
  digitalWrite (redPin, 255);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 0);
}
//Turns yellow after one sensor has been activated
if (count == 2)
{
  digitalWrite (redPin, 255);
  digitalWrite (greenPin, 255);
  digitalWrite (bluePin, 0);
}
//Initial state LED is green
if (count == 1)
{
  digitalWrite (redPin, 0);
```

```
  digitalWrite (greenPin, 255);
  digitalWrite (bluePin, 0);
}
//Code for when button is pressed
if (buttonstate == HIGH)
{
  digitalWrite (redPin, 0);
  digitalWrite (greenPin, 255);
  digitalWrite (bluePin, 0);
  delay (100);
  r2D2();
  delay (100);
   buttonstate = digitalRead(buttonpin);

    digitalWrite (redPin, 0);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 0);
  delay (100);
  count = 1;
  }
//Reaction when potentiometer is touched
while (potvalue > 200)
{

  digitalWrite (redPin, 200);
  digitalWrite (greenPin, 100);
  digitalWrite (bluePin, 0);

  closeEncounters();
  // Set motor A to CCW at
  digitalWrite(DIRA, CCW);
  analogWrite(PWMA, 45);
  // Set motor B to CW at half
  digitalWrite(DIRB, CW);
  analogWrite(PWMB, 90);
  delay(3500);


  //Set both motor A & motor B to stop
  digitalWrite(DIRA, 0);
```

```
  analogWrite(PWMA, 0);
  digitalWrite(DIRB, 0);
  analogWrite(PWMB, 0);
  delay(500);
  count++;

  potvalue = analogRead(potpin);


  digitalWrite (redPin, 0);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 0);


}
//Reaction for high temperature value
while (tempvalue > 175) //Over abmient temp
{
  //Adjust temp value reading based off of ambient temperature
  digitalWrite (redPin, 255);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 0);
  delay (100);
  tempvalue = analogRead(temppin);

  catcall();
// Set motor A to CCW at max
  digitalWrite(DIRA, CCW);
  analogWrite(PWMA, 80);
  // Set motor B to CW at half
  digitalWrite(DIRB, CW);
  analogWrite(PWMB, 80);
  delay(800);

  //Set both motor A & motor B to stop
  digitalWrite(DIRA, 0);
  analogWrite(PWMA, 0);
  digitalWrite(DIRB, 0);
  analogWrite(PWMB, 0);
  delay(500);
```

```
 count++;

 tempvalue = analogRead(temppin);

  digitalWrite (redPin, 0);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 0);


}

while (tempvalue < 40) //under ambient temp
{

  digitalWrite (redPin, 0);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 255);
  delay (100);

 // Set motor A to CCW at max
 letitgo();
  digitalWrite(DIRA, CCW);
  analogWrite(PWMA, 80);
  // Set motor B to CW at half
  digitalWrite(DIRB, CW);
  analogWrite(PWMB, 80);
  delay(800);

    //Set both motor A & motor B to stop
  digitalWrite(DIRA, 0);
  analogWrite(PWMA, 0);
  digitalWrite(DIRB, 0);
  analogWrite(PWMB, 0);
  delay(500);

  count++;

  tempvalue = analogRead(temppin);
```

```
  digitalWrite (redPin, 0);
  digitalWrite (greenPin, 0);
  digitalWrite (bluePin, 0);

}

}
```

A5: Prototype Photos

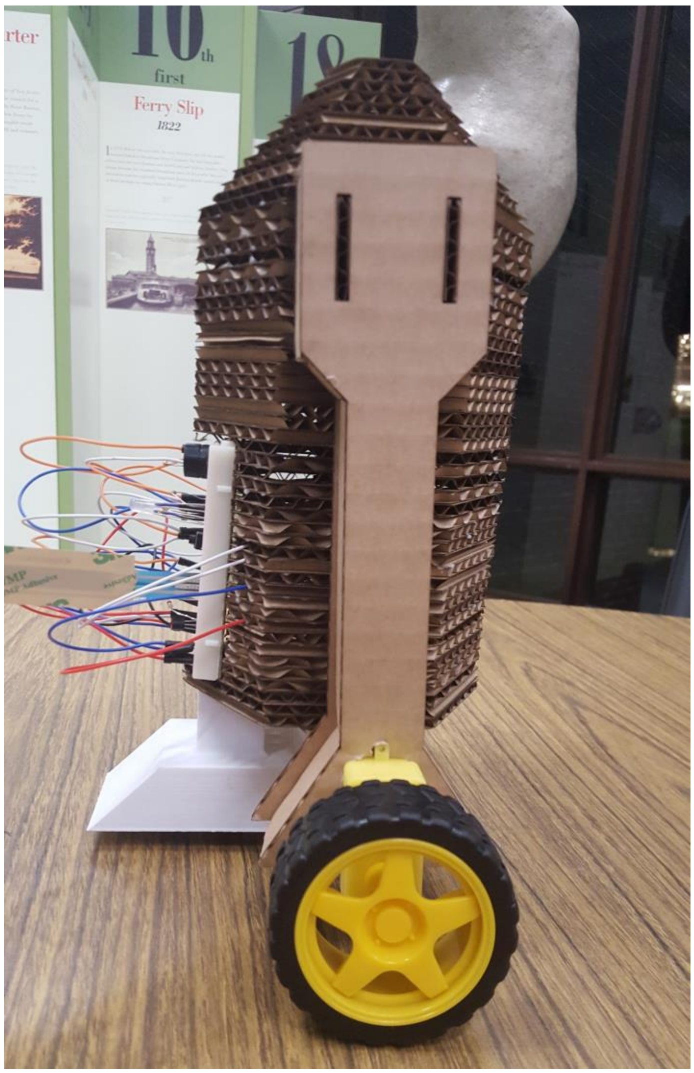

Figure A5-1 : Side View of M3F1 Alpha Prototype

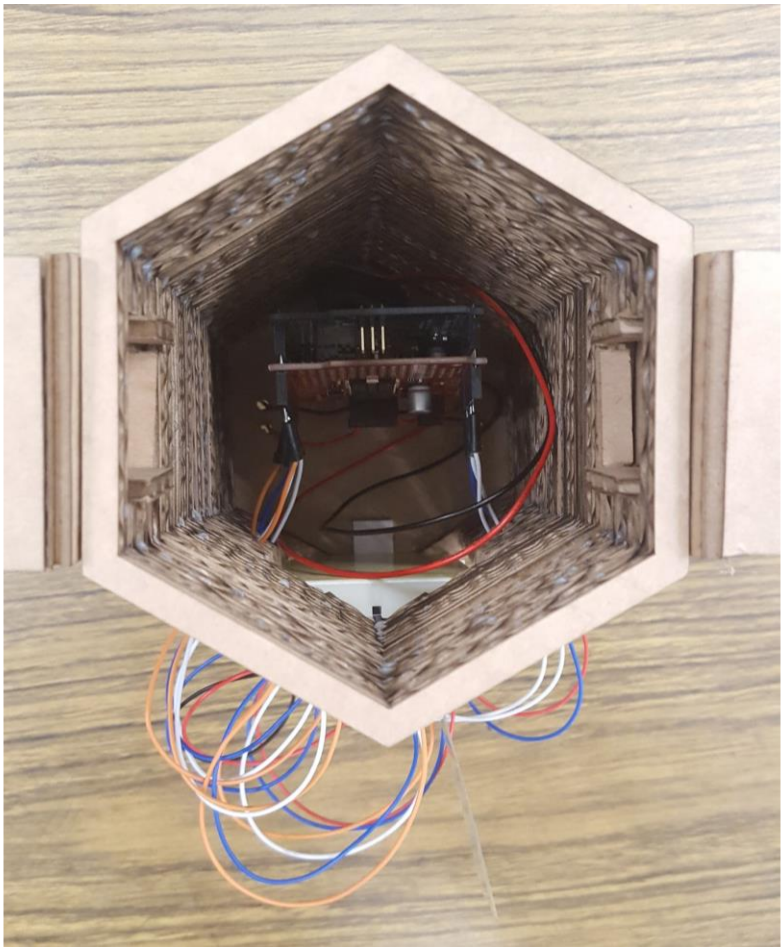

Figure A5-2 : Top View of M3F1 Alpha Prototype

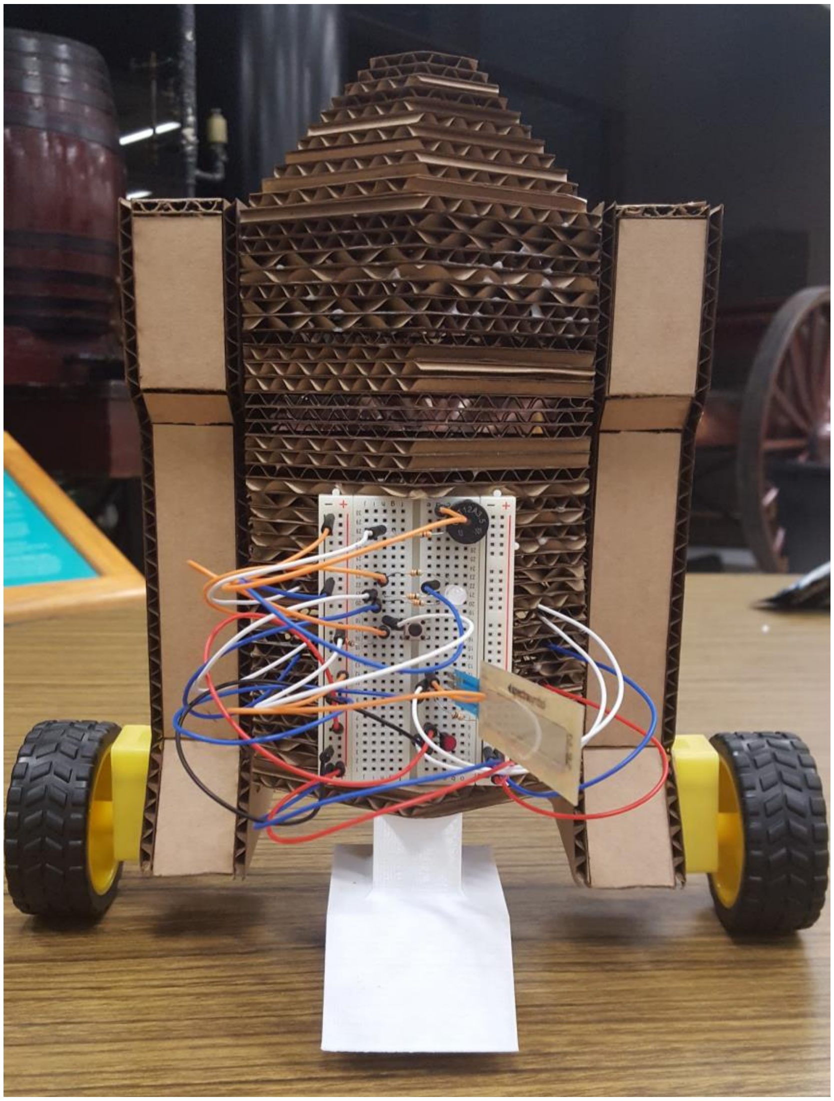

Figure A5-3 : Front View of M3F1 Alpha Prototype

A6: Videos

A link to a video demonstrating the key capabilities of M3F1:

https://www.youtube.com/watch?v=NwlHr_A0BDQ