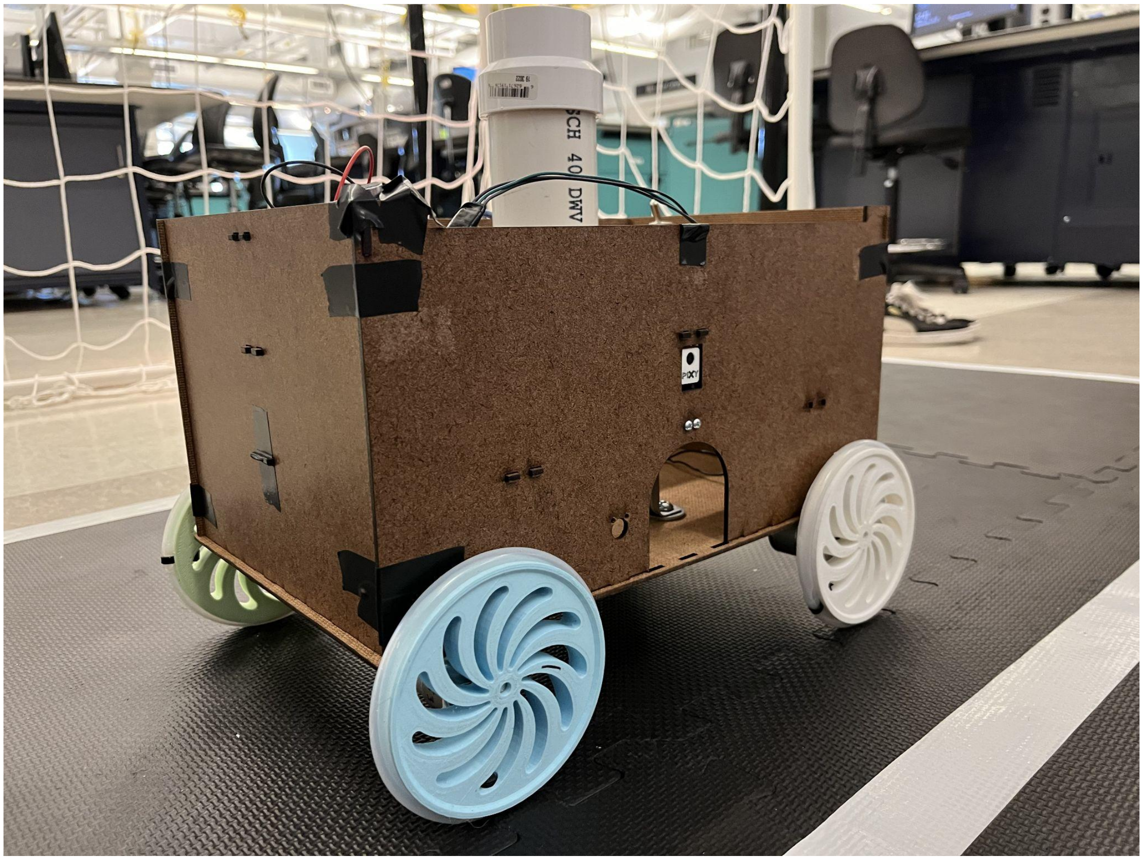


# Soccer Penalty Kicker Robot

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MCEN 5115: Mechatronics
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## Introduction

Within the Mechatronics I course, students learn the skills necessary to control mechanical systems with electronics and computers. The class culminates with a final design project which combines many aspects of mechatronics. This year the students were tasked with building a Soccer Penalty Kick Robot, capable of shooting and defending autonomously.

The robot must be capable of navigating a Penalty Kick Shootout field. This includes alternating between playing offense (Penalty Kick taker) and defense (goalie) for the shootout. The playing field is a rectangular foam exercise mat, with a 40” high and 80” wide net on one side. The ball is a 7.5” diameter inflatable red plastic kickball. While on offense, the robot is responsible for waiting for the referee’s whistle and then shooting the ball autonomously. In order to accomplish this task, the team implemented a servo actuated, spring-loaded kicker to shoot the ball. While on defense, the robot must attempt to block any shot from entering the goal. This was accomplished using the Pixy camera, which was trained to output the position of the ball. A proportional control loop was tuned to position the cart directly in front of the ball, attempting to block any shot.

Through the design and testing of this project, the Messi Bots’ group have been able to learn how to integrate electronics, software, and mechanical design. These skills are relevant to autonomous robotics applications and will carry into the professional development of the Messi Bots as mechatronics engineers.

## Learning Objectives and Goals

*Mechanical Design*

The most challenging aspect of the mechanical design was the creation of the shooting mechanism. This device had to be relatively small, powerful, and actuated with a simple servo. The team hoped to learn how to build a system that was reliable enough to fire consistently throughout the competition.

In order to house the spring loaded shooting mechanism, the cart frame had to be designed to be sturdy enough to block an oncoming shot, but also be removable from the base. In order to accomplish this, the team hoped to put their theoretical design for manufacturing (DFM) skills into practice. In order to build this system, the team had to learn many prototyping manufacturing techniques, including using the 3D printers, the laser cutter, and the machine shop tools.

*Electronics*

For the electronics design, the main learning objective was to switch from breadboards to a more permanent system. Through the beginning of class the team had become familiar with breadboard circuit design, but since the robot would be on a mobile platform, a more permanent solution was necessary. The team needed to learn about and build a more robust system capable of securing the wiring running between multiple motor controllers, a servo, the Pixy camera, and a sound sensor.

*Software/Autonomous Systems*

When designing the robot's software, the largest challenge was the scale of the program. Throughout the labs, the team became familiar with accomplishing simple tasks independently. For example, the team was capable of reading a switch, or responding to a sound input. The goal of this project was to learn how to incorporate all of these skills into one program. Depending on different variable states, the robot had to take on very different functions, so the team had to learn how to create a program that was capable of handling many different inputs and outputs.

## Initial Design Concepts and Changes

The team's initial design parameters included a 14" x 12" footprint constraint and the ability to kick and defend goals similar to penalty kicks in soccer. Having not worked with computer vision systems before and not knowing the extent of mobility needed, the initial design consisted of mecanum wheels on a light plastic body with a lithium polymer battery and Raspberry Pi mounted above with a camera (see **Fig. A.1**). This initial concept was quickly simplified to use simpler wheels and solely an arduino for motion and vision.

A couple of shooting mechanisms were brainstormed; the main focus was on having the ability to set up the shot and kick the ball into the air to make the shots more difficult to defend against. The most intuitive solution was to give the robot a foot (**Fig. A.2**), this proved impractical because of size constraints. **Fig. A.3** depicts an airbag based kicker which uses compressed CO2 canisters to push the ball forwards and upwards; this was a gamble because no team members had experience working with pneumatics. **Fig. A.4** depicts a linkage driven end effector which kicks via rotational springs. These kicking mechanisms proved unlikely to succeed given the lack of experience with each system and the limited timeframe.

The design which the team decided to build (**Fig. A.5**) was the most feasible because it was a self contained assembly that was simple to manufacture. This allowed for faster prototyping and testing. The design was further simplified from the sketch by omitting the rotational servo because during testing the end effector normal plane angle did not produce a notable effect on the trajectory of the ball. The final design assembly was a self contained linear spring kicker system with an external actuation servo.

## Electrical Diagrams

The electrical system for the Messi Bot consists of an Arduino Mega connected to two motor drivers, four motors, the Pixy camera, a sound sensor, a servo, and two switches. These were soldered together using wiring harnesses. The pinouts for the Arduino Mega can be seen in the Appendix (**Fig. B.1)**. The pinouts for each motor driver are available **(Fig. B.2)** and **(Fig. B.3)**. The direction that the wheels spin was discovered with trial and error, so when recreating this design if the motor spins the wrong direction there are two solutions: either the pins can be reversed physically or switched within the code. The pinout for the servo **(Fig. B.4)** consists of one control pin, a supply voltage, and ground. The sound sensor diagram **(Fig. B.5)** consists of an analog pin, a supply voltage, and ground.

## Mechanical Design and Drawings

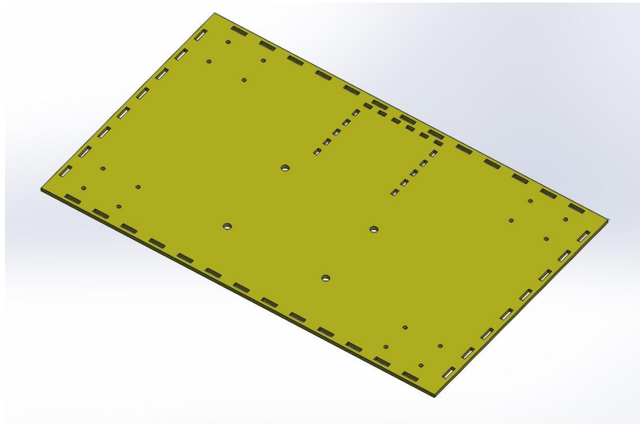
The cart was constructed using a number of manufacturing techniques and materials. MDF was used to create the main cart body as it was provided, easy to laser cut, light weight, and relatively strong. The wheels were constructed using 3D printed PLA, allowing for customization and iteration. The components of the shooting mechanism were machined metal, purchased PVC, and 3D printed PLA. Detailed drawings of each individual component are available for reference in the online repository shown below.

https://drive.google.com/drive/folders/1SMCjIi7TH0jRBTf9YPn4rqQdiAq-ANuc?usp=sharing

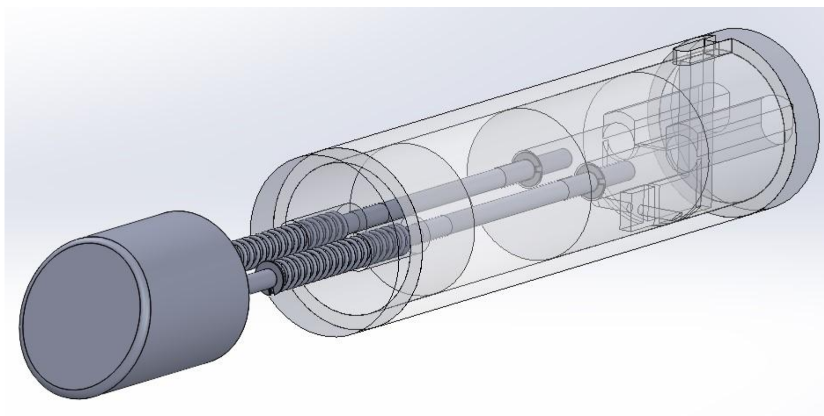
## Mechanical Assembly Instructions

The following instructions show step by step how to assemble the robot. Detailed drawings of each assembly are also available in the drawing repository previously provided.

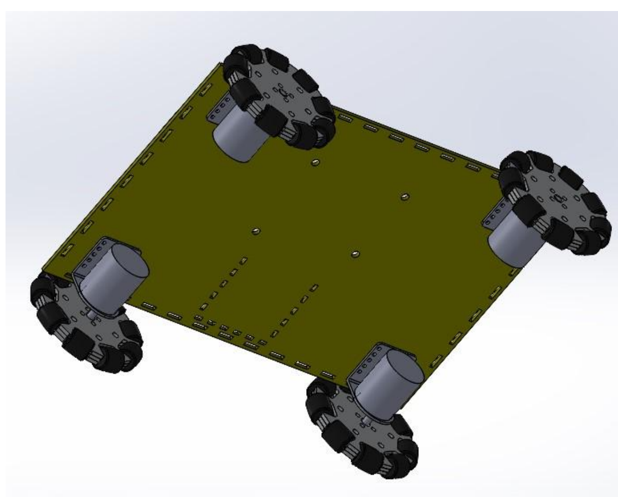
1. Laser cut all frame pieces to dimensions based on engineering drawings. Begin with the bottom frame laid out.



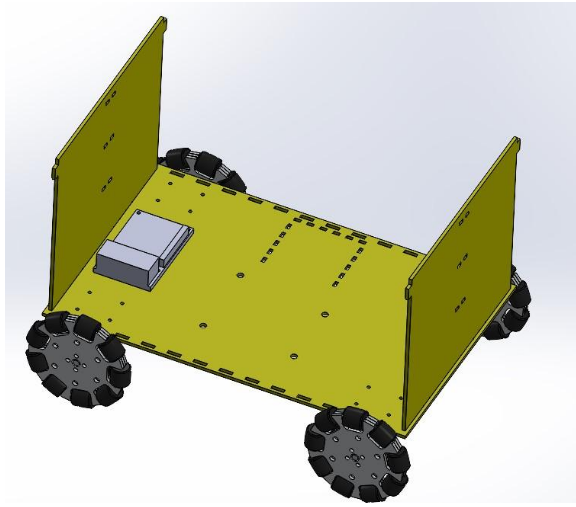
2. Manufacture all components within the kicker sub-assembly, then fit them together as shown below.



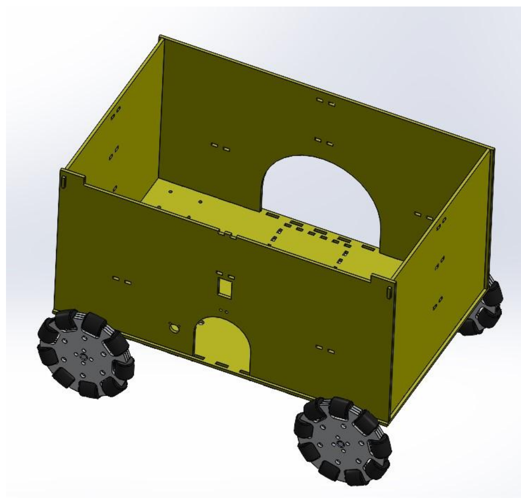
3. Install wheel mounts to the bottom panel, install stepper motors to the motor mounts, press fit wheels to the motor axles.



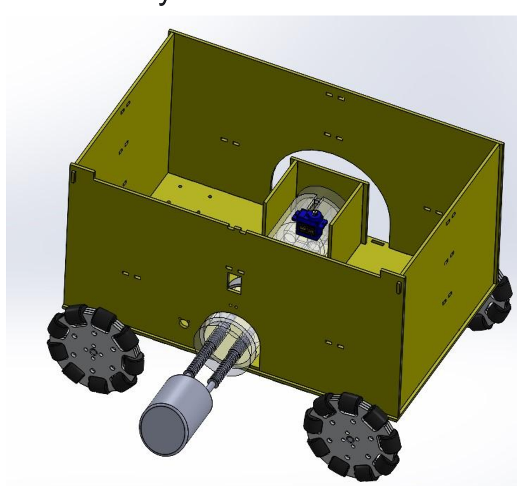
4. Insert the side panels grooves into the bottom panel slots.



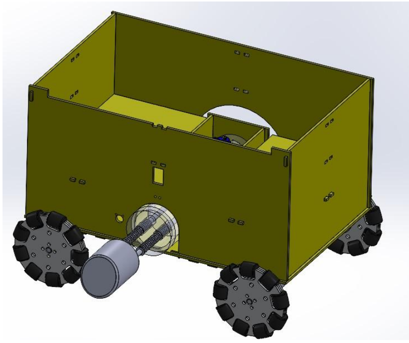
5. Install the front and back panels to the chassis.



6. Install the kicker sub-assembly to the chassis.

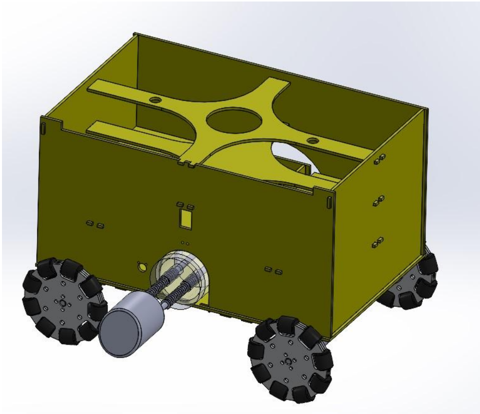


7. Install the shelves to fit within the grooves of the front, back, and side panels.

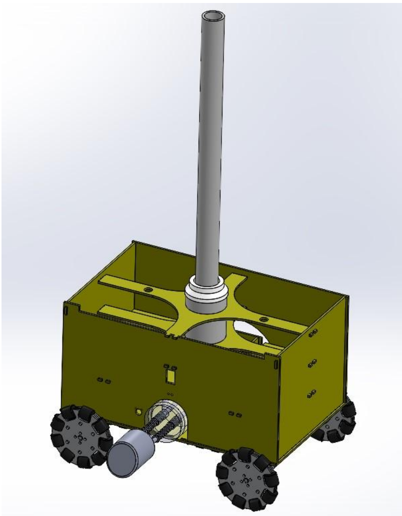


8. Route the electronic cables from the motors and kicker assembly to the microcontroller.

9. Install the two top panels within the grooves of the front, back, and side panels.



10. Finally, install the PVC base, adapter, and 18-inch tube to the upper top panel.



## Testing Plan

*Offensive Testing Plan*

1. Load kicker: To load the kicker, press down the guide rods into the enclosure (PVC) while pushing the key into the locking mechanism. Make sure that the clips are fully inserted. When the shaft is pressed all the way down, release the key so that it's locked.
2. Place the kicker gently on the bot through the kicker mounts. Make sure that the bot is switched into offense mode. Connect the servo to the Arduino.
3. Position the robot in front of the ball in the penalty kick area, angled towards the edge of the goal, with the kicker just barely touching the ball.
4. Turn the robot on and play the whistle tone. This activates the servo to fire the kicker.

*Defensive Testing Plan*

1. Switch the robot into the defensive setting. Make sure that the robot is off.
2. Remove the unloaded kicker and connect the DC motors to the arduino.
3. Place the robot in the center of the defensive area, facing the ball.
4. Switch on the robot to start the code loop for defense.
5. After the opponent takes the shot, turn off the robot

## Bill of Materials

The total cost of the robot was $114.62, which is less than the $200 allowed. The part prices in parentheses were provided components, and not included in the total cost.

The team used MDF for the panels to create a cost-effective and lightweight soccer penalty kick robot. The wheels were 3D printed to allow customization and multiple design iterations. The sound sensors, camera, motors, and microcontrollers were provided by the class. The kicker components were fabricated in the ITLL manufacturing area from materials that were available for free. The full BOM and price breakdown can be seen in Appendix C. **(Fig C.1)**

## Software Development/Code

The robots' software is run entirely on the Arduino Mega, and was written in the Arduino IDE with C++. Many functions were used to control the robots actions, with the main loop simply checking the status of on/off and offense/defense switches onboard the device. The full file is available for review in the online database located below.

https://drive.google.com/drive/folders/1K5THzVCt9zY7dR8B3jrJrPVDoO9CKDm8?usp=sharing

## Conclusion

After the completion of testing the Soccer Penalty Kick Robot, the team met the project goals. Mechanically, the offensive mechanism is capable of being loaded and fired by a servo when commanded by the referee’s whistle. Defensively, a control algorithm was put in place that allowed the robot to sense the position of the ball and rapidly respond to its movements. The algorithm was tuned so that if the ball was located outside of the perimeter of the robot, the robot moved at full speed to defend. When the ball is located within the perimeter of the robot, the robot calmly moves to center itself and block the ball. A switch installed on the top of the robot allows for the user to easily switch between offense and defense. An additional switch functions as an on/off or “kill” switch which allows the user to tinker with the robot without it responding to its surroundings.

An important lesson learned from this project is that integration is the most challenging step. While each function may work independently, there are always intricacies involved with combining systems together that are not always foreseen.

Another lesson learned is that cable management is extremely important for ease of testing. For this reason, it should be thought about at the beginning of the project and not the end. Trying to debug a function that isn’t working could seem like a software issue, but in reality the error could be caused by a loose wire in a breadboard. At the finalization of the project, every wire was secured, zip tied and taped into position, fixing this issue. With additional time, however, the use of a PCB, cable connectors, and secure methods to connect/disconnect every system would be beneficial.

After the completion of this project, the team is happy with their successes and have learned from the challenges along the way. The project was a rewarding mechatronics challenge and taught us the scope of what is possible with mechatronic engineering.

# References


[1] Servo Motor Code; https://docs.arduino.cc/learn/electronics/servo-motors

[2] SPI connection and Code;
https://learn.sparkfun.com/tutorials/raspberry-pi-spi-and-i2c-tutorial

[3] Sound Sensor frequency tuning;
https://create.arduino.cc/projecthub/lbf20012001/audio-frequency-detector-617856

[4] Pixy2 Documentation; https://docs.pixycam.com/wiki/doku.php?id=wiki:v2:start

## Appendix A: Concept Art and Preliminary Designs

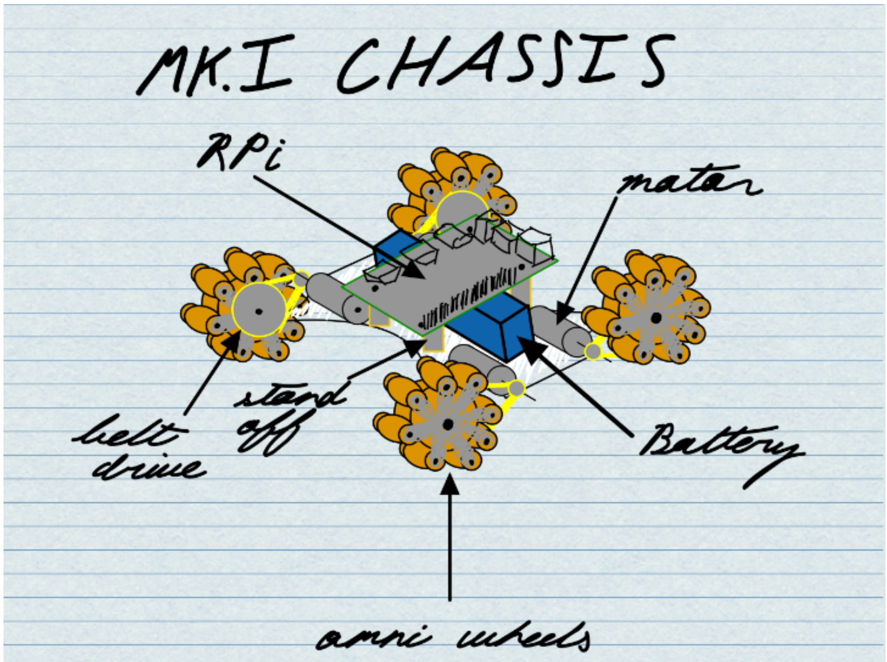



**Figure A.1:** Preliminary Chassis Sketch

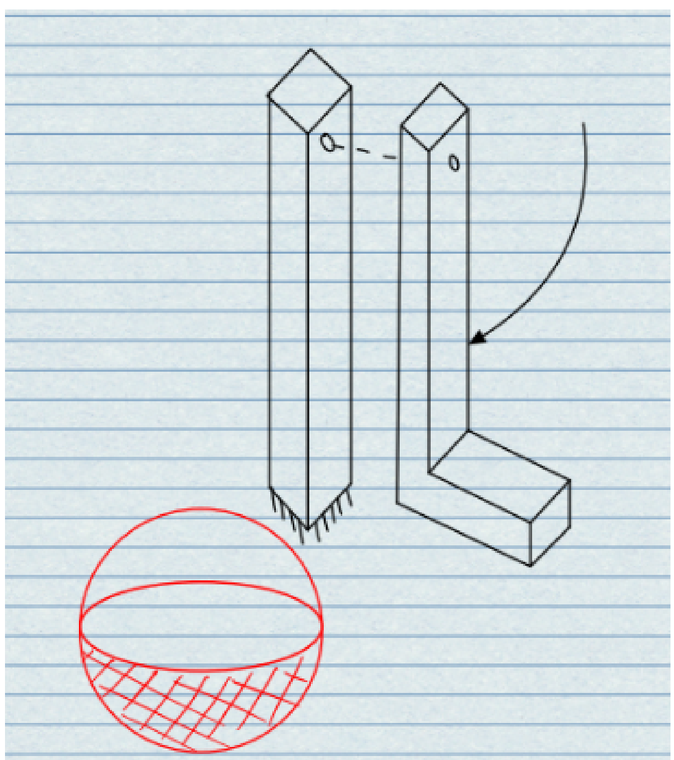


**Figure A.2:** Rotational Kicker

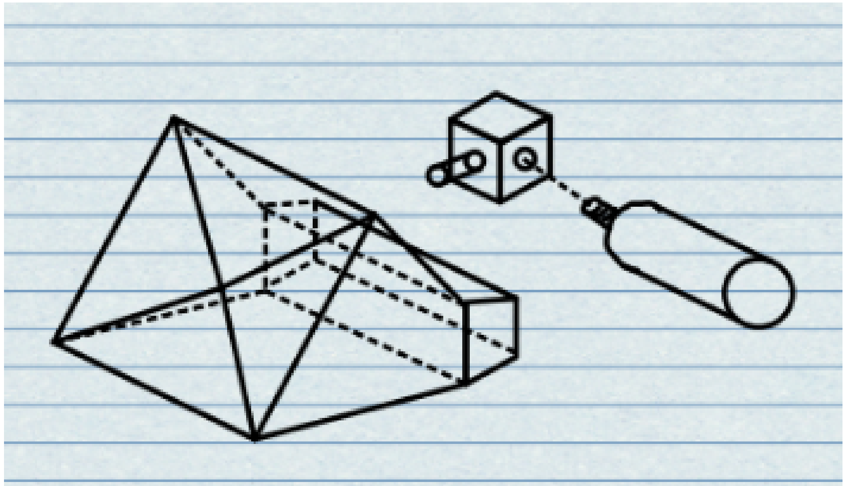


**Figure A.3:** Airbag kicker

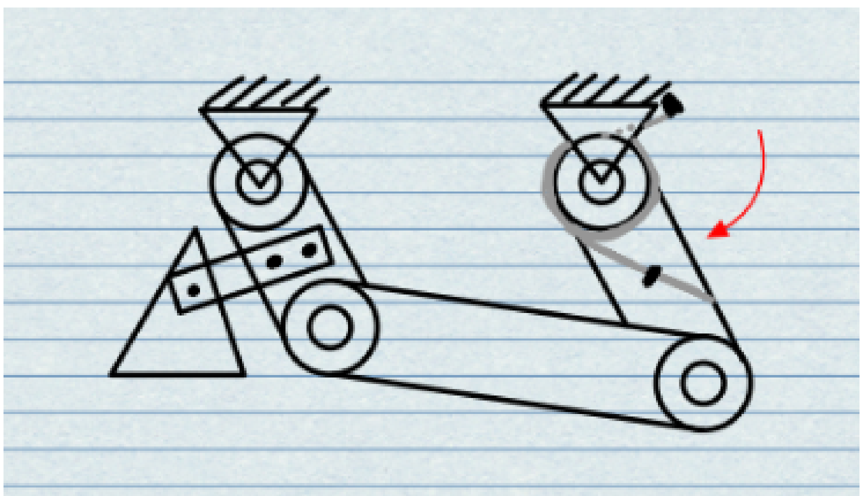


**Figure A.4:** Linkage driven kicker

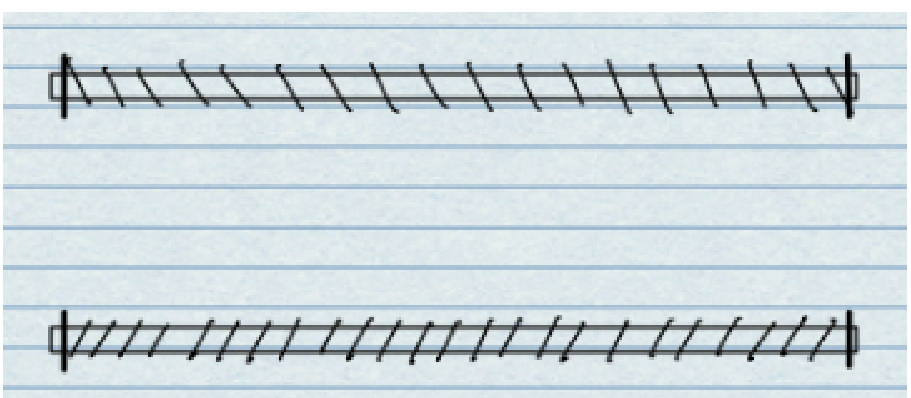


**Figure A.5:** A pair of linear spring and guide rod assemblies

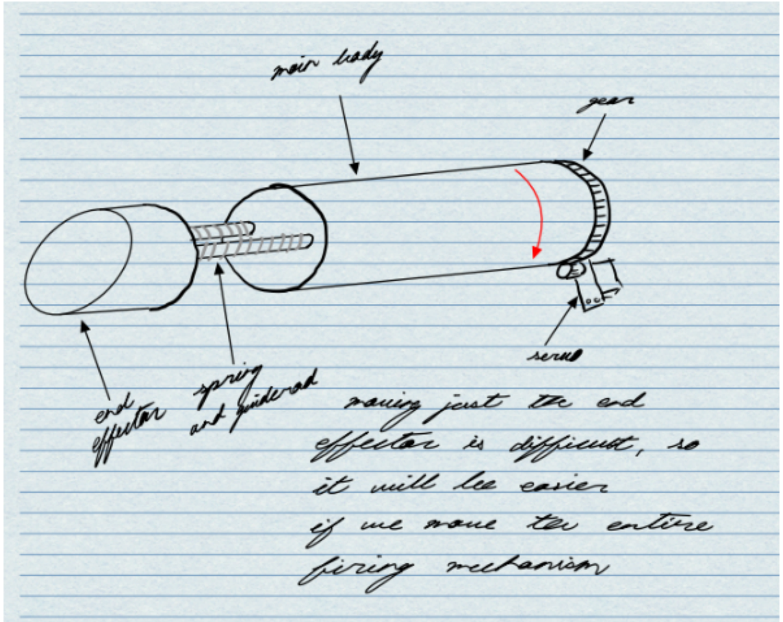



**Figure A.6:** Linear spring kicker initial sketch

# Appendix B: Electrical Diagrams

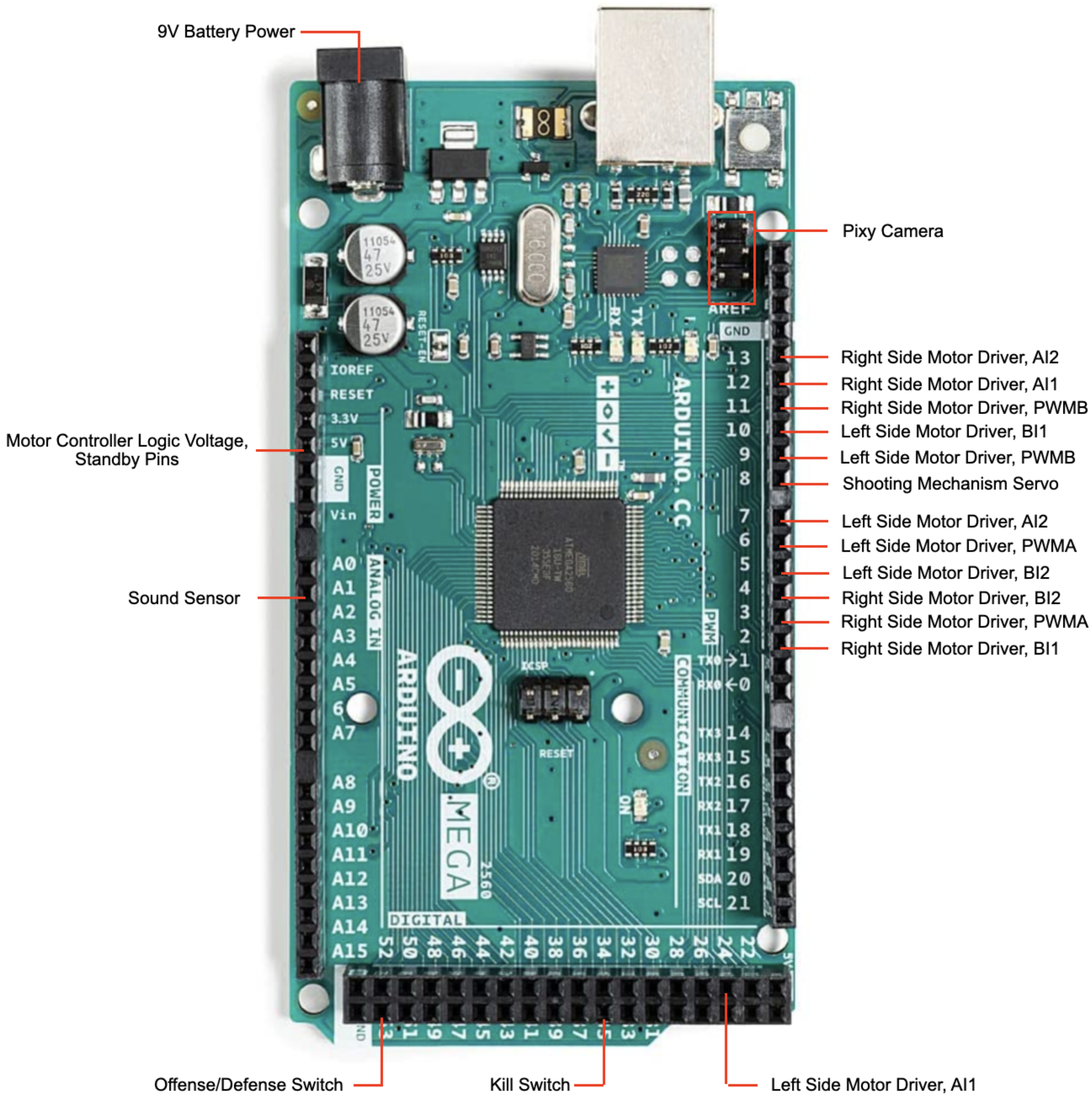



**Figure B.1:** Arduino Mega Pinout

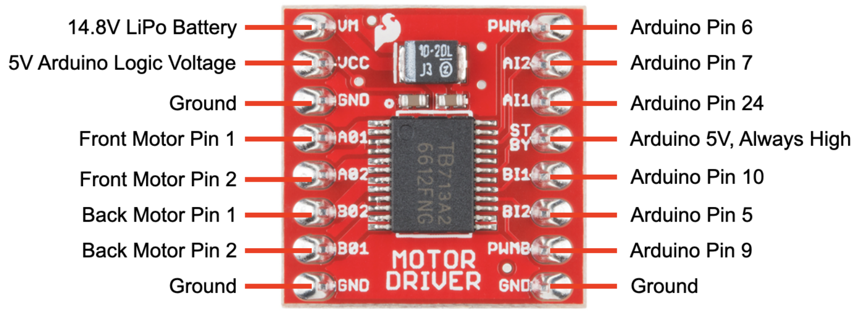



**Figure B.2:** Left Motor Driver Pinout

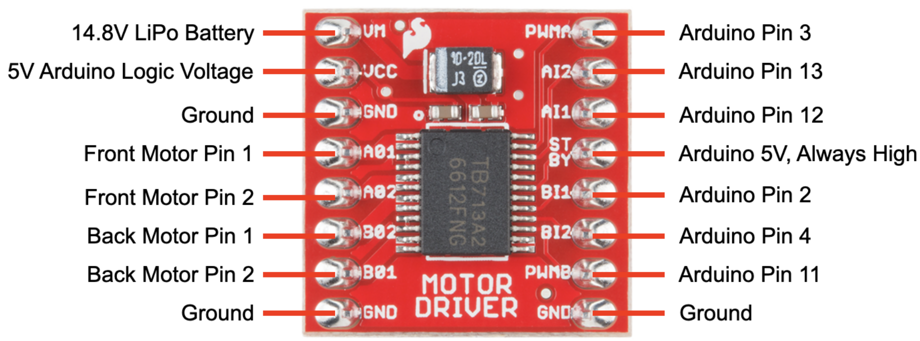



**Figure B.3:** Right Motor Driver Pinout

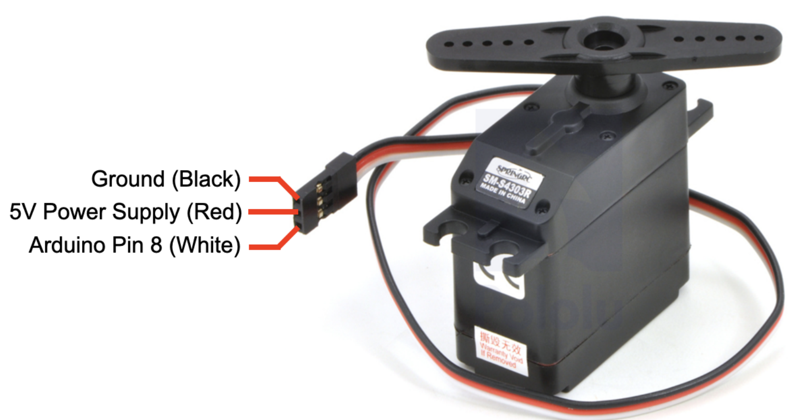



**Figure B.4:** Stepper Motor Pinout

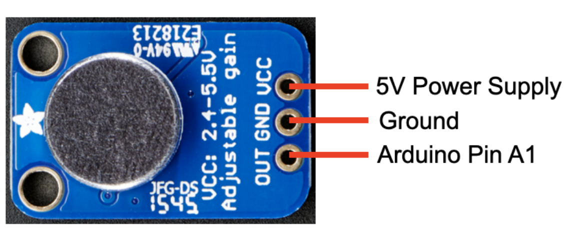



**Figure B.5:** Sound Sensor Pinout

## Appendix C: BOM

| Part# | Part Name | Material (or PPN) | QTY | Cost Per Item |
|---|---|---|---|---|
| 1 | Bottom Panel | Medium Density Fiberboard (MDF) | 1 | ($2.30) |
| 2 | Front Panel | MDF | 1 | ($2.22) |
| 3 | Back Panel | MDF | 1 | ($2.10) |
| 4 | Side Panel | MDF | 1 | ($2) |
| 5 | Upper Top Panel | MDF | 1 | ($1.75) |
| 6 | Lower Top Panel | MDF | 1 | ($1.75) |
| 7 | Shelf | MDF | 2 | ($1.80) |
| 8 | Kicker Panel | MDF | 1 | ($1.25) |
| 9 | Kicker Panel Support | MDF | 2 | ($1.20) |
| 10 | Wheels | PLA | 4 | ($1.30) |
| 11 | 12V DC Gearhead Motor | 253500 | 4 | ($15.95) |
| 12 | Stepper Motor Mount | STL | 4 | ($8) |
| 13 | Solderable Breadboard | - | 1 | ($2) |
| 14 | Sound Sensor | MAX4466 | 1 | ($6.95) |
| 15 | Pixy 2 (Camera) | - | 1 | ($69.90) |
| 16 | PVC Base | PVC | 1 | ($4.15) |
| 17 | PVC Tube | PVC | 1 | ($4.49) |
| 18 | PVC Adapter | PVC | 1 | $9.02 |
| 19 | Kicker Boot | PLA | 1 | ($3.15) |
| 20 | Kicker Guide Rod | STL | 2 | ($4.55) |
| 21 | Kicker Guide Rod EClip | STL | 4 | ($0.75) |

| | | | | |
|---|---|---|---|---|
| 22 | Kicker Springs | STL | 2 | ($0.80) |
| 23 | Kicker PVC Tube | PVC | 1 | ($2.18) |
| 24 | Kicker Front Cap | PLA | 1 | ($2.95) |
| 25 | Kicker Back Cap | PLA | 1 | ($2.95) |
| 26 | Kicker Servo Motor | SM-S4303R | 1 | ($15.95) |
| 27 | Kicker Servo Mount | PLA | 1 | ($2.70) |
| 28 | Kicker Clamp | STL | 2 | ($0.78) |
| 29 | Arduino Mega | - | 1 | $55.60 |
| 30 | Motor Driver | - | 2 | ($5.95) |
| 31 | Electrical Switch | - | 2 | $1.99 |
| 32 | Battery | - | 1 | ($12.99) |
| - | PLA Roll | PLA | 2 | $50.00 |
| | | | TOTAL: | $114.62 |