PURRFECT CLEANER

Automatic Cat Litter Box

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Group 5

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Chapter 1: Executive Summary

For many years, cats have been a beloved pet for humans. Many centuries ago, the ancient Egyptians treasured cats, and many had domesticated them in their homes. They were one of the first civilizations to have cats as pets. Then soon throughout the years cats have grown in popularity as domesticated pets in many countries. People long for companionship and friendship and look to cats to form these connections over some other domesticated animals. Just how dogs can be described as a man's best friend, cats are just as capable of filling that role. Cats, like dogs, offer affection, and their ability for self-grooming not only keeps them clean but also reduces the need for frequent bathing, which is what many cat owners appreciate. Additionally, their preference for indoor environments makes them well-suited for urban living, where outdoor space may be limited. As the adage goes, "A house is not a home without a cat," highlighting the impact these furry friends have on human lives.

However, as much as people love their feline companions for these characteristics they have, there are issues when taking care of them in the household, the issue of cleanly disposing of their waste. To solve this issue, litter boxes were made to hold cat's waste and urine in a clean manner. They were made to be easily accessible for cats and utilizes cat's instincts with the use of clay litter since cats instinctively relieve themselves on sand covered surfaces. However, despite the effectiveness of litter boxes as a solution, they can become a source of frustration for cat owners due to the ongoing maintenance they require. Once a cat uses the litter box, the responsibility falls on the owner to manually scoop out the waste regularly, a task that can quickly become annoying, especially when it needs to be done on a daily basis.

This need for a more efficient and hassle-free solution inspired the creation of our innovative product, the **Purrfect Cleaner**. Our self-cleaning litter box gets rid of the hassle of scooping by hand, giving cat owners a super easy and clean way to manage their pet's waste. With the Purrfect Cleaner, you can say goodbye to the boring task of cleaning up after your cat and instead focus on enjoying quality time with your furry friend.

Our Purrfect Cleaner represents an affordable innovative cat-care technology, addressing the common challenges associated with manual litter box cleaning. At the core of this product is a motorized comb that completely changes the way cleaning is done. This comb is designed to sweep through the litter box horizontally, scraping out waste and directing it into a conveniently placed side bin. This bin makes it effortless for users to dispose of the soiled litter, promoting a cleaner and more hygienic living environment for both cats and their owners.

While self-cleaning litter boxes are not entirely new to the market, what sets our Purrfect Cleaner apart is its comprehensive set of features that prioritize safety and affordability. We have integrated multiple weight and motion sensors into the design, potentially a mobile app that can control the device. All these features act as safeguards for the customers.

For instance, imagine a scenario where a cat enters the view of one of the motion sensors while the cleaning cycle is in progress. In such a situation, our Purrfect Cleaner automatically stops the cleaning process, ensuring the safety of the cat. This intelligent response mechanism demonstrates our commitment to creating a stress-free experience for both pets and their owners. Furthermore, our weight sensors serve as an additional layer of protection. In the rare event that a motion sensor fails to detect the cat's presence, the weight sensors step in, detecting any added weight within the container. This triggers an immediate pause in the cleaning cycle, preventing any potential accidents or disturbances.

Our product’s goal is to make it easier for cat owners in households to maintain a clean and healthy environment for their beloved pets. In order to reach this objective, we explored into thorough research to carefully choose and incorporate the best components into the design and functionality of the Purrfect Cleaner. We analyzed every single detail of its construction, from the materials utilized to the complex mechanisms that drive its self-cleaning features. We wanted to make sure our product was able to deliver all necessary features that others on the market can do and more.

Chapter 2: Project Description

This chapter of the paper details the specific aspects of the project that have been created, meaning its description and our plan for its creation. The following sections discuss the project background and goals, project objectives and motivation, description of its features and functionalities, existing similar products or projects, key specifications, hardware and software block diagrams, and the house of quality for the project.

Project Background and Goals

Cat litter boxes have proven to be a highly successful method of regulating feline waste. Litter boxes allow cats to relieve themselves in a comfortable and low-maintenance environment for the owner. However, in the past, owners had to scoop the cat excrement manually. Over the years, companies have designed better-quality litter boxes that automate the poop scooping and bagging process. Our team's goal is to further the development of modern automatic cat litter boxes by making economical improvements and adding quality features.

Automatic Cat litter boxes are retailed from around $150 on the low end to $700 for higher quality devices. For many boxes on the cheaper side, there are very minimal features and lower overall performance ratings from customers. Our team aims to produce a cost-efficient automatic litter box that provides quality features to the consumer while maintaining a lower price. These features include safe-cat features to ensure the litter box doesn’t run when the cat is present, accessible waste bag collection and management, a mobile component to allow the litter box's storage to be monitored and cleaned remotely, and a mobile notification to indicate when the litter box storage needs to be changed.

As technological innovations have led to more changes in the quality of life of modern devices and applications, the cat litter box can be further improved. Increases in feline waste storage capacity and sealing allow for users to change the waste less frequently. For example, a future possibility for automatic cat litter boxes is vacation mode. During vacation, the cat waste is stored in heat-sealed bags to minimize odor while the owner is on holiday. Furthermore, sealed bags allow the automatic cat litter box to support multiple bags, as a new bag can be installed when the previous one is sealed. The concept of improvements in cat waste sealing is a stretch goal for our team.

Cat litter boxes have the potential for automatic litter replacement and waste sealing hygienic improvements. A litter box that replaces its litter provides a longer time between user interactions with the device, improving the quality of life. Paired with

better waste management, an automatic cat litter box has the potential to be changed far less than even current state-of-the-art devices. Our team's stretch goal is to not only make an automatic cat litter box that is competitive with our devices on the market but also add unique and effective features that have not been marketed.

Our group intends to create a practical, multi-featured automatic cat litter box that is economically cheaper than other devices while providing quality features. Our group has the stretch goal of delivering new innovative features to the automatic litter box.

Objectives and Project Motivation

Our group aims to develop and design a practical automatic cat litter box with multiple quality-of-life features. Additionally, our team intends to cut the price compared to other high-end, multi-featured cat litter boxes on the market. We want to make an automatic cat litter box with cat safety features, advanced excrement management/storage, and mobile features allowing remote access and user interface.

Our group intends to make a litter box that supports cats of varying shapes and sizes. The group's motivation is to create a quality-of-life cat waste cleaning device that improves the quality of life for users, from reduced prices to added features. Our team is set to produce a device that can be marketed to consumers at a low price compared to upscale products while still providing the same features. We want to enhance the livelihood of cat owners by creating a product that provides their cats with a safe and efficient waste-cleaning environment.

Description of features/functionalities

Our project includes many features to enhance a modern litter box design. The first significant feature our project consists of is the innovative, safe feature for cats. Multiple weight sensors are built into the box to detect excess weight inside the litter box. Specifically, when the device goes through a cleaning cycle, any trigger to the weight sensor stops the device from finishing until the weight is removed. The device includes a standby mode when it is interrupted, which keeps the device from operating until the interruption is fixed.

The next prominent feature of our project includes a user-friendly mobile component. The feature supports a mobile app that allows users to sign up and connect their account to an automatic litter device. Once connected, the users can monitor the

excrement stored in the litter box waste compartment. Additionally, the app notifies when the litter box waste has reached its limit. The limit is determined by a weight sensor that is set to a specified amount (ex., 5 pounds). Finally, the device tracks the cat's weight through the weight sensor and displays that information in a chart through the app.

Existing Projects/Products

When we decided that we were going with the idea of making a cat litter box cleaner with some additional features, we searched throughout the internet for multiple versions and examples of cat litter box self-cleaners to get a basic idea of how it could work and look. In order to ensure we had a project idea that was able to be worked on extensively for the duration of two semesters, we made sure when looking for products that they had differing features and functionalities. This was incredibly important so that we could have insight into which features seemed more effective and what we could take as inspiration for our own version of a cat litter box cleaner.

We searched on various commercial sites such as Amazon and sites dedicated to cats' care products. One of our main concerns was about how the cat litter would be moved and deposited so when searching for various examples, we made sure that the ones we found had different ways of dealing with the unclean litter. This would allow us to decide what method of disposing of the litter would be best for our project.

One of the examples we viewed was called Nature's Miracle Multi-cat self-cleaning litter box. Their self-cleaning litter box has a built-in rake that is used to clean the litter, which we thought was an effective feature of the product. It also included motion detection sensors that would detect whether the cat was in the box in order to prevent cleaning the litter while the cat was still inside. The product had many solutions to problems not easily thought of at first glance, for example a light for the cats for when it gets dark and a ramp for them to gain access to the litter box to limit the possibility of the dirty litter getting on the floor. The Nature's Miracle company had established many features that gave us more thought on how to implement our project and a useful reference to look back on during the duration of this project.

We had also discovered a self-cleaning litter box created by engineering students at the University of Illinois. They decided to make an elevated version of a self-cleaning litter box with a closable door. The features of their self-cleaner was that it had used a rake instead of a shovel to clean the litter, motion sensors to detect if the cat has entered the litter box, and sealer for when the wasted dumped in the bag it would be sealed via a heat sealer for clean disposal of litter. This previous project had made us

understand what goes into creating a product like this and how we could elevate it and how to proceed with it throughout the two semesters.

In conclusion, researching on various sites for more information of self-cleaning litter boxes has given us some more insight of what the standard requirements are for it to work. The basic features needed to operate, and optional features all gave us many ideas on what to implement in our project.

Figure 2A: Existing Products

Key Specifications

Below are the specifications for the parts we are using to build our version of a self-cleaning litter box. Each part has its own set of specifications regarding the width, height, or requirements. The three demonstrable specifications are the scooper moving the poop in the bag, motion sensors being able to detect if the cat is in the litter box, and weight sensors as a secondary precaution to detect if the cat is in the litter box.

Three Demonstrable Specifications	
Motion Detection	Checks within 7 meters with 90% accuracy if the cat is inside or near the litter box to prevent the cleaning cycle from occurring
Weight Detection	Checks with ±98-99% accuracy before cleaning the waste to see if the cat is the box and for minor weight increases such as waste to begin the cleaning process
Waste Removal	During a cleaning cycle the 90% of the waste is removed from the box using a scooper and is placed in a waste bag

Table 2A: Three Demo Specifications

Casing	
Maximum Height	20 inches
Maximum Width	30 inches
Maximum Weight	7 kg
Minimum Weight	4 kg
Maximum Weight for cat	3 kg
Power	
Max Consumption	<1,000 watts
Scooper	
Maximum Width	11 inches
Internet Adapter	
Data Transfer Rate	<1,200 Megabytes per second
Motion Sensor	
Maximum Width	45 millimeters
Maximum Height	17 millimeters
Quantity	1
Motor	
Power	12 V
Weight Sensors	
Maximum Width	3 centimeters
Maximum Height	4 centimeters
Quantity	8

Table 2C: Specification Chart

Hardware Block Diagram

The hardware block diagram is shown in **Figure 2D**, a visual representation of the system that we are creating. Starting from left to right, the weight sensors are used in the litter compartment, continuously reading the weight and sending the information to

the MCU through an Analog to Digital Converter on the PCB. The MCU takes this information in order to determine if the cat is currently in the litter, and to use it to prevent the motor from turning on while the cat is inside. The system is also using two buttons to allow for user intervention. The first button is used to put the system on standby, this can be used for when the owner would like to replace the current cat litter, clean the container, or remove something that is stuck in the container.

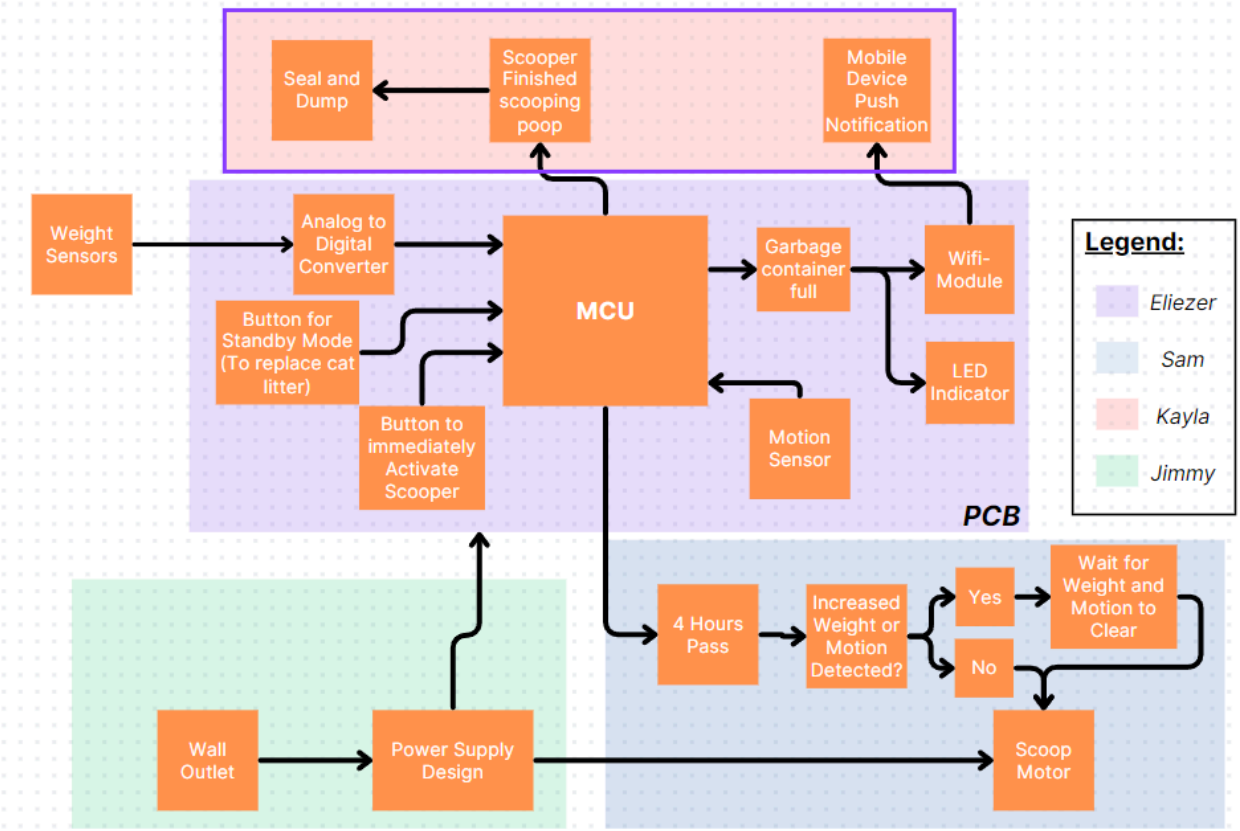

Figure 2B: Hardware Block Diagram

The second button is to have the scoop motor run immediately; this allows the owner of the feline to manually remove any poop that is currently sitting in the container. Sometimes the poop from our pets comes out, as we say, "unusual" and can have a more pungent odor that may need to be removed quickly; the button allows this quick removal. We added this because we planned to have the scoop motor run in specific time intervals, around every 4 hours. This may seem like an extended amount of time, but an average cat poops every 12-24 hours, depending on nutritional intake. Of course, this would mean that at any time of the day, the cat can poop in the container, and having a four-hour interval allows the motor to scoop morning, afternoon, and night, covering all times of day for when a cat might poop.

The following equipment on the PCB is the Wifi-Module and the LED indicator. The purpose of these two is to notify the owner that the container for holding the cat feces is full. The Wifi-Module connects the system to an application for sending push notifications to the owner's mobile device. The LED light is used for a visual indication on the system itself for the feces container to notify the owner that the container is full. Everything in this system, of course, needs to be powered, and we have elected to create a wall-plugged power supply. Since this system is mainly present in the owner's home and never moved, a battery source was not needed. Our options for powering the system through the wall remain open for discussion. We can choose a simple Nema 5-15p cord that connects to an AC/DC converter and directly feeds the PCB and the motor, or we can have the connection to the PCB be a USB type A or C connection, like how a mobile device works.

House of Quality

The House of Quality (HoQ) diagram is a structured matrix connecting customer requirements with corresponding engineering characteristics. It consists of customer needs listed on one side, engineering features on the other, and a matrix indicating the relationships and priorities between them.

- **Compatibility**: Ability to work with a variety of cat litters
- **Stability**: Durable construction to withstand regular use
- **Mechanism**: Scooping motion
- **Functionality**: the functions and features of the product
- **Motion Sensing**: The ability to sense cat existence in the litter box
- **Weight measurement**: To monitor weight of the whole box
- **Build quality**: Durability of the box
- **User-friendly:** The difficulty level for use
- **Affordability:** Price of the product
- **Compatibility**: the ability to operate with different types of litter

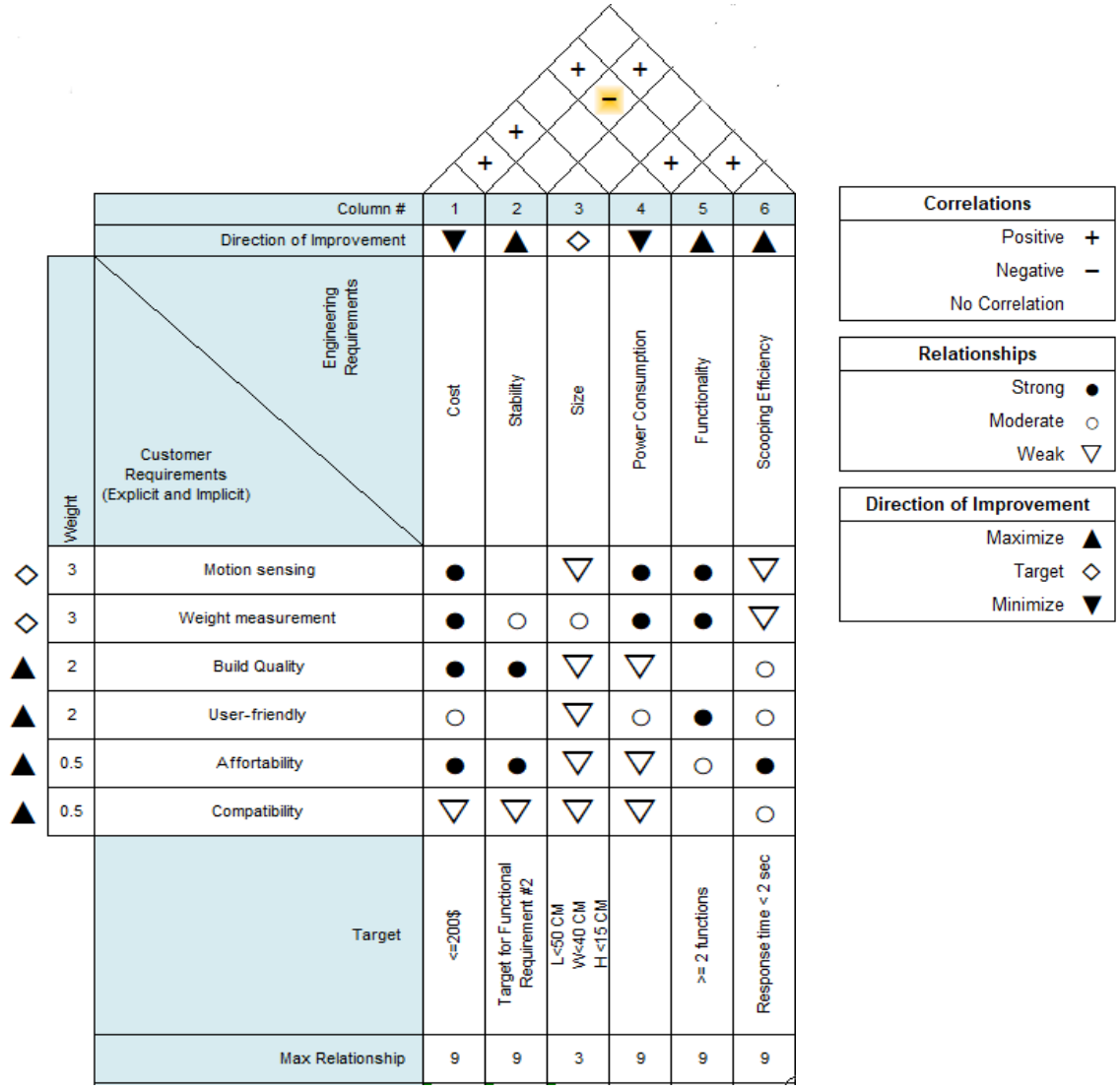

Figure 2C: House of Quality

Chapter 3: Research and Investigation

This chapter of the paper includes extensive research into the different technologies that we can use to create the project, as well as a comparison of manufacturing companies and their products. The following sections detail the comparisons of the different technology, such as different motion and weight sensors, and its part comparison between manufacturers.

Technology Comparison

In this comparison section, we discussed various technological aspects essential for the functionality and user experience of our product. Our primary focus are five key

features: motion sensing, weight sensing, waste removal mechanism, wireless communication capabilities, and user interface software.

Motion sensing technology is used to detect the presence of the cat within the litter box, initiating the scoping process only when the area is clear. We explored different motion sensor types such as Passive Infrared Sensors (PIR), Ultrasonic sensors, and Microwave Sensors, evaluating their range, accuracy, and pros and cons with our specific application.

Weight sensing technology serves as an additional layer of security and functionality, ensuring that the scooping mechanism is not activated if there are any weight changes within the litter box. We compared various weight sensor types including Strain-Gauge, Hydraulic, and Capacitive Based sensors, analyzing their precision, reliability, and suitability for integration with our system.

The waste removal mechanism is at the core of our product, facilitating the efficient removal and disposal of cat waste. We explored different motor technologies such as worm gear motors, etc. the motor is attached to a filter that pushes out the waste.

Wireless communication capabilities are essential for remote monitoring and control of the litter box, enabling users to receive notifications, track usage patterns, and adjust settings through a connected app or interface. We compared wireless communication protocols such as Wi-Fi, Bluetooth, and Zigbee, considering factors like range, data transfer speed, and energy efficiency.

Motion Sensing Technology

To ensure the absence of the cat within the litter box during the initiation of the scooping motion, the device employs two distinct technologies for prevention. Upon the activation of the timer, which issues a command to commence the scoping process, the Microcontroller Unit (MCU) systematically assesses the status of both motion sensors and weight sensors. Subsequently, the MCU proceeds with the scoping process only if the motion sensor does not detect any active objects. There are many motion sensing technologies but for the purposes of this project, the most compatible options include Passive Infrared Sensors, Ultrasonic sensors, and Microwave Sensors. The following sections mention the working principles and evaluate the advantages and disadvantages of each motion sensing technology .

Passive Infrared Sensors (PIR) operate based on the fundamental principle of detecting alterations in infrared radiation either emitted by or reflected from objects within their designated field of view. Specifically designed for integration into the cat litter box scooping device, PIR sensors offer a commendable combination of cost-effectiveness and energy efficiency, rendering them a judicious selection for this application. The

advantages of employing PIR sensors encompass their economical nature, minimal power consumption, and their proficiency in identifying living things, including cats, through the capture of their distinctive heat signatures.

Despite these advantages, it is important to recognize the limitations of PIR sensors. One notable constraint is their restricted detection range, needing strategic placement to ensure comprehensive coverage of the litter box area. Additionally, PIR sensors exhibit sensitivity to fluctuations in ambient temperature, which can potentially result in false positives or negatives, impacting the overall reliability of the cat detection feature. Therefore, while PIR sensors present a cost-effective and energy-efficient solution for cat presence detection, careful consideration must be given to their placement and environmental conditions to optimize their performance within the intended application.

Ultrasonic Sensors operate by emitting ultrasonic waves and measuring the time it takes for those waves to reflect off of nearby objects. This technology showcases a commendable range and is versatile in its capacity to detect a broad spectrum of entities, encompassing both living things and inanimate objects. Their notable flexibility lies in the effectiveness of ultrasonic sensors across diverse lighting conditions, ensuring consistent functionality in a variety of environments. Moreover, their capability to cover large areas positions them as invaluable instruments in situations requiring extensive spatial awareness.

However, it's crucial to consider a couple of limitations associated with ultrasonic sensors. Though their power usage is typically moderate and deemed acceptable, it becomes a significant factor in applications where maintaining stringent energy efficiency is crucial.Additionally, these sensors may encounter challenges in environments characterized by acoustically reflective surfaces, leading to potential interference and a compromise in accuracy. Despite these drawbacks, the inherent versatility and wide-ranging capabilities of ultrasonic sensors render them indispensable in situations where thorough and expansive object detection is essential.

Microwave sensors operate on the fundamental principle of emitting microwaves and analyzing changes in their reflection caused by moving objects. These sensors emit microwave pulses and scrutinize the returning signals, detecting motion by interpreting the Doppler shift in the frequency of reflected waves. This mechanism enables the sensor to identify the presence and movement of objects within its designated range.

One significant advantage of microwave sensors is their ability to cover a wide area efficiently. Compared to some alternative motion-sensing technologies, they excel in applications requiring extensive coverage. Additionally, microwaves can penetrate certain materials, making these sensors suitable for scenarios where detection through obstacles, such as walls or covers, is necessary. Moreover, microwave sensors

demonstrate versatility in various environmental conditions, including darkness or adverse weather, as their functioning is not reliant on visible light.

Despite their advantages, microwave sensors come with certain limitations. Potential interference from other electronic devices operating on similar frequencies can affect the accuracy of these sensors. Additionally, the cost of microwave sensors tends to be higher compared to some alternatives, impacting the overall expenses of implementing a system. Moreover, the installation and setup of microwave sensors can be more complex, requiring meticulous adjustment to avoid false alarms or blind spots in their detection range.

In conclusion, each motion-sensing technology boasts distinct advantages and drawbacks. Passive Infrared Sensors stand out for their cost-effectiveness and energy efficiency, rendering them well-suited for detecting the presence of a cat in the litter box scooping device. While Ultrasonic Sensors offer versatility, their drawbacks include moderate power consumption and potential interference issues. Given that the litter box is constructed from plastics, the benefits of utilizing microwave sensors, which can penetrate materials, may not be necessary. The primary objective is to detect the cat's presence in the litter box, and considering the box's dimensions (not exceeding 30 inches in length), Passive Infrared Sensors emerge as the most compatible option to achieve this specific goal.

Name	**Cost**	**Range**	**Field of View**
PIR	low($3)	1-5 meters	< 180 degrees
Ultrasonic Sensors	moderate($5)	< 5 meters	< 60 degrees
Microwave Sensors	highest($8)	< 16 meters	< 72 degrees

Table 3A: Motion Sensing Type Comparison

Weight Sensing Technology

In addition with the motion sensor, our product includes the use of weight sensors. In some cases, there may be an object moving around in the litter that the motion sensor can not detect, this can be for example, a baby cat that has wandered into the litter without the owner's knowledge. For an extra layer of security to prevent harm, the motion sensors are used to continuously read the weight currently present within the box to ensure there is no obstruction to the scooping motor.

There are three different types of weight sensors, and each one has their own unique way of measuring weight. These types include Strain-Gauge, Hydraulic, and Capacitive Based weight sensors. Strain-Gauge weight sensors are the most common type of sensor for commercial use, it is usually a small-medium scale sensor that uses a spring connecting a diaphragm and a beam (Chen). When an object is placed on the sensor the diaphragm contracts and the strain caused by this contraction is measured to determine the weight of the object. The spring allows the beam to return back to its original state when the object is removed from the sensor. The Strain-Gauge weight sensor is one of the cheapest due to it mainly being made for human use, for example, a typical weight scale in a household uses a Strain-Gauge type weight sensor.

The next type is a Hydraulic weight sensor, this type is mainly used in industrial contraptions, such as a hydraulic press. The force exerted from the hydraulic pressure on an object is used by the sensor to measure the strain being created, allowing it to measure the weight being put on the sensor (Chen). This weight sensor technology is very expensive due to it being made mainly for heavy-duty use in industrial areas, and therefore would not be a viable candidate for use in our project.

The last type of weight sensor is the Capacitive Based weight sensor. Its functionality uses a spring connected to a variable capacitor, when there is a weight placed on the spring the strain increases, which then changes the value of capacitance in the capacitor. The value of capacitance is then read to determine the amount of strain on the spring and output the value of weight on the sensor. Its functionality is very similar to a Strain-Gauge weight sensor, the main difference is the way it measures the strain on the spring (Chen). This type of sensor is usually found in interface devices that use touchscreens or touchpads where it senses the weight of the human finger pressed on the sensors.

Name	**Cost**	**Use case**
Strain Gauge	Low ($5-10$)	Most common commercial weight sensor, usually found in household weight scales
Hydraulic	High ($60-$100)	Made for heavy duty industrial use, usually found in a hydraulic press machine or a forklift
Capacitive Based	Low ($5-$10)	Made for sensing small changes in weight pressure, usually found in touchscreens or touchpads

Table 3B: Weight Sensing Type Comparison

Buttons/Buttons Technology

In order to maintain simplicity and budget constraints for this project, the decision has been made to implement mechanical button technology for the two buttons responsible for setting the mode of the device. Mechanical buttons are chosen for their straightforward design, cost-effectiveness, and reliability in basic applications.

Mechanical buttons operate on the principle of a physical mechanism making or breaking electrical contact when pressed. Compared to more complex button technologies such as capacitive touch buttons or membrane buttons, mechanical buttons are particularly suitable for this scenario due to their inherent simplicity. In this context, where the primary functionality revolves around toggling between low and high states, while other technologies may offer additional features, the simple binary input mechanical buttons offer them the optimal choice for a basic mode-setting function in this project.

In addition to the buttons dedicated to mode-setting, a switch is required to control the device's power, allowing it to be turned on or off. Like buttons, switches come in various technologies, after excessive research, Slider Switches and Rocker Switches are the best option for the application of controlling the power of the device.

Rocker switches and slider switches are two distinct types of electrical switches widely utilized in various applications. A fundamental difference lies in their operational mechanism. Rocker switches employ a back-and-forth rocking motion, facilitated by a lever that moves horizontally or vertically to open or close the circuit. In contrast, slider switches operate by sliding a knob or lever along a linear path to achieve the same purpose.

The usage and applications of these switches cater to specific needs. Rocker switches find common applications in appliances, automotive contexts, and industrial equipment, where their decisive rocking motion is advantageous. On the other hand, slider switches are often employed in audio equipment, lighting controls, and situations requiring precise linear movement.

Durability and sealing capabilities are important considerations for this project. Rocker switches, depending on design, can offer good sealing against dust and moisture, making them suitable for rugged environments. Slider switches may vary in sealing capability and could be more susceptible to dust and moisture ingress, in this case, cat litter might be stuck in the gap on the slider switch, causing the machine not be able to turn on and off.

Considering cost, both types are competitively priced, with rocker switches generally being cost-effective. They are both less than a dollar each and have similar operating voltage. But considering the durability and sealing capabilities aspect, Rocker Switch might be the best option in this scarinero.

Stack Technology

In preparation for developing our app for our self-cleaning litter box, we researched various software/techniques that would benefit our product the most. We wanted our app to be able to alert the user to when the waste box is full via push notification, track the cat's weight, and allow the user to create a personal account to be able to view this information. So, we have looked into stacks which are a combination of APIs, programming languages, servers and databases that are helpful tools when creating an application. The two technology stacks that we have decided would work best with our project are called Mern stack and Lamp stack.

The first stack we had investigated was Lamp stack which was a stack that was made up of four software technologies useful in web-app development. The acronym Lamp stands for Linux, Apache, MySQL, and PHP. Linux is the operating system being used, Apache is the server the web application is on, MySQL is the database server, and PHP is the programming language used for this kind of technology stack.

To go more in depth, Linux is an operating system that is free to use and supports most programming languages. The Linux server is very customizable and can have many development packages downloaded as well. It also has bash scripting which allows for starting, deploying, and building with ease via creating commands. It is basically the foundation for the rest of the Lamp Stack elements to make sure that the project remains stable and be able to run smoothly.

Apache is a web server that allows the application to be deployed on the internet. It uses HTTP internet protocols to transfer the user's software into web pages on the Internet. HTTP is basically a protocol for transferring information in HTML files, such as text, scripts, images, and layout information. The HTTP internet protocol is a secure way to transfer information because it goes through the process of receiving requests and verifying the authority of the user requesting.

MySQL is a database management service that can be used to create tables that can store information and edit or query data in those tables. For example, it can hold user's information for a webpage into one of its tables. To be more specific, when a client is creating an account on a webpage, the client's username, email, and password can be sent and stored into the appropriate table. When the client wants to login into their pre-existing account then the information can be requested from the MySQL database.

Finally, the PHP language is a recursive acronym that stands for Hypertext Preprocessor. This language enables the interactive features of a website and has them changing dynamically after each action made by the client. It can be embedded into html files, where it can directly receive the client's information from the web page and then access the MySQL database to retain the information into the tables. It can also be able to send query commands to MySQL to receive information to be posted on the site.

Similar to Lamp Stack, the other stack called MERN stack is also a stack technology that is made of four software-technologies. The acronym MERN stands for MongoDB, ExpressJS, React, and Node. MongoDB is another database management system like MySQL, ExpressJS is a node web framework, React is a JavaScript library, and lastly Node is an open source JavaScript runtime environment.

The first part of MERN Stack, MongoDB, is a cross-platform documented oriented database system. It is also referred to as a NoSQL database, which means that it is a database that doesn't hold its data in a table format but instead into a document, graph, wide-column, or key-value format. In the case of MongoDB, it uses documented format with key-value pairs that correspond to JSON objects. Then when data needs to be retrieved it can be retrieved in JSON format. JSON format stands for JavaScript Object Notation and is a structural format that stores and retrieves data in the form of objects that holds the user's information from the webpage. It is also flexible and easily editable when moving or transferring data.

The next part of the Mern Stack is ExpressJS which is a web structure specifically for Node that helps to set up and write the backend part of a project. This is responsible for creating the API which is the Application Programming Interface that helps front-end portion, html web pages, of the project to communicate to the backend portion that includes the databases. Express supports dynamic content on apps and web pages, by sending back and forth requests from the app and database in order to receive/send information to clients with a quick response.

React is a JavaScript library with the main focus of helping programmers create user interfaces for their apps. Within React is a JavaScript package called ReactJS that is a tree made of JavaScript components meant to act as a DOM tree. A DOM tree stands for Document Object Model where the nodes of the tree represent one part of an html file as an object. In the case of ReactJS, the JavaScript components are represented through the nodes to have those updated regularly to reflect user input. The JavaScript components making up the nodes of the tree are straightforward and detailed making it easy to manipulate for future editing.

Finally, the last part of the Mern Stack is Node. Node is a JavaScript run environment where it can have access to the project files of an application. It can allow

programmers to open, edit, read, and close documents as well as run and test them on a server. It also has the capabilities of managing the formation of threads that are formed in a single process once the project is run on the server and requests are made, making the likelihood of errors and bugs forming decrease. In the chance of block behavior occurring in the code, NodeJS includes non-blocking standards in its libraries to prevent them from occurring when the project is run on the server.

Lamp Stack	Features	Mern Stack	Features
Linux Server	· Uses bash scripting · very customizable	MongoDB database	· Keeps data in document format · Uses JSON format
Apache Server	· Uses HTTP Protocols · Deploys application on the internet	ExpressJS	·Supports dynamic content · Helps write the API of the backend
MySQL Database	· Uses Tables to hold data · Uses query commands	React	· Contains the package ReactJS ·Uses a DOM like data structure
PHP Language	· Can be embedded into HTML Files · Ability to send query command to SQL database	NodeJS	·Allows to run/edit files · Has the capabilities of managing threads

Table 3C: Stack Technology Comparison

Cloud Service Comparisons

For the development of the app for our Purffect cleaner, we decided that between the two stack technologies discussed previously, Mern Stack and Lamp Stack, that Mern Stack would be a better fit. What made us come to this conclusion is that Mern stack is that the software technologies used is much more suited for app development since they have much better scalability in regard to the database when comparing databases like MongoDB and MySQL and that Mern has a non-blocking structure as one of its

features in the software technology NodeJS that would result in a better performance and decreases the chance of the application of breaking.

Now having chosen our preferred stack technology, we now have to decide which cloud hosting services would be best fit for our application. Cloud hosting services are very beneficial since it would help in deploying the application, the handling of traffic from multiple users, and it includes some security features that would help with encryption and prevent unauthorized data requests from the user who doesn't have permission to access the data. The potential cloud hosting services that we considered were Digital Ocean, Heroku, and Amazon Web Services. These three different cloud hosting services provide many different benefits and features worth looking into and considering for a Purrfect cleaner app.

The first service that was researched was Digital Ocean. Digital Ocean is a cloud service provider that offers access to a virtual machine, disk storage, and a monitoring system to examine the performance of the virtual machine all through the various droplets they provide. The droplets are not free, and how they are categorized depends on the amount of space and features they provide for each one. The prices for each vary based on the amount of memory needed, number of virtual central processing units, transfer size, and the solid-state drive space. Digital Ocean also provides three CPU options that are regular, premium intel, and premium AMD that would also change the prices.

The first droplet is called Basic where it would provide a simple droplet with the virtual machine and basic features mentioned previously. It is mostly used for simple applications that use small databases, low-traffic applications, and blogs and forums. The standard price for the basic droplet monthly is 4 dollars and with the need to increase memory or space it can get to 96 dollars.

The next and last droplet worth considering is the CPU Optimized Droplets. This droplet’s main focus is on the efficiency of the virtual CPUs being offered. The number of virtual CPUs offered that would be necessary for our app ranges from one to eight and the number increases by two each time. The starting price is 4 dollars with one virtual CPU and the maximum price is 96 dollars with eight CPUs.

The next service is Heroku. Heroku is also a cloud service provider popular for many development projects. It is used mostly to help deploy many applications though their dynos containers. Similarly to Digital Ocean, their dynos containers are Linux based and are offered based on the performance and features. Some of the features dynos generally offer are a certain number of process types, automated OS patching, RAM space, recorded application metrics, custom domains, and free SSL(Secure Socket Layer) on those custom domains. Secure Socket Layers encrypts requests from the web server and web client thus protecting the data being transferred. There are 4 dyno

containers offered which are the Echo and Basic, Standard and Performance, Private, and Shield. The dyno containers are not free, they have options where it can cost up to 69 cents an hour depending on which you use and for a monthly option it could cost up to 500 dollars or more depending on if the private dyno container it picked. For the private version and the Shield version it is required to contact Sales to get a custom pricing.

The first dyno container offered is called the Echo and Basic. The Echo and Basic are categorized as one dyno container but are two separate containers just based on the same model. The similarities are that they both offer a RAM space of 512MB, deploys from Git, customized domains with SSL certificates, OS patching, and certificate management on the customized domains. Where the two differ are the number of process types they offer, the amount of time they remain on, and how much time they record on the application metrics. For the Echo dyno, it offers only two process types, stays on for at most thirty minutes and then sleeps, and it does not offer the feature to record the application metrics. The Basic dyno, offers 10 process types, is always on and never sleeps, and it records the past 24 hours on the application metrics.

The final dyno considered is the Standard and Performance version. The Standard and Performance version is an upgrade to the Echo and Basic versions where it offers everything included in both the Basic and Echo dynos and just like them, they are both separate dynos based on a single model. The Standard dyno comes with two versions which are the Standard 1X and the Standard 2X. The Standard 1X and the Standard 2X both offer unified logs, preboot, unlimited number of process types, horizontal scaling, and are always on. The only difference between the two is that for the Standard 1X version it offers 512 MB of RAM and the Standard 2X version offers 1 GB of RAM. The Performance dyno also comes with two versions which are the Performance M and the Performance L. Both offer the same features as both of the Standard dyno versions but with the addition of being able to auto scale and being a dedicated run environment. They only differ in the amount of RAM they offer where Performance M offers 2.5GB and Performance L offers 14 GB.

The final service is Amazon Web Services. It is a cloud computing service that offers various of resources for many different applications. It is a very popular service used by many recognizable product-based companies. They offer various options based on different categories such as storage, database, containers, and mobile and web development. Amazon Web services offers a free trial where you can have total access to a product for 12 months if you create an account. Which is very beneficial since the two previous options above required a monthly service in order to use their products. One of the free products is the AWS amplify hosting which would work well for the app we are planning to create.

The AWS amplify hosting is a free tier product that is a fast and secure service for deploying apps. It supports many web frameworks such as react and contains built in CI/CD (continuous integration/continuous deployment) frameworks. The amount of RAM it offers is 15 GB per month and it allows for 5 GB of data storage per month as well. It also offers preview requests where it can allow users to test features before deploying, easily allows connecting domains to apps along with a free SSL certificate, monitoring metrics with alarms that records data of the app in real time, and username and password protection through encryptions.

Name	Cost	Features
Digital Ocean Droplets	Low/High($4-$96 Monthly)	• Multiple vCPUs • Disk Storage • Monitoring System
Heroku Dyno Containers	Low($7-$500 Monthly)	• SSL Certificates • Disk Storage • Monitoring System • OS Patching • Certificate Management
AWS Free Tier Products	Free	• CI/CD Frameworks • Disk Storage • Preview Requests • SSL Certificates • Monitoring Systems • Encryption

Table 3D: Cloud Services

Internet Adapter Technology

To make sure that the app we created for our Purrfect cleaner is able to record the information from the weight sensor and motion sensor for our users to be able to see the data if they are not present in real time. It is important for the user to have the ability to see the weight of the litter in the box as well as how much their cat weighs while in the box as well as when the cat is either near or inside the box based on the motion. This is necessary so that the user may keep track of their cat's weight and its safety, so it would be very important to have an internet adapter. An internet adapter is a component that can enable a device to connect to a local network or the internet. They can transfer data from the device as data packets to be sent over the network and be received back as well. There are different types of internet adapters on the internet such as the wired versions and the wireless versions which could be viable for our product.

The wired version of the internet adapter involves a physical wire that would make for a faster and more reliable connection than that of the wireless version. They also include various ports on either side of the wire. Examples of these different ports include the USB-C type, Ethernet, and USB-A type. These ports come with different transfer speeds and benefits when it comes with transferring data through the internet. On the market, the cost for wired internet adapters can range from 10 to 15 dollars making it an affordable part to add to our Purrfect cleaner.

The USB-A type is the most common of the three and has a wide rectangular shape, commonly used by computers and televisions. Depending on the type of USB-A, the transfer speed and bandwidth can be different. For the USB 2.0 standard it has a max data transfer speed of 480 Mbps and an aggregate bandwidth of 10 Gbps and for the USB 3.0 standard it has a max data transfer speed of 5 Gbps and bandwidth of 20 Gbps. Some of the disadvantages when it comes to using the USB A type is that when inserting the pins are not always lined up so it may have to be reinserted multiple times and that the data transferring speeds are slow when compared to other ports.

The next port type, the USB-C is a popular port used by smartphones and tablets. It is made to have a smaller and slimmer shape when compared to the USB-A type and is much more capable. Because of its smaller and slim shape there is little issue when inserting the USB in devices unlike the type A model. Same as the USB-A type discussed before, there are different transfer speeds and bandwidths based on the standards. Starting with the USB 3.2 Gen 1, its maximum transfer speed is 5 Gbps and has an aggregate bandwidth of 5 Gbps, the USB 3.2 Gen 2 is 10 Gbps and bandwidth of 10 Gbps, and the USB 3.2 Gen 2X2 is 20 Gbps and bandwidth of 20 Gbps.

The last port type is the Ethernet port which is a type of socket that establishes an ethernet connection to a network. Ethernet ports are designed to have a square shape with 8 pins inside and can be plugged in directly to the wall of some households that can be connected through wires to the user's router. Ethernet cables come in various categories starting from 1 to 8. Each category with a different max transfer speed and which environment it would be applicable in. For example, category 1 has a maximum transfer rate of 1 Mbps and a bandwidth of 0.4 MHz and is most commonly used with telephones and modems and category 6a has a maximum transfer rate of 10 Gbps and can be found in commercial buildings and data centers. Since our Purrfect cleaner is supposed to be catered to cat owners' households, the suitable category would be category 5e which has a max transfer rate of 1 Gbps and bandwidth of 100MHz.

Wireless internet adapters is a device where it can be attached to a computer to establish connection to Wi-Fi networks. Basically, they pick up Wi-Fi signals and can establish a connection to them without the need of an ethernet cable, but instead using radio waves. They only need one port to connect to the device that needs Wi-Fi connection and the most common port that is used is the USB type A and the standard

would be that of USB 2 or 3 which have a max data transfer speed of 480 Mbps and 5 Gbps as discussed previously above with the wired version. The bandwidth of wireless adapters can range from 20 to 400 Mbps depending on the network it connects to. There are different types of Wi-Fi adapters that would do well with our product, which are Bluetooth and the ones that have the Wi-Fi antennas attached.

Name	Cost	Maximum Transfer Rate	Bandwidth
Wired Internet Adapters	Low($10-$15)	480 Mbps to 10Gps	10 to 20 Gbps
Wireless Internet Adapters	Low/Moderate($7-$40)	Up to 480 Mbps	20 to 400 Mbps

Table 3E: Wireless Adapters Comparison

Power Supply Technology

In order to make sure that our Purrfect Cleaner is able to operate for a substantial amount of time, we have researched various types of power supplies, regulars, adapters, and ports. The Purrfect Cleaner needs to be able to have a motor do clear out the waste inside the litter box, motion detectors to detect of the cat is near or inside the litter box, and lastly weight sensors to detect if a notable amount of waste is in the box as well as if the cat is in the box. To be able to have these features, an appropriate power supply must be required to provide the necessary power needed. We have researched three different types of power supplies that are AC-DC converters, battery operated, and switching power supplies.

The first type of power supply is the battery-operated power supply which involves the use of only one battery to power up the device. This option would allow for the Purrfect cleaner to be able to operate without the need to be always plugged into an outlet in the wall. One example of a battery power supply that would work well with our product would be a lead acid battery. This type of battery can have multiple galvanic cells each with a voltage of 2 volts. These cells have negative and positive oxide lead plates and when discharging the oxide lead turns to lead.

One of the advantages of the lead acid battery is that in the industry it is very affordable, and prices can range from 15 to 100 dollars depending on the number of cells contained in one battery. The range of voltage that the battery can hold that is appropriate for the cleaner is from 6 to 12 volts. It can also have reserved power that can last up to 48 hours for the 12-volt version and is easily rechargeable by applying a constant voltage charge depending on the number of cells in the lead acid battery. The

battery is very robust and durable and as a result the battery can last for typically more than 5 years for some models.

The lead acid battery comes with many advantages but also does have some disadvantages that could make it not a good fit for our Purrfect cleaner. The battery can be bulky making it heavy and may be too big to be able to be placed on the cleaner. The weight can be an issue since in the case that it can fit on the cleaner without interfering with the other parts required space, the possibility of the battery making the cleaner be unbalanced and tip over to one side would be high. If a higher voltage is necessary, then the price can be higher, typically up to 100 dollars for some models.

The next type of power supply that was researched are the switching power supplies. Switching power supplies are power supplies that use switches in their circuits to regulate the amount of voltage without expending any energy. They are popular and dependable power supply in the market and industry support a wide range of voltages. This power supply consists of rectifiers and transformers but can also include filters or inductors. Typically, the prices can range from 12 dollars to about $200 on some stores and websites, when more voltage is required the prices can increase considerably.

Some advantages of the switching power supply is that they are highly efficient. When being used the load and line are regulated to smoothly increase or decrease the input voltage to get the desired output voltage, thus producing the necessary power for a product. Another advantage is that they are very compact and dense so that they won't take up a lot of space and additional components can be installed to improve and enhance features.

The main disadvantage of a switching power supply is the amount of frequency noise it produces. This would not be ideal for the Purrfect litter since it could scare the cat with its noise and generally be very noisy when operating.

The final type of power supply is the AC to DC converters. AC to DC converters are power supplies that convert the alternative current from power sources such as outlets to direct currents. These are a very popular power supply most electronic products use, and they are the most commonly used charging device for other similar litter box cleaners on the market. AC to DC adapters on the market can range from outputting from 5V to 48V.

How AC to DC converts work is that they modify the AC current using diodes to then change the waves of the AC signal to have positive peaks via the rectifier and then lastly run it through a filter to get a steady DC current flow. This process is necessary to ensure that electronic devices that need power are able to constantly receive direct current. Since alternative current during a period of time can go down to zero, meaning

the output can stop and start producing current which is less efficient than using direct current which is a continuous current.

There are many advantages when it comes to using AC to DC converters. One of the advantages is that it is highly efficient. Unlike most power supplies it doesn't expend unnecessary amounts of energy while being used. Some are usually made to be very compact and small in size making them easy to install in small places and having them weigh very light, which would be good for making the charger be easily moved when necessary. The last advantage is that they are very affordable. Some prices on the market for them range from 10 to 50 dollars from various websites.

Along with the advantages there can be a good number of disadvantages for AC to DC converters. One of them is that they could produce a lot of heat while being used, usually depending on the model made. Some can also be made to be quite big and bulky, having more capacity for power but with the added weight.

Specifically for the versions of AC to DC converters that are smaller and more compact in size, these can come with multiple different charging ports. Some examples of these charging ports are lightning ports, USB type C ports, and USB power delivery ports. These types of ports can output various ranges of voltages.

The lightning charging port is very popular, mainly used to charge phones and other electronic devices. The 8-pin port itself is very small and thin compared to the USB type C port which is a positive since the wire can be easily inserted in it. Its voltage ranges from 1 to 5 Volts max, so it is preferably used for smaller electronics. The 30-pin port is much wider, and its maximum voltage is 1 Volt. Mainly used as an alternative to the 8-pin to connect to speakers and other dock connectors.

The USB type C charging port is a commonly used industry standard. It is used to charge many phone brands as well as a wide range of electronic devices. These ports are considerably bigger than a standard 8-pin lightning port because it contains a total of 24-pins. The maximum voltage it can handle is 5 volts, the same as the lightning port above.

Lastly USB power delivery ports are fast-charging ports that are based on the USB type C model. This port type can be used to charge various laptops and fast-charge smartphones. However, even though it is based on the type-C model it is much more powerful. The voltage ranges from 5 volts to 20 volts via the handshaking approach by configuring the proper voltage the device needs in order to charge efficiently.

Name	Cost	Voltage Range	Size	Weight Range
Lead Acid Battery	Low/High ($15-$100)	2V - 12V	(50x94x100)-(343x172x213)mm	2-72 pounds
AC to DC Converters	Low ($10-$40)	5V - 48V	(4.52x2.91x1.02)-(10.71x8.78x2.83)inches	2-20 pounds
Switching Power Supplies	Low/High ($12-$200)	5V - 240V	(50x82x36)-(200x90x275)mm^3	0.9-6 pounds

Table 3F: Power Supply Comparison

Motor Technology

To properly sift and remove the cat poop in the automatic litter box, our design contains two reversible gear motors that push two mechanical arms, one on each side of the litter box. Upon going into the scoop action, which the MCU initiates after the sensors have verified no cat is present, the MCU tells the two gear motors to begin turning. As the two gear motors rotate clockwise, respective to the front of the litter box, the two mechanical arms extend towards the end of the litter box. Finally, after the mechanical arms have fully extended and pushed the cat poop off of the litter bed and into the trash collection, the gear motors begin to rotate counterclockwise, and the arms retract back to their initial position.

There are many advantages to using gear motors over other common alternatives. Reversible gear motors have low maintenance requirements compared to standard motors, usually only requiring occasional lubrication over long-term use. In addition, with proper load management, gear motors can last even longer. With an average cat expelling poop in the size range of 1-3 oz, our reversible gear motor have light loads to manage, making them excellent for the task.

In addition to maintenance, reversible gear motors boast low noise output and high precision. The gear motor's rotating angular stability allows for highly accurate readings and consistent results. Most modern gear motors have great teeth contact and small gaps, allowing for menial noise. Furthermore, gear motor lubrication lowers noise output.

Gear motors are very efficient due to their low speed and high torque design. The motor's gearbox lowers motor speed, allowing the motor to operate more efficiently and expend less excess power. Due to innovations in gearbox scalability, gear motors are also incredibly compact and can be used in small workspaces that benefit discrete designs.

Though gear motors offer a wide variety of potential advantages and features, it's essential to recognize that there are limitations to the design. The main disadvantages to standard gear motors are low speed and high potential heat generation. Depending on the motor's load, gear motors can generate heat due to the friction between moving parts. Though gear motors are designed to dissipate heat, large workloads can stress the motor and produce excess heat. In addition, gear motors move at low speeds, which can prove ineffective for products that require faster movements. Though the aforementioned potential disadvantages have been recognized, they do not extensively apply to our group's automatic cat litter box design. Because speed is not essential for the mechanical arms when sifting the cat poop, the gear motors can operate at their ideal speed. Moreover, the average loads placed on the mechanical arms are as low as our design incorporates frequent poop scoops every 3 hours. Because our litter box runs frequently, our design avoids the issue of buildup.

A possible motor alternative to the gear motor is the direct drive motor. Direct-drive motors are very efficient and maintainable due to their gearless design. Direct drive motors outlast standard gear motors due to their non-mechanical transmission system, allowing fewer points of failure in the design. Direct drive motors produce less noise than gear motors because their transmission is non-mechanical.

Though the direct drive motor has notable advantages over the gear motor, it also contains a few significant disadvantages. The massive price difference is the main disadvantage of using a direct drive motor over a gear motor. Direct drive motors are much more expensive, ranging from $50-150 in price, compared to the gear motors, which are listed at $10-25 on major retail websites. The price alone offsets the multiple benefits of the direct drive motor as our group's automatic cat litter box is budgeted for low cost.

Another potential alternative to the gear motor is the linear motor. Linear motors, like the direct drive motor, do not require a mechanical transmission, giving them upfront advantages over gear motors, such as low maintenance and faster speeds. The linear motor also generates less noise due to its non-mechanical transmission.

Though the linear motor has similar advantages to the direct drive motor when compared to the gear motor, it also maintains similar disadvantages. Just like the direct

drive motor, the linear motor is, on average, more expensive than standard gear motors. The faster speeds from the linear motor are not be properly utilized in our group's design as the mechanical sifting arms are intended to move slowly through the litter. A fast sifting motion may displace the litter and cause unnecessary mess. Because our group favors a slower mechanical arm, the linear motor is not as suitable as a reversible gear motor.

Name	Cost	Use Case
Gear Motor (reversible)	Low ($10-25*)	Low cost budget slow speed standard mechanical motor
Direct Drive Motor	High($50-150*)	High end efficient motor for heavy loads and intensive use
Linear Motor	Moderate($25-50*)	Linear directional motor for fast speeds and high precision

**relative prices found on major retail sites (Amazon, StepperOnline, Transmotec)*

Table 3G: Motor Technology Comparison

Parts Comparison

This section of the paper goes into detail the similarities and differences between manufacturers between the part components that we used in our system. These parts include the motor, motion sensor, weight sensor, buttons, switches, microcontrollers etc. It explains which manufacturer we chose to go with, as well as explanations as to why we chose it based on a functional reason and budgetary reason.

Gear Motors

Gear motors are a great choice for robotic arms because their sturdy mechanical structure allows for greater loads and consistent movements. For the automatic litter box our group has chosen to employ two reversible worm gear motors on each side of the litter box. When the MCU is prompted to begin cleaning the two gear motors begin to rotate clockwise, extending the mechanical join arm forward, which pushes the

sifting filter through the litter. After the arm is fully extended the litter is pushed off of the box into a garbage shoot that collects the litter.

Worm gear motors have advantages and disadvantages. Some of the main advantages to worm gear motors involve compact design, self locking mechanism, and high torque output. Some of the disadvantages to worm gear motors are their inefficiencies with high loads and heat dissipation with high loads. However, with our model these disadvantages aren't major concerns as the automatic litter box won't require heavy loads or constant movements resulting in light heat dissipation.

Worm gears consist of a worm and worm wheel, whose output shafts are placed perpendicular to each other. When the worm rotates, the teeth of the worm wheel are also rotated as the worm pushes the teeth either clockwise or counterclockwise. The worm gear's design allows for high gear reduction while providing power and torque in a very compacted space. Additionally, worm gears cannot be back driven, which allows them to have a self locking mechanism, where the worm gear does not move if the worm wheel attempts to rotate the worm. Worm gears are often very quiet as they operate using a sliding contact. The main issue with worm gears is their lack of efficiency due to their sliding contact mechanism. Worm gears have high contact areas, which result in greater frictional forces to overcome during rotation. Moreover, the great frictional force from worm gear generates heat, which can become an issue depending on load size and duration of motion.

The worm gear is the **NFP-5840-36ZY-1280** Single Shaft Self-Locking Reversible Worm Gear model. The model supports up to 10 kg of load weight. Looking at the data sheet the gear ratios vary depending on rpm and support a high of i = 1,340 at 4.5 rpm and a low of i = 17 at 370 rpm. The data sheet explains the drawbacks of worm gear motors at high speeds as the gear ratio is vastly different compared to lower speeds. Additionally, the torque also varies depending on the rpm as seen in the data sheet with a high of 100 kg.cm and a low of 3. All of the data sheet information shown is for a rated load. Because the worm gear is reversible the data above is applicable for both directional rotations.

A possible alternative to the worm gear motor is a brushless gear motor design. The brushless gear motor has the benefits of better efficiency and reduced maintenance, and long over lifespan when compared to a worm gear motor. However, a brushless gear motor is more expensive than a worm gear motor and generally requires more advanced MCU's to operate them. The model our group had in mind is the **57BLR50-24-01-HG10** model brushless DC model with 24V 84W 350 RPM Geared Brushless DC Motor 1.89Nm(267.65oz.in). The brushless gear motor can support up to 20kg. The component is priced around average at $70-73 depending on the vendor.

Another possible alternative to the worm gear motor is the planetary gear motor. Planetary gear motors are more efficient, higher load capacity, better heat dissipation, and higher load capacity. On the other hand, planetary gear motors have louder noise, are more expensive, and harder to integrate with an MCU compared to the worm gear motor design. The model our group decided to research is the **PD1230-2.4-1024-F** with 2.4VDC 0.45A at 10rpm 0.09W.

Planetary gear motors use a combination of planetary gears and a sun gear to rotate the output load. Generally, planetary gear motors use spur motors for their planetary gears and sun gear. Spur gears have rolling surfaces, which allow for high torque and speeds due to their lack of friction and heat generation unlike worm gear motors. Spur motors also are highly efficient due to their rolling contact design, which reduces friction and allows for uniform motion between gears. However, one of the main drawbacks from a rolling contact design is the loud noise output due to their constant contact and vibration.

Name (model)	Cost	Rated Voltage	Torque (rated load)	Rated Speed
NFP-5840-36ZY-1280	Moderate ($30)	12V	3-100kg.cm	4.5-370 rpm
57BLR50-24-01-HG10	High ($71.24)	24V	19.27kg.cm	340-360 rpm
PD1230-2.4-1024-F	High($60.30)	2.4 V	1.99kg.cm	10rpm

Table 3H: Gear Motor Model Comparison

Passive Infrared Sensors

As discussed in the section earlier, for motion sensing technology, we are using PIR (passive infrared sensor). For this technology, there are multiple manufacturers that supply the parts. This section compares multiple aspects of parts produced by different manufacturers, such as, price, durability, energy efficiency, product specifications, and a little of brand reputation. Since not every manufacturer sells

through the same vendor, the following websites are used for the information: Digikey, Amazon, and Mouser Electronics.

I found three parts that are from different manufacturers on the internet that are most compatible with the project. The first part is the "**Miniature PIR Sensor**" from Mantech, it operates within a versatile DC voltage range of 2.7 to 12V, the sensor demonstrates energy efficiency with a minimal static power consumption of 0.1mA during standby. Configured in a repeatable trigger mode with a 2-second delay time, the PIR sensor swiftly responds to detected motion within its wide 100-degree cone angle sensing range, spanning 3 to 5 meters. Its robust operational temperature range from -20 to +60 °C ensures adaptability in diverse environments. The compact PCB dimensions of 10mm by 8mm enhance its versatility, facilitating seamless integration into electronic systems with space constraints. There aren't many details provided by the product's datasheet.

The second part is the "**HC-SR501 PIR Sensor**" from KuongShun Electronics,

It features three output pins - Vcc, Output, and Ground - it is compatible with various platforms such as Arduino, Raspberry Pi, PIC, ARM, 8051, etc., due to its 3.3V TTL logic output. The pinout configuration includes Vcc (input voltage, typically +5V), High/Low Output (Dout) providing a digital pulse high (3.3V) when triggered, and Ground, connected to the circuit's ground.

This PIR sensor has multiple features, including an input voltage range of 4.5V to 12V (with +5V recommended), a high/low output of 3.3V TTL logic, the ability to distinguish between object and human movement, two operating modes (Repeatable and Non-Repeatable), a coverage distance of approximately 120° and 7 meters, low power consumption at 65mA, and an operating temperature range from -20° to +80° Celsius.

To utilize the PIR motion sensor, power it within the voltage range of 4.5V to 20V (typically 5V). Allow the module to calibrate itself for a few minutes before observing the output on the Dout pin. The sensor operates in two modes: Repeatable(H) and Non-Repeatable(L). In Repeatable(H) mode, the output goes high when a person is detected and goes low after a set time, while in Non-Repeatable(L) mode, the output stays high as long as the person remains within the sensor's range.

The sensor is covered by crystal for detecting heat signatures from living organisms and Fresnel lenses to widen the detection range. The white lens is used in extending the sensor's coverage. Removing the lens reveals the pyroelectric sensor housed within a protective metal casing.

The third component is “**ZRE200GE**” from ZiLog. The electrical characteristics of the device are comprehensively outlined in the datasheet. The signal output is specified with a minimum of 2.5 VP-P and a typical value of 4.0 VP-P. The noise output is given a maximum of 250 mVP-P and a typical value of 90 mVP-P. The balance output, expressed as a percentage, has a maximum of 15%. The balance output (Bo) is calculated using the formula Bo = [(SA - SB) / (SA + SB)] x 100, where SA represents the absolute signal output on Element A, and SB represents the absolute signal output on Element B. The source voltage range is defined as 0.3 V to 1.4 V with Vd at 5V and Rs at 47K ohms. The operating voltage (Vd) range extends from 1 V to 15 V with Rs maintained at 47K ohms.

Moving to the optical and environmental characteristics, the datasheet delves into the device's visual and climatic aspects. Optically, it defines a generous field of view, spanning 138 degrees from the element center on axis X and 125 degrees on axis Y. The filter substrate is identified as silicon, and the cut-on wavelength (5%T ABS) is specified as 5.0 ±1.0 microns, with a transmissivity averaging ≥70% across the wavelength range of 8 to 13 microns. Shifting focus to environmental considerations, the device exhibits a robust operational temperature range from -20°C to +70°C. Simultaneously, the storage temperature can extend from -30°C to +80°C. Both operating and storage humidity conditions are defined as 95% relative humidity (RH) or less at 30°C.

In conclusion, the analysis of Passive Infrared Sensors (PIR) for motion sensing technology reveals three notable components. Mantech's "Miniature PIR Sensor" offers versatility in its DC voltage range but lacks detailed product information. KuongShun Electronics' "HC-SR501 PIR Sensor" stands out for its compatibility, features, and adaptability with crystal and Fresnel lenses. ZiLog's "ZRE200GE" excels in electrical characteristics, undergoing thorough testing. Each sensor's optical and environmental aspects are scrutinized for their suitability. This analysis helps in selecting the ideal PIR sensor for the motion sensing technology project, considering price, durability, energy efficiency, and specifications.

Considering the dimensions of the litter box, with a maximum allowable length of 30 inches, all three tested components demonstrate capability within this range. In terms of cost, all components are priced similarly, eliminating cost as a decisive factor. While "ZRE200GE" boasts the largest sensing range, the others also meet the project requirements. Regarding working voltage, "Miniature PIR Sensor" has the broadest range, although the MCU selection remains undecided. Ultimately, the decision to adopt the "HC-SR501 PIR Sensor" for motion sensing is based on a team member's hands-on experience with its physical prototype, offering confidence in its performance and reliability.

After testing the functionality of the “HC-SR501 PIR Sensor”. Due to its poor sensitivity and false feedback we decided to move to the “ e18-d80nk” IR Proximity Sensor. This sensor has the same pinouts as the “HC-SR501”, with a small change of polarity of the output signal. The advantage of using this sensor compared to the previous one is the accuracy, it has close to 100% of accuracy. However, the cons are it consumes higher current and the range of detection is much smaller. Although the cost of the “E19-D80NK” is more than triple of the motion sensor, the reliability and accuracy are weight more than the cost in applications of our project.

Name	Cost	Working Voltage	Sensing Range	Operating Temperature
Miniature PIR Sensor	Low ($1.69)	2.7V - 12V	≤100 degree cone angle, 3-5 meters	-20 - +60 °C
HC-SR501 PIR Sensor	Low($1.8)	4.5V - 12V	<110 ° cone angle	-15-+70 degrees
ZRE200GE	Moderate($2)	3 V - 15 V	138 degrees from center of element on axis X 125 degrees from center of element on axis Y	-20°C to +70°C
E18-D80NK	High($6)	5V	3 cm to 80 cm	-20°C to +70°C

Table 3I: PIR Parts Comparison

Mechanical Buttons

The chosen mechanical button for our project is the "**TS02-66-60-BK-260-LCR-D**" from CUI Devices. This selection is based on its cost-effectiveness and its ability to fulfill the criteria of providing both low and high states. The decision not to compare

across various manufacturers stems from the fact that similar capabilities and low costs are prevalent among the available options.

The specified mechanical button is designed to operate within a range of electrical and physical parameters. It is rated for a voltage input ranging from 1 to 12 Vdc, accommodating a variety of voltage requirements. The rated current spans from 0.01 to 50 mA, ensuring compatibility with a wide range of electrical systems. Additionally, it is capable of withstanding a voltage of 250 Vac for one minute, providing a measure of electrical resilience.

Parameters	Conditions/Descriptions	Min	Max	Units
Rated Voltage		1	12	Vdc
Rate Current		0.01	50	mA
Withstand Voltage	For 1 min		250	Vac

Table 3J: Mechanical Button Specifications

Rocker Switch

The rocker switch that is used for this project is the "**RA1113112R**" from manufacturer "E-Switch". This switch boasts a high rating of 16A at 125VAC (cULus), making it suitable for various electrical requirements. To ensure protection against environmental elements, it is equipped with a PVC cap, providing effective shielding against dust and water. Similar to the button, this part is inexpensive and excessive features are not required for the application. Therefore, no comparison is required among different manufacturers.

Strain Gauge Weight Sensors

Strain Gauge Weight Sensors are the type of sensor that we used in our Purrfect Litter automatic cat litter box. This was explained earlier in the "**Weight Sensing Technology**" section of this report, but a quick summary is that Strain Gauge is the most commercially used type of weight sensor because of its accuracy and

affordability. This section goes over the different Strain Gauge sensors from different manufacturers to determine which one is best suited for our system.

We looked at three strain gauge weight sensors from different manufacturers for comparison. The first one is a strain gauge weight sensor from NEXTION. The weight sensors read up to a maximum weight of 50kg, or around 110 pounds and operate within 3.3-5V. It is made out of a polycarbonate material with an operating temperature of -10-+50°C, or 14-122°F and an accuracy class of C2 meaning a plus minus 0.03% measurements.

The specifications on this product with its price is why we considered it, while most average healthy cats only weigh 8-12 pounds, and an overweight one being 13-15 lbs, the large sensing range is to accommodate the weight of both the container itself with the cat poured into it and the cat itself present in the litter. Next, the operating temperature covers plenty of ground for what a normal household climate would be like, typically having a temperature of 65-73°F depending on where you live, so this specification is well within our parameters.

The next part is a load cell strain gauge weight sensor from Seeed Studio.The form factor for this sensor is more elongated than the one from NEXTION and only comes with one load cell rather than four, so it would not be used the same way as the NEXTION sensor. The rated weight limit is 50kg/110lbs with an excitation voltage of 10-15V and an operating temperature of -35-80°C/-31-176°F. Accuracy of class C2, plus minus 0.03% measurements and the sensor is made out of Aluminum.

The main difference between the sensor from Seeed Studio and NEXTION is the form factor. Seeed Studio uses an elongated rectangle form, while NEXTION uses four smaller sensors that were meant to be used on the corners of a container. The increase in operating voltage can be due to the load cell for Seeed Studio being just one cell, while NEXTION uses four, meaning all the measurements of the sensor come from one source instead of four. The Seeed Studio sensor has a much larger operating temperature, possibly due to the material it is made out of. The sensor fits the criteria we are trying to meet for our system for 10% more of a price than the NEXTION sensor, while the price increase is justified due to the increase in operating voltage and quality of material, it does not mean that it is the best choice for our system.

The last part we analyzed is the Load Cell Weighing Sensor from ShangHJ. Like the sensor from NEXTION it uses a rectangular form factor with four units for each corner of the container, and it also comes with rubber grommets attached to act as the feet for placing the container on the ground. It measures weight up to 50kg/110lbs with an operating voltage of 5-10VDC and operates in the range of -10-40°C/14-104°F with an accuracy measurement of plus or minus 0.3%.

The price for this sensor is more expensive than the two previous sensors we looked at, and it may be due to the inclusion of the rubber grommets on the sensor. While it is a nice addition, our system may not need these grommets as the container would have to be built around them, rather than us creating our own form of solution. The 44% increase in price versus the similar NEXTION model is also not appealing when considering the NEXTION model has a slightly higher operating temperature at a lower voltage rating, and certainly not when compared with the model from Seeed Tech where for 23% less cost we gain more than double the operating temperature with the same sensing range.

For our choice of sensor it comes down to choosing between Seed Tech and NEXTION. The model from ShangHJ, while meeting our system parameters, does not justify the 33-44% price increase versus the competitors for the inclusion of a rubber grommet and the lowest operating temperature. Between the two remaining sensors, our choice would have to be the one from NEXTION. It is the cheaper of the two options, has a lower working voltage range, and has the same sensing range as the one from Seeed Tech. While the sensor from Seeed Tech has a much higher operating temperature it is unlikely that our system ever comes across such extreme temperature variations in its life cycle, and the sensor from NEXTION still meets our criteria for operating in simple home environments.

Name	Cost	Working Voltage	Sensing Range	Operating Temperature
NEXTION Strain Gauge Weight Sensor x4	($8.99)	3.3V - 5V	<50kg	-10 - +50 °C
Seeed Tech Load Cell	($9.95)	10V - 15V	<50kg	-35 - +80 °C
ShangHJ Load Cell Weighing Sensor	($12.99)	5V - 10V	<50kg	-10 - +40 °C

Table 3K: Weight Sensor Model Comparison

MCU

In order to manage and control all the different sensors, the motor, and any other peripherals on our system we need an MCU. The MCU is where we upload our code to,

and be the center to where communication between every part in the system communicates. This section goes over different MCU from different manufacturers. Their differences, similarities, upgrades, and downgrades are compared with one another to determine which MCU is best for our application.

The first MCU is the MSP430FR6989 from Texas Instruments, a reputable brand and highly interactive component that we have seen before. It features an up to 16MHz frequency with a supply voltage of 1.8-3.6V operating in temperatures of -40-85°C, and capabilities for ultra-low power modes for applications that would see substantial downtime. Has 128KB of Volatile Ferroelectric low power RAM with fast write speeds of 125 nanoseconds per word, and multiple multifunctions I/O pins with built in capacitive touch support. A built in 32 KHz crystal for low frequency timings, a built in low power low frequency clock source, and a high frequency crystal source. It has support for enhanced serial communication and code security and encryption, including UART with automatic baud rate detection, I^2C with multiple-slave addressing, and SPI for serial communication. For code security and encryption, it uses 128-Bit or 256-Bit AES Security Encryption and Decryption Coprocessor. Finally, the MSP430 supports the coding for C using the platform with the Code Composer Studio application to write code directly into the MSP430.

The MSP430 boasts a multitude of different features, although not all of them are needed for our system, the ones we do need are present. The 32KHz crystal is useful for keeping track of time in our system to schedule routine sweeps for the motor. Security features can be used to prevent malicious people from trying to cause problems with the system should we use an app feature, and a low power mode for when the system is idle for long periods of time. Finally, the multiple input/output pins with fast memory can allow for a fast and responsive system with capabilities for multiple peripherals.

The next MCU to look at is the ATMega328PB Microcontroller, this model is typically found on developer boards such as the Arduino Uno. It is an low power 8-Bit microcontroller with Advanced RISC Architecture that features 32x8 working registers with up to 20 Million Instructions Per Second (MIPS) throughput at 20MHz. It has high endurance non-volatile memory, 32 KB of In-System Self-Programmable Flash program memory, 1KB of EEPROM, 2KB of internal SRAM, and has programming lock for software security. It has a Peripheral Touch Controller (PTC) that supports capacitive touch buttons, sliders, and wheels, two 8-bit timers/counters, three 16-bit timers/counters, ten PWM channels, and an 8-channel 10-bit Analog to Digital Converter (ADC). It has support for features such as UART with two programmable serial USARTs, SPI with two master/slave serial SPI serial interfaces, and I^2C with a two byte-oriented two-wire serial interface. It has 27 programmable input/output lines,

operates at a voltage of 1.8-5.5V in temperatures between -40-105°C, and has a power-save mode that draws as low as 1.3μA.

The ATMega, like the MSP430, has multiple interesting features that makes it a compelling MCU to choose from. It has features that we are looking for, fast memory for a responsive system, support for multiple I/O devices, low power mode for long idle sections of times in the day, a timer for scheduling the motor sweeps, and it also prefers the C coding platform. Our choice to choose the ATMega328P came down to price to performance, and the chip we know about and have used in the past can lead to ease of use.

The last MCU to look at would be the RP2040 MCU from Raspberry Pi, a Dual-Arm Cortex-M0+ MCU that operates at 133MHz frequency. It has 264kB of on-chip SRAM, and support for up to 16MB of off-chip flash memory via dedicated QSPI bus. It has a Direct Memory Access (DMA) controller, a fully connected Advanced High Performance-Bus (AHB) crossbar, and an interpolator and integer divider. On chip programmable LDO for generating core voltage, two on chip PLLs to generate USB and core clocks, and 30 I/O pins in which four can be used as analogue inputs as well as an internal temperature sensor that must be user calibrated. The RP2040 also has support for peripheral connections through two UARTS, two SPI controllers, two I^2C controllers, 16 PWM channels, USB 1.1 controller and a Physical Layer (PHY), or 8 PIO state machines. The MCU is a two core CPU that operates at a voltage of 1.8-3.3V and temperature of -40-85°C, and uses the C/C++ development platform or MicroPython environment.

MCU Name	Cost	Working Voltage	Operating Temperature	# Of I/O Support	Memory
MSP430FR6989	($6.50)	1.8V - 3.6V	-40 - +85 °C	12	128KB LPRAM
ATMega328P	($1.63)	1.8V - 5.5V	-40 - +105 °C	27	1KB EEPROM, 2KB SRAM, 32KB Flash
RP2040	($5.99)	1.8V - 3.3V	-40 - +85 °C	30	264KB SRAM

Table 3L: MCU Model Comparison

The RP2040 is an interesting MCU that makes it a compelling choice to choose from. It has features that we are looking for, support for multiple I/O devices, low standby current for long idle section applications, a timer for scheduling the motor sweeps, and it also prefers the C/C++ coding platform. But as said before, our choice for MCU for our system is the ATMega328P.

USB-C Power Supply

To select the device's power supply, it is necessary to calculate the total power dissipated by all peripherals, including the MCU. The primary power-consuming component is the gear motor, which assumes a load of 3 lbs. The power dissipation for the motors can be obtained from the table presented below.

Ratio	No Load		Rated Load			Stall	
i : 1	Speed	Current	Speed	Current	Torque	Torque	Current
40	150rpm	0.10A	100rpm	0.4A	1.2kg.cm	4kg.cm	1.8A
65	90rpm	0.10A	70rpm	0.4A	2kg.cm	6kg.cm	1.8A
87	68rpm	0.10A	51rpm	0.4A	2.8kg.cm	8kg.cm	1.8A
150	40rpm	0.10A	30rpm	0.4A	4.5kg.cm	15kg.cm	1.8A
200	30rpm	0.10A	22rpm	0.4A	6kg.cm	20kg.cm	1.8A
260	23rpm	0.10A	17rpm	0.4A	8kg.cm	26kg.cm	1.8A
340	18rpm	0.10A	13rpm	0.4A	12kg.cm	34kg.cm	1.8A
448	13rpm	0.10A	10rpm	0.4A	13kg.cm	40kg.cm	1.8A
600	10rpm	0.10A	7rpm	0.4A	17kg.cm	54kg.cm	1.8A
1,000	6rpm	0.10A	4rpm	0.4A	25kg.cm	91kg.cm	1.8A
1,800	3.3rpm	0.10A	2.5rpm	0.4A	25kg.cm	91kg.cm	1.8A
3,000	2rpm	0.10A	1.5rpm	0.4A	25kg.cm	91kg.cm	1.8A

Table 3M: Worm Gear Specifications

The specs that are used are the 150:1 ratio, 6VDC, with 0.4 A of current. With these specifications, the motor runs at a speed of 40 rpm with no load, and 30 rpm rated load. The power dissipated by the motor is 6*0.4 = 2.4 watts.

The HC-SR501 PIR Sensor operates within a supply voltage range of 5 to 20 volts, with a current consumption of 65mA, resulting in a power dissipation ranging from 0.32W to 1.3W. The MSP430FR6989 consumes 0.35 watts, while the NEXTION Strain Gauge Weight Sensor requires a supply voltage between 2.5V and 6.5V. Negligible energy consumption is observed for the two buttons. Considering all peripherals and the microcontroller, the recommended power supply capacity is approximately 4.5 watts.

Given the minimum power consumption of 4.5 watts, the optimal configuration for the AC-DC converter is 10 watts. There are multiple products on the market that meet this

requirement, in this section, 3 products are compared in this section. The safety protocol, pricing, compatibility, and voltage/current ratings aspect have been evaluated.

The first product is the “USB-C Cube Wall Charging Power Adapter” from BSTOEM. This lightweight charger is equipped with a built-in multiple protection system, safeguarding against over-voltage, over-charging, and overheating. The high-quality smart chip automatically turns off when your iPhone is fully charged for extra convenience. Crafted for global travelers, this charger boasts international voltage compatibility (100-240V) and is made from durable ABS material. Supporting 12W fast charging for iPhone 8 models and above, it delivers a speedy charge, taking just 40 minutes to power your iPhone from 15% to 50%, twice as fast as the original cable.

Enhancing its specifications, the charger features an output voltage of 5V/2.4A, providing optimal power for your device. Additionally, it incorporates EMI protection, ensuring a smooth and interference-free charging experience. Elevate your charging game with our compact and efficient Safe Portable Charger—designed for safety, convenience, and global compatibility.

The second product compared is the “Mini Type C Phone Wall Charger Fast Charging Blocks Power Adapter” from AGTRAY. This product also has similar features to the product described above. With a rapid charging speed of up to 5V/2.4A max, it's 2.5 times faster than the traditional 5W charger, reaching 0% to 50% for iPhones in about 35 minutes. The Portable Small Travel Plug, weighing just 1.13oz, is perfect for travel or business trips and conveniently fits into your pocket or backpack. Equipped with a comprehensive protection system, it safeguards against over-charging, over-heating, and more. This USB-C charger is compatible with a wide range of devices.

The third product is the “USB C Charger Block 20W” from Ocupwei. Ocupwei presents a high-speed charging solution with its 20W PD 3.0 USB Type C Fast Charger Block. Featuring PD 3.0 Quick-Charge technology, the USB C port delivers a maximum output of 20W, allowing your iPhone to reach 50% battery in just 30 minutes. The charger ensures universal compatibility, seamlessly working with a wide range of devices, eliminating compatibility issues.

Prioritizing safety, the Ocupwei Type C Wall Charger is certified with ETL(US), FCC, CE, and ROHS, conforming to U.S. and global electrical standards. The AI-controlled chip intelligently adjusts the output power (5V/1A to 9V/2.2A) based on your device's requirements, ensuring safe and efficient charging while protecting the battery. Compact and lightweight, this charging brick is designed for travel convenience.

Name	Cost	Output Voltage	Output Current	Wattage
BSTOEM	$4.00	5 volts	2.4 amps	12 watts
AGTRAY	$4.25	5 volts	2.4 amps	12 watts
Ocupwei	$4.50	5 volts/ 9 volts	1 amps/ 2.2 amps	5 watts/ 20 watts

Table 3N: AC-DC Converter Block Comparison

Internet Adapters

Since we are planning on making an application that would track the weight of the waste in the case that the waste container is full and track the weight of the cat as well each time it enters the container it is necessary to have an internet connection. To make this possible, we looked into various internet adapters on the market with different designs and features that would work best with our Purrfect Cleaner. The types of internet adapters that were considered were the wireless and wired internet adapters that were listed on the websites Amazon and Best Buy.

When choosing suitable internet adapters for our product, the main specifications that we decided would be necessary for the internet adapter to be implemented effectively in our product were the maximum transfer speeds, the design in terms of weight and size, and the ports being used. The maximum transfer speed has to be high enough so that the user is able to receive information from the Purrfect cleaner in an appropriate amount of time. The design must be small and lightweight since it is going to be placed along with the PCB and must fit inside our perfect cleaner so that it wouldn't be exposed to any possible damage outside. The type of USB port is important as well since USB types can have different data transfer speeds and how they affect the strength of the Wi-Fi connection to the device.

The first internet adapter was found on the website Amazon. It is a wireless adapter that uses Bluetooth and is made by a brand called Auscoumer. It uses a USB type A port that follows standard 2.0. It is a two in one internet adapter where it can connect a device to the Wi-Fi but can also connect the device to another through Bluetooth using the double built in antennas. It has a maximum data transfer rate of 600 Mbps and its built-in chip called the RTL8821CU can offer speeds up to 2.4 GHz, which is optimal for general web surfing and communicating online. The dimensions of the wireless internet adapter is 0.6 inches for the length, 0.3 inches for the width and 1.3 inches for

the height and the total weight of the adapter is 13 grams. This is good since the adapter would not take up any unnecessary space while being connected to the PCB.

Even with some of the advantages that this type of internet adapter provides, there can be some disadvantages as well. One of them can be that since it is wireless, the Wi-Fi connection can be weaker when compared to adapters that are wired with ethernet ports. This can be an issue if the user would be a good distance away from the Purrfect cleaner and when logging into the application and viewing the tracked data it could take a while for it to load and update consistently. The other disadvantage would be the transfer speed since it uses the USB type A model its transfer speed can be on the lower end compared to other possible choices but even if that is the case it would still work well with our app with that speed since we are only tracking the weight of that cat and waste in the container.

The next internet adapter is a wired internet adapter from Amazon as well. It has two ports that are a USB type C port and an ethernet port and is made by the brand called uni. It has a max transfer rate of 1 Gbps and to be able to utilize the maximum speed, CAT 6 and up ethernet cables must be used. It is also downward compatible with networks that have speeds of 100 Mbps/10Mbps which is good since most standard households have Wi-Fi services where that would be their maximum transfer speed. The dimensions of the internet adapter is 5.92 inches for the length, 2.36 inches for the width, and 0.67 inches for the height and the total weight is 36.3 grams. The wire connecting the USB type C port is braided with nylon cable to make it more durable and less prone to tear. These design features are very beneficial since as discussed above with the main specifications, the design would have to be small and compact enough to not interfere with the other components of the Purrfect cleaner.

There are still some disadvantages that this wired internet adapter can face. One of them is that when compared to the wireless version it is considerably wider and longer in size. Not having as much as a compact design. It also requires an ethernet cable to connect to the port in order to get a stronger internet connection where the wireless version does not require one but still has a viable connection.

Lastly the final internet adapter considered was Best Buy essentials BE-PA3U6E to Ethernet adapter. This is also a wired adapter with a USB type A port that follows the standard 3.0 but can be backwards compatible with ports following standard 2.0. Its maximum transfer speed is also 1 Gbps but can still support networks that have speeds from 10 Mbps to 100 Mbps. The Ethernet cable type needed to use this adapter is cat 5 in order to be able to get up to the maximum speed when using it. On Best Buy's website, it does not provide the dimensions of the adapter but looking through the pictures provided by the company and users who have bought the product, it seems that it would be similar in size to the wired internet adapter from Amazon.

This adapter also has some disadvantages which could be that since the size is similar to the previous wired adapter mentioned above, it would be considerably larger than the wireless adapter from Amazon. Unlike the previous wired adapter, the wire connected to the adapter and USB type A port is not braided with nylon cable or any other durable cable. This would make it more likely for the wire to get easily bent which would cause a disruption in the connection of the wiring as well as increasing the probability of tearing.

Name	Cost	Max Data Transfer Speed	USB Standard	Ethernet cable
USB Wifi Bluetooth Adapter	$17.99	600 Mbps	Standard 2.0	N/A
USB C to Ethernet Adapter	$17.99	1 Gbps	Standard 3.0	Cat 6 and up
Best Buy Essentials USB to Ethernet Adapter	$12.99	1 Gbps	Standard 3.0 and 2.0	Cat 5

Table 3O: Wireless/Wired Internet Adapter Comparison

PCB Assembly Vendors

This section details the different vendors in which we can order our PCB assembly for this project. PCB vendors allow us to create a PCB schematic of the system we wish to create, and send it to the vendor for order, in which they take the schematic and make an entire circuit board that matches exactly how we laid our components. Vendors are very efficient at creating these boards at reasonable prices, which saves us a lot of time from having to personally solder every single component onto a board ourselves. This leaves us time to test our prototype of the system even more, as to ensure that the schematic we send to the vendor matches how we set up the working prototype. We looked at three separate PCB vendors in this section: JLCpcb, AAPCB, and SFCircuits. Each one offers varying quotes depending on the level of complexity of the PCB design.

JLCpcb is our main choice for the PCB assembly vendor, it is a reputable company that has quick delivery times for the assembly, which is a good quality in case something catastrophic happens to a previously ordered board. They have a build time of 24 hours, and a delivery time of 7 regular days, not business days. Its pricing is relatively fair, starting at a cost of $8 for an assembly of up to five components, and then an additional $8 for every five extra components. For example, a PCB assembly consisting of six components priced at $16 before tax. However, they do have a quoting system that allows you to submit your PCB schematic ahead of time and receive the true price. JLCpcb is also a recommended assembly vendor by the PCB software we use in our project, EasyEDA. Not only is it recommended by the software, but a previous graduate from UCF, Jimmy Kessler who now works for Burns &

Mcdonnell, recommended the vendor to us directly, saying how it was very useful to have a vendor that works as quickly as they do. We had not known about many PCB vendors before starting this project, but as we went, many classmates and a co-worker had recommended this vendor, which influenced our decision to choose it for the high publicity.

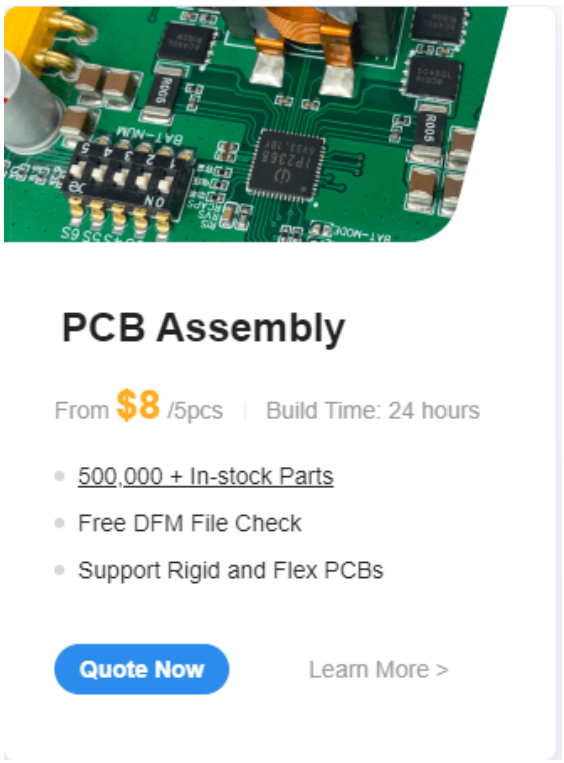

Figure 3A: JLCpcb Assembly Pricing

The following vendor we looked at is Advanced Assembly PCB, a PCB assembly vendor based in the United States. Unlike JLC we did not receive much publicity from this vendor, however, it does not mean we shouldn't consider other manufacturers to determine their competitiveness. Similar to JLC, they offer a quote on the PCB you wish to order by submitting the schematic into their system, allowing us to know the true price, but they do not have an average estimate that JLCpcb has that's shown in **FIgure 8I**. They do have flexible turn-time for building and delivering the PCB to us, this means that we can choose what day we wish to receive the PCB, and AAPCB created and delivered it by that day. Of course there are limits to AAPCB turn times, and the shortest amount of time you can have a PCB built and delivered to you is three days, much shorter than the seven days for JLCpcb, but of course the shorter the time, the higher the cost.

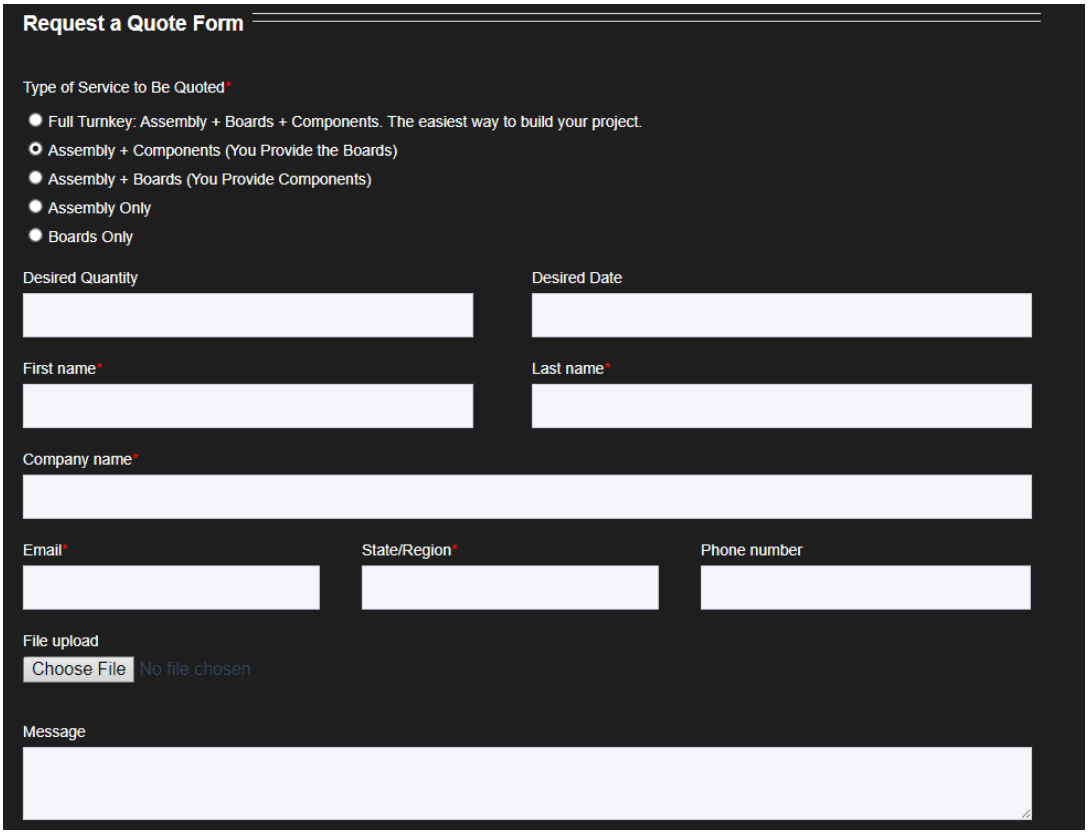

Figure 3B: AAPCB Quote Form

The last vendor we looked at in this section is San Francisco Circuits, which in the name are based in San Francisco, USA. Similar to AAPCB, SFCircuits requires the PCB schematic to get a quote on how much your PCB would cost, there is also no estimated cost like how JLCpcb has on their descriptions. Build time and turn-in times for SFCircuits varies based on the complexity of the PCB that is being ordered. Build times can range from one to five days, as well as turn in times and be as low as one day and as high as five days. SFCircuits claims that it is flexible in both aspects to fit the needs of the consumer. They also list specifically what their capabilities are when it comes to PCB assembly, which is shown in **Figure 8K** below. It gives details on how they would test certain PCBs for ensuring quality control of their products.

Capabilities	Testing Services
Small, medium, and high volume PCB assembly	X-Ray (2-D and 3-D)
Surface Mount Technology / Parts (SMT Assembly)	BGA X-Ray Inspection
Double-sided SMT	AOI Testing (Automated Optical Inspection)
Standard lead & lead-free builds (RoHS compliant)	ICT Testing (In-Circuit Testing)
Through-Hole Device / Parts (THD)	Functional Testing (at the board & system level)
Mixed Parts: SMT & THD assembly	Flying Probe
BGA / Micro BGA / uBGA/td>	
QFN, POP & lead-less chips/td>	**Rework**
2800 pin-count BGA	BGA Rework & Repair
0201 resistors / 1005 passive components	Engineering Rework
0.3 / 0.4 Pitch	BGA Reballing
PoP Package	Board Debugging & Repair
Flip-chip under-filled CCGA	
BGA Interposer / Stack-up and more…	
High speed component placement with X-Ray verification	
Supply chain management	

Figure 3C: SFCircuits Testing Capabilities

The three vendors discussed in this section have the same goal, deliver a high quality, error free PCB for the consumers testing, prototyping, or use for a project. Each one gives different variables for how they price, how they deliver, and how they ensure quality in their PCBs. Our choice for JLCpcb came down to high publicity and referrals from current students, and past students who graduated from UCF, as well as clear descriptions of how the process works, and their support for the software we use for PCB design.

Chapter 4: Standards and Design Constraints

In this chapter, we researched many different relevant standards that we abided by while working on our project. We understand that standards are extremely important when building and designing a product that would be sold on the market. There are many guidelines and requirements to ensure that products are reliable, safe to use, and efficient in what they can offer to the buyer. We have mentioned standards on both the hardware and software parts of our project to make sure that the major parts of our product follows these standards during the construction process in Senior Design 2. It is also important to address the possible constraints that we had to face later in the future, where we would discuss possible solutions to overcome these obstacles.

IEEE Paper Format

The final report that is due at the end of Senior Design 2 is going to follow the IEEE Conference Paper format.

USB-C Standards

USB-C, short for USB Type-C, is a modern and versatile connectivity standard designed to simplify device connections. Its reversible connector eliminates the frustration of plugging in the wrong way, offering a user-friendly experience. USB-C supports rapid data transfer speeds, reaching up to 40 Gbps with Thunderbolt 3, and provides a single-cable solution for charging, data transfer, and video output. Its compact and slim design allows for thinner and lighter device profiles, contributing to the sleek designs of modern laptops, smartphones, and other gadgets.

One of USB-C's standout features is Power Delivery, enabling the transfer of higher power levels. This makes USB-C not only suitable for charging smartphones and tablets but also powerful enough for laptops and other energy-demanding devices. As USB-C gains widespread adoption across a variety of devices, it has become a universal standard.

American Power Standards

Most of the world population (Europe, Africa, Asia, and much of South America) use a supply that is within 6% of 230 V. The American power standard follows a system characterized by a voltage of 120 volts and a frequency of 60 hertz. This standard, commonly referred to as 120V/60Hz, is used throughout North America, including the United States, Canada, and some parts of Central and South America. The electrical outlets in the U.S. typically feature a Type A or Type B configuration, with a standard voltage suitable for powering household appliances, electronic devices, and industrial equipment. The standard is well-established,ensuring compatibility in the electrical

infrastructure across the region. This device's power supply follows the American Power Standards.

Ingress Protection Classifications

IP (Ingress Protection) is a standardized system that defines the degree of protection provided by enclosures against the intrusion of solid objects and liquids. The IP rating is represented by two digits. The first digit indicates the level of protection against solid objects, ranging from 0 (no protection) to 6 (dust-tight). The second digit signifies the level of protection against liquids, with a scale from 0 (no protection) to 9K (protection against high-pressure, high-temperature water jets). For this device, the Printed Circuit Board is going to be covered by plastic and placed on the side of the litter box. There is a 2 centimeter gap between the cover and the litter box. In the case of this device, the Printed Circuit Board is shielded with plastic and positioned on the side of the litter box. There is a 2 centimeter gap separating the cover and the litter box. According to Ingress Protection guidelines, the solid object protection is rated at level 2. Regarding liquid protection, as the top and sides are partially covered by plastic, the IP rating is determined to be **IP22**.

Network Protocol Standards

Network protocols are a set of rules, methods, and regulations made to help regulate the transmission of data packets from one network to another on the internet. The main problems network protocol regulations try to address and prevent are that all data packets are delivered properly and that they arrive at the proper destination.

Data packets are separated pieces of much larger data that are condensed to be sent across the internet and are then reunited to their original combined state once they reach their destination. The reason as to why they are cut down into pieces during transmission is that it would be impractical to send the data fully as it is because when involving two or more devices each device would have to wait until the current device sending the data would finish its transmission resulting in a slow process. That's why the process called packet switching was made to replace this impractical method. Packet switching is when data packets from different computers can take multiple paths to get to their destination. It has been the standard method for sending data packages on the internet and is used by many devices currently.

Data packets have headers which are labels that have descriptions about where it was sent, where it is going, and information about its contents. These headers are useful since they can be headers specifically for a certain type of protocol in order to guarantee that the packages were sent in the correct order and place if necessary.

These headers can be registered to different protocols such as the IP protocol and the Transmission Control Protocol.

IPv4 Protocol

The IP protocol is a type of network protocol that primarily uses the source IP address and the destination's IP address to deliver the packages across the internet. There are different versions of the IP protocol that are used currently today, they are called IPv4 and IPv6. The IPv4 protocol has the packets have an IP address of 32-bits with four sections and contains two important parts called the network prefix and the host number. As a result of the 32-bits making up the IP address the IPv4 protocol uses an addressing system based on the classes A, B, and C. Where each class would use different bytes in the IP address to represent the host number and network prefix. The protocol also uses subnetting which is when a large network is broken down into smaller networks to minimize the drawbacks and limitations of only using one large network. These smaller networks would be based on the classes as discussed before where they would contain an interface that contains a network number and an identifying network address.

IPv6 Protocol

The IPv6 protocol is similar to IPv4 where it is mostly used with the Internet. What makes it different from the IPv4 protocol is that it supports an upgraded system for the header and the security of the data packets. To go more in depth, IPv6 offers a modified and more simple header for the packets, more mandatory data security, and more support for mobile devices. The protocol requires the IP address to have 128-bits and supports a new address type called anycast where the data packets are transported to the closest node in sub networks.

Transmission Control Protocol

The next network protocol is called the Transmission Control Protocol. It deals with maintaining the transportation of messages between users on the internet. Same as the IP protocol it transports the original data into smaller data packages to the right destination using its headers information on the destination's IP address. The main difference is that this protocol orders the data packets in the right order when they reach their destination while the internet protocol doesn't care to make sure it is in the right order. The protocol has a unique segment numbering system that assigns a number for each segment of data being delivered to keep track of positions. It also has other features such as flow control to ensure that the data is transported properly with none of the data being lost and not delivered and as well as error control where each segment goes through error detection to see if any corruption exists in the data.

The transmission control protocol is also a model along with the IP protocol that is made of four layers. The four layers are the network layer, internet layer, transport layer, and application layer. Each of these layers are responsible for different parts of the process of delivering data packages across the internet that would go hand in hand with the transmission control protocol.

The internet layer is responsible for managing all protocols that deal with transporting data packets throughout the internet. The various protocols used in the network layer consist of many ways of transporting these data packets via the IP address or working around the issues during the transportation. Some of these protocols included in the network layer are the IP protocol, ICMP protocol, and the ARP protocol. The ICMP protocol stands for the Internet Control Message protocol, its main purpose is to send information about network issues to the hosts. The ARP protocol stands for the Address Resolution Protocol, it deals with using an IP address to find the hardware address of a host.

The next layer is the transportation layer. Similarly to the network layer, it is responsible for protocols that deal with delivering data through the internet, but its main focus is on whether the data has reached its destination and without having many errors along the way. As a result the protocols it contains deal with maintaining an organized system when sending data. Some of these protocols are the TCP protocol and the less reliable the UDP protocol which stands for the User Datagram Protocol. This protocol doesn't require a connection inorder to send data which could cause some data to be lost, but it does have a faster transfer speed than the TCP protocol.

The network access layer contains protocols that are responsible for defining how data packets should be sent. The protocols focus on transmissions between two devices and contain IP datagrams into frames to be sent. One of the protocols that can be found in this layer is the token ring protocol. It is normally used in an LAN network where it decides the direction of which the stations or monitors send the frames to.

The last layer is the Application layer. Unlike the other layer, this layer can directly interact with users. This is because it focuses on end to end communication, which means the process of sending information from the sender to the receiver. Protocols that can be found in this layer are the HTTP protocol and the SMTP protocol which are discussed in more detail below.

Simple Mail Transfer Protocol

The other protocol is called the Simple Mail Transfer Protocol. It is a protocol that is responsible for the regulation of emails transmitted on the internet. Its primary goal is to deliver the mail to the recipient, it doesn't deal with receiving mail from others. In order to get an email delivered successfully, a connection must be opened along with the

Transmission Control Protocol and then the email is then sent to the internet and similar to data packages it has its own email header with the appropriate information on the IP address of the sender/receiver, the body of email, and the subject line. Next the email is then checked by the Mail Transfer Agent that checks if the sender's domain is the same as the receiver's. If it is not the same as the sender's, then a request is sent to the Domain Name System to get the receiver's IP address in order to send the email. After that the connection is closed after the email is sent.

HyperText Transfer Protocol

The last network protocol is the HyperText Transfer Protocol. This protocol is an application layer protocol that deals with loading web pages through HyperText links and requests. How the HTTP requests work is by asking the web application for information needed to load the webpage on the internet.

The typical information requested are the HTTP version type, a URL HTTP method, HTTP request header, and a HTTP body if needed. The HTTP method is basically a key word that dictates what action needs to be carried out by the server. Some of the key words that can be found in an HTTP method are GET, HEAD, POST, and DELETE. Where the GET keyword deals with retrieve data from the server, HEAD is the same as GET but doesn't require a response body along with the transmitted data, POST deals with transferring data from the web page to server inputted by the user, for example usernames/passwords, and the DELETE keyword deals with the deleting the information specified on the webpage as well as in the server database.

The HTTP request and response headers hold information regarding the type of data it accepts/requests and the data it contains. Some examples of the request and response headers are the authority header which has the client credentials which can be used to determine if the client has the proper authority to access protected server data, the HTTP method which was mentioned previously, the content type response header which details what type of data the server sends to the webpage, for example application/json or text/html, and the content type head which is the same as the content response header but deals with specifying the type of date being sent to the server to limit any errors happening when the server processes the information. It also contains the status codes which are codes made of 3 digits that determine whether a request or response was accepted or transmitted successfully. The type of codes that can be returned are '200 ok' which states that the request was successfully sent and the '404 NOT FOUND' code for the response header indicates that the server couldn't find the webpage to send the data from the server.

When using HTTP headers, there are methods that should be used when trying to implement them properly to avoid mistakes that can cause requests to fail and not go through. One of them is to not use plain text headers that may contain sensitive

information. Headers are liable to cyber attacks and can be easily accessed by bad actors so it would be safe to exclude security information like passwords and keys.

Access Control Standards

Access control standards are one of the integral rules to be followed when creating a software application. User's privacy is a major priority and there needs to be rules and regulations to make sure that the user's data is secure and cannot be accessed by unauthorized users. There are many different ways of ensuring the security of that data which are used by many applications and websites currently today. The Authentication Authorization, and Accounting from Identity and Access Framework has some standards that all organizations must follow on their software applications that regards user security, privileges, and account usages.

Authentication Standard

Some of the methods regarding authentication is for each user to have their own unique user Identification number and going through multi-factor authorization with at least 2 methods. What multi-factor authentication can consist of is having a code sent to the user via a text message or email and then having them type in the code. The other method is to have the user use a separate application to confirm their identity and allow the user to access their account after confirmation. Once a user creates their own account to access all the features of the software application, they must create a unique username and password. Then an identification number is created only for that user and for any information that relates to them when inputting or receiving data when they use the application. That user ID is also used in the software's database to organize all user data separately so that no user can access another user's information without permission. It is also important for the case that if a user were to delete their account, that their identification number would be deleted as well along with the data stored in relation to that account.

Authorization Standard

The next method called authorization is the managing of the number of privileges a user has when they create an account or upgrade to a new plan. It is standard for users that make an account to have the standard CRUD operations. CRUD stands for Create, Read, Update, and Delete and these would be standard privileges that users have to manipulate their data. The CRUD operations would also be linked to the user's identification number so that they have access to only their data and not anyone else's. The CRUD operations for some software can be limited if the software application has a standard plan with a limited number of create and delete options. In that case there would be upgrades for the account, there needs to be a method to grant more

privileges for the user and when they decide to not pay for the upgrade anymore then the additional privileges must be taken away.

Accounting Standard

Lastly, the final method is about monitoring user's account usage. This method involves looking at when the user of the account logs in/out and what actions they partake when accessing the account. By looking at these data, it would highlight any suspicious activity taking place on the accounts as well as to see if the owner of the account hasn't been online for some time. If there was any suspicious activity, then the account would be locked, and the account holder would be notified to change their password. For the case if the account hasn't been active for some time, the account can be deleted. It would depend on the company's policy for the amount of time required to approve the termination of the account, some may range from 90-day to 2 years.

Wi-Fi Standard

With information being sent across the internet with the use of a dependable Wi-Fi connection, there were standards created to ensure stability, fast transmission rates, and longer connectivity ranges. There have been many standards across the years since the year of 1997 to 2021 which contributed to new enhancements for Wi-Fi features. The latest Wi-Fi standard is an iteration of the IEEE 802.11 that is called the IEEE 802.11ax™ or Wi-Fi 6. Wi-Fi 6 has a theoretical data transfer rate of 9.6 Gbits/s and lists many systems to improve the range and strength of Wi-Fi connectivity. Why they provide these many systems is to express the importance of making sure the Wi-Fi is strong and consistent when in large public areas such as stadiums and public transports in order to avoid the possibilities of connection failure or slow loading time. The other system provided by this standard is a multi- user mechanism that allows the transfer rate to be split between multiple devices to be able to schedule transmissions between routers. As a result, providing more support for the use of Wi-Fi in much larger environments.

Authentication Constraints

In regard to the app we are planning to create for our Purrfect Cleaner, we do understand that security is important for our application. Each user's data about their cat, cleaner, and personal information must be protected in order to prevent bad actors from accessing and exploiting that information. As was mentioned before in the Access Control Standards section, there are methods of authorization for users when accessing their account. Some main methods were having personal identification numbers for each user as well as recording their username and passwords, using a multi-authorization application to send a code via email or text. These are very good

methods of assuring account security. However, some of these may come with many difficulties when trying to implement them for our application, but we consider them as stretch goals if we have time.

Starting with the implementation of personal identification numbers for each user that creates an account for our application, this would require code in the backend part of our application where a unique number is created for the user as the ID. Then the identification number would be transferred to the database where it would be paired with the user's personal information. This could be done by either a random number generator with code statements to check if any other user has this number or a unique number system to make sure each number is unique. This method, compared to the other two, is pretty much standard with other companies' software and would be standard as well with our application.

Next is having the multi-authorization application on our app. One example that we could use for our perfect cleaner would be the Google Sign In. The Google Sign In is a program made by Google that allows users to login with their google account instead of having to create a username and password only for that website or app. In order to be able to use this feature, there are authorization credentials that you must create in order to get the client ID that would be used in the code to have the multi-authorization on the webpage. This could be a bit of an issue to set up in our application, but with the right amount of time we could pull it through in the final stages of our app.

The other method would be using a multi-authorization feature to send a text to the user's phone or email address. This would require the use of a third-party source to get the resources to be able to send emails to the users of our app in order to send them a code for them to prove their identity. Google also does provide this feature as well as Microsoft but would also include the creation of a ClientID or a free trial as well as the same issues when trying to implement it.

Electrical Safety Constraints

As with any other products with electronic parts, there would be safety procedures and methods to prevent harm to us while making the Purrfect Cleaner. We would have to make sure that there wouldn't be any heating issues with the motors, sensors, and power supplies we are using during testing and constructing our product. In this case, it would be detrimental to the container if we were to decide to use one made of plastic or any material liable to melt or catch fire. A possible solution to be considered for the electrical components overheating could be the addition of another part added to our product which would be a cooling part such as a fan and of course a small opening on the side for the heat to escape from. Since our product is in contact with liquid and solid waste from the cat, we would have to make sure our electronic parts are covered

and protected properly so that it would not short circuit and as result may have the potential to harm the cat or the product owner.

Time Constraints

Before going into the design phase of our self-cleaning cat litter box, it's important to take into account several key factors. Among these are constraints and standards, which play a crucial role in shaping the design process. Constraints refer to the limitations that can impact our project's design, including factors like the environment, size restrictions, time constraints, and availability limitations. Meanwhile, standards ensure the health and safety of the product and are the professional requirements and guidelines that we must adhere to, depending on the specific requirements and scope of our project.

Our assignment involves crafting a 120-page paper within a 16-week timeframe, but practically, the writing period is condensed to 14 weeks. This adjustment is necessary as the initial weeks are devoted to group formation and topic selection at the semester's start, detailed in our project proposal outlined in the document's beginning. For a comprehensive project schedule, please refer to Figure 6A, and specifics regarding the prototype/building phase can be found in Figure 6B. Given that the written portion precedes prototyping, unforeseen challenges may arise, potentially leading to changes in the project's scope or specifications as outlined in this document.

A delay in our timeline has the potential to postpone our graduation date, requiring the identification of a new group or project and an additional semester before completion. The building phase of our project requires thoughtful consideration. For instance, an error in the PCB design could necessitate another PCB printing request, taking up several weeks and substantially hindering project progress. Additionally, since this project involves the use of various peripherals that require purchasing, we must take into account the stock availability and the time needed for the components to be shipped.

The schedule of our group members could play a crucial role in the completion of our project. During the SPRING 2024 semester, Junxu is taking Modern Robust Control, Computing and Big Data, and Electric Machinery. Modern Robust Control has a lab section that is the most time-consuming class. However, overall, it is not a super busy schedule, and Junxu contributed a good amount of work to the paper. In the summer, Junxu is working for Black & Veatch as an intern part-time, and taking Electronics 2 with Senior Design. He might not contribute to the project as much as he did in the Fall semester.

Kayla is taking Linear Control System with Senior Design, she is currently looking for a part-time internship for the summer. Linear Control System doesn’t offer a lab session. Therefore, Kayla is the one of the main people that work on software development.

Eliezer is taking Electric Machinery and Introduction to Smart Grids. Both classes require some effort to complete. Besides these classes, Eliezer is doing a part-time internship at Burn & McDonnell, where he works 15 hours a week. Eliezer is taking Senior Design and two other engineering classes in the summer. overall , not a really busy schedule he would have time to work on the project.

Sam is taking a lot of hard classes such as Fundamentals of Power Systems and Machine Learning, but Sam is only taking a GEP class with Senior Design 2 in the summer, so he has more time to work on the project than everyone else.

We're lucky to have Dr. Lei Wei helping us with our self-cleaning cat litter box project. He gives us advice and shows us the way forward. Dr. Chung Yong Chan and Dr. Weeks also support us a lot, making our project easier and helping us succeed. With their guidance, we can handle problems, meet deadlines, and reach our goals. Their expertise helps us tackle challenges and make progress smoothly, ensuring that our project stays on the right track. With their support, we feel more confident and capable of achieving our goals.

Chapter 5: Comparison of ChatGPT With Other Similar Platforms

In this chapter, we embark on a thorough comparison between ChatGPT and other similar platforms, discussing their usages, advantages, and drawbacks to understand their impact on the learning and research experience in developing the Self-cleaning cat litter box. Through 3-4 illustrative examples, we showcased how these platforms either support or hinder the self-cleaning cat litter box learning journey, offering insights into their suitability and potential areas for improvement in supporting project development.

Comparison of ChatGPT Pros and Cons

ChatGPT is a chatbot developed by OpenAI, whose purpose is to answer users' questions with insightful and detailed answers. The most recent version of ChatGPT, GPT-3.5/GPT-4 was trained on massive datasets, including knowledge from wikipedia and other informational sources, with a size of roughly 600GB of data. ChatGPT uses machine learning to make prediction based answers from human inputs. Specifically, ChatGPT employs reinforcement learning from human feedback (RLHF) to not only make the best predictions but also adjust for human preferences.

ChatGPT offers a wide variety of benefits for users. The first main benefit of using ChatGPT is the vast archive of information contained within the chatbot. ChatGPT can access most information that would be found on the internet. Pulling from roughly 600GB of trained data, the latest ChatGPT contains a depth of knowledge. Unlike the internet however, ChatGPT makes prediction based answers using the trained data, allowing the user to immediately pull from the archives instead of having to sift through information. If a user wants to learn about cats using just the internet alone, they would have to scour the internet clicking on multiple different websites to gain more knowledge about cats. This process could prove incredibly tedious and inefficient as manually searching for information on websites requires extending reading and downtime between searches. ChatGPT, on the other hand, pulls what it believes to be the best information, based on the users' inputs, from its archive of data and then generates a response that best suits the users' question or task. This process is exponentially faster than the traditional manual searching method as ChatGPT can pull from multiple sources at lightning speeds. What might take a student 5 hours to research online can be provided in 30 seconds by the chatbot.

The next great benefit of using ChatGPT is the educational assistance provided by the chatbot. ChatGPT is great at explaining many educational concepts such as math, history, science, programming, and other well structured concepts. ChatGPT is

excellent at teaching students the basics of any concept contained within its rich datasets. ChatGPT has been finely tailored for human preferences, allowing users to receive responses that benefit their requests to a t. For students, ChatGPT can be a godsend as the AI has been trained to give responses that are not only highly detailed with information, but are also formatted to relay information clearly and effectively. A good example of ChatGPT's superior educational assistance is when it's compared to a standard textbook.

Most students complain about textbooks, especially advanced concept textbooks, as being too confusing and complex to understand without hours of thought processing and reviewing. Though most textbooks contain critical information about a subject or idea, they often lack clarity and readability. ChatGPT, however, generally provides clear and concise answers. This is due to the training of ChatGPT, which incorporates the reinforcement learning from human feedback (RLHF) mechanism. This mechanism allows the model to be rewarded based on human preferences. Over time, deep machine learning models provide outputs that focus on human preferred answers.

As such, ChatGPT gives educational answers that are formatted to give the most optimal learning experience to human users. ChatGPT is incredibly useful when pulling from online educational sources with similar content. For example, if a student were to look up a homework problem that was similar to one archive in ChatGPT's database, the AI would be able to apply the concepts of the archived homework to the user's input. ChatGPT has a great baseline of educational skills and is able to solve most problems involving fundamental concepts.

Another great benefit of ChatGPT is its ability to create content based on users' parameters. ChatGPT has the ability to generate content based on its datasets. Users find this feature exceptionally beneficial when needing to create content. Desired content can include programming code, data graphs, fliers, resumes, and other virtual products. ChatGPT's ability to create content can greatly accelerate a student's project or task by helping them get a solid foundation created within seconds. Content creation using ChatGPT has been one of its most controversial features as when used improperly or against the guidelines of institutions such as colleges it can be considered a form of cheating or plagiarism. Assuming it's used for proper content creation, ChatGPT is a vital source for brainstorming and creating ideas for future content. The creation of content allows for users to spend less time designing project bases and speeds up workflow for personal projects.

ChatGPT offers a diverse set of accessible languages to communicate in allowing for many different people around the world to use it. ChatGPT also can understand and respond to questions involving code and other forms of communication, creating an incredibly accessible environment to send and receive information. ChatGPT can allow

users to ask questions about books and texts in other languages and give a translated answer or synopsis. This feature is incredibly useful as otherwise, the user may have to physically translate the text to understand it. ChatGPT is accessible at all times of the day, unlike a translator or library, giving the chatbot an edge over conventional forms of literature translation. Additionally, ChatGPT's full time accessibility allows for users the freedom of gathering information at any time, which benefits users with busy schedules or inconvenient researching hours.

A great benefit of ChatGPT is its ability to translate inserted data rapidly and effectively. Specifically, ChatGPT is able to store and manipulate large sizes of data, which can be incredibly important for research and statistical analysis. ChatGPT was created using the Python programming language and demonstrates great aptitude for addressing large quantities of data. For example, if a user wanted to make an x and y graph based on information found online. ChatGPT would be able to handle the data much faster than any human and produce the desired graph first. Moreover, if the information online contained over 10,000 entries, a human would have a grueling process to mark each entry on the graph, while ChatGPT could supplant the information exponentially faster. ChatGPT is able to parse information extremely well and can manipulate large quantities of data unlike any human. This allows users to change data without having to endure the physical labor of processing the information.

ChatGPT also has a few potential downsides or cons for users. One of the greatest concerns with ChatGPT is its malicious use such as cheating and plagiarism. ChatGPT has provided users, especially students, a platform to obtain information at an accelerated speed. The issue resides when students abuse the abilities provided by ChatGPT to complete tasks or assignments that do not allow outside help. ChatGPT can be used to write papers, solve coding problems, and answer examination questions. Many educational institutions, ranging from middle school to college, forbid external help on assignments as they are intended to test the students personal knowledge and grasp of the material. ChatGPT can be used to artificially support the students' knowledge and even complete the assignment entirely. Additionally, students can use ChatGPT to answer test or quiz questions at exceptional speeds, gaining an unfair advantage. This issue has become so great that many schools and institutions have placed measures to combat cheating and plagiarism from ChatGPT. One of the most common measures seen by colleges and other educational programs to limit ChatGPT created work is AI writing detection. Applications have been created to determine if a paper was created by a human or chatbot with incredibly high accuracy. Though not perfect at the moment, professors and teachers can use this software to check submitted work to determine if the paper was made by ChatGPT. One continuous issue is the progression of ChatGPT's ability to create authentic and unique content. As the model becomes better at providing human-like responses, previous chatbot detection programs may become obsolete. There appears, at the moment, to

be a forever arms race between those who intend to use ChatGPT for academically dishonest purposes and those who intend to eliminate fraudulent work.

ChatGPT is not only used for academic dishonesty but also challenges the concept of intellectual property. ChatGPT is able to write cover letters, create AI art, create music, and record people's voices. ChatGPT has been viewed as unethical in its use for creating content that may use intellectual property from others on the internet. For example, a major issue at the moment is ChatGPT's ability to take a person's voice and use it to sing songs. Specifically for professional music producers ChatGPT has come under fire for claims of intellectual theft and abuse. ChatGPT can create a music song using professional singers voices for content generation. Many prominent music producers and singers claim that ChatGPT is stealing their voices and affectations. Though ChatGPT is simply creating a sound that matches the pitch and frequency of the singer, the sounds are so identical that people believe their voice is being used for someone else's work.

ChatGPT also has the ability to create AI generated art, which can be used for a variety of purposes. The main problem stated with AI generated art is that it copies artistic patterns and styles used by other artists when creating a new piece. The problem is exacerbated when AI generated art is used for monetary gain, which many artists believe is unethical as it takes their skills and styles and creates a free image for the user. Many artists fear that ChatGPT may lead to them losing income or work as the resource can provide free art, which hurts the art market. Artists are very worried about the future as AI progresses and can create more elaborate artistic pieces.

Another major concern about ChatGPT is the informational accuracy. Just like on the internet not all information is fully accurate and correct. ChatGPT is trained on information pulled from the internet and therefore can fall victim to the issue of being trained on false data, which can lead to skewed results. Though OpenAI claims to have taken the best precaution to minimize false data from being trained from by ChatGPT, even they admit that some of the information may not be fully accurate. Therefore, students who rely on ChatGPT for information may be subject to inaccurate answers. ChatGPT is great for fundamental and basic information on a topic, but is at a greater risk of providing incorrect results as the topics become complex. Additionally, because advanced concepts and data are on average less accessible on the internet, ChatGPT is often unable to assist users with difficult concepts due to a lack of training data. Furthermore, ChatGPT is trained as an overall educational content archive with little focus on advanced learning. Though future models of ChatGPT may have more data on advanced topics the current state of ChatGPT is unreliable for such topics. ChatGPT is a machine learning model and therefore inherently makes inaccurate predictions. Even if the proper training data exists, ChatGPT is a prediction based model, which intends to approach zero loss but always makes mistakes.

ChatGPT has the concern of creating dependence on its application for information. ChatGPT can provide users with a vast variety of data and ideas. However, ChatGPT has gained the concern that users use its information without critical thinking or truly grasping the information they search for. As a result there could be an educational dependence of ChatGPT for information, which defeats the purpose of personal education. If students are not using ChatGPT to learn, but are simply using its applications to provide answers, then they are not learning any new information. If students use ChatGPT to complete all of their work they are not developing critical thinking or problem solving skills, which stunts their intellectual growth and sets them up for failure.

In connection to dependence, ChatGPT has been linked to concerns of widespread misinformation and security risks. ChatGPT is intended as an educational resource, but can fall victim to uncontextualized data or simply inaccurate outputs. If a user does not verify the data received from ChatGPT, they may act and use that information without verifying its correctness. For example, a team of engineers are working on a project and one of the workers uses ChatGPT to look for engines. If the engineer choses an engine that claims to have a certain horsepower, as listed by ChatGPT, without verifying that the information is accurate, then the part may not actually have listed horsepower. Assuming the engineer uses the engine with the wrong horsepower rating the project could become a disaster. Likewise, relying on information stated by ChatGPT must be verified with other sources to ensure no spread of misinformation or uncontextualized bias.

Another major concern of ChatGPT is its negative impact on the job market for employees. ChatGPT is so great at certain tasks such as providing resources and helpful information to users that many workers in informational fields are concerned that their jobs may be replaced by ChatGPT. Specifically, workers in the customer service field are seeing the impact of ChatGPT’s effective communication to users as more big companies are decreasing staff in customer services departments. ChatGPT can be optimized for effective basic communication between users and companies, eliminating the need for customer service representatives. As ChatGPT continues to advance and develop, more jobs may be at risk of elimination through automation and increases in efficiency.

Another concern of ChatGPT is in regards to the privacy of the user. Because ChatGPT is a constantly learning model, any inputs from the user continue to train the model. There is a concern that inputs from a user may give intellectual information to the chatbot without the consent of the user. There is also a concern that ChatGPT may track users' inputs and use that information for tracking and advertisement, again without the consent of the user. ChatBOTs algorithms and features are not fully known

and many users are worried that their personal ideas and preferences may be shared to others without their knowledge.

An example of how ChatGPT can benefit our group's learning experience in Senior Design is by using it to find similar parts for our parts comparison. ChatGPT can allow our group to suggest other parts that are similar to the ones we have selected for the projects. By using ChatGPT's rich resource archive, we can speed up the research process for finding comparable parts. Of course, our group would do the research without relying on ChatGPT for the entire explanation of the parts comparison. However, ChatGPT provides great initial ideas for users to expand on. For example if we were to use ChatGPT to suggest other gear motors similar to the worm gear motor, ChatGPT would provide helpful examples of other parts that can be used for comparisons. ChatGPT's ability to provide a solid foundation for further research would greatly help our group's research speed and allow us to focus more on other parts of the project such as PCB design.

Another example of how ChatGPT can benefit our group's learning experience in Senior Design is by using it to create quick diagrams and visual models to help with design brainstorming. If our group wanted to draw a rough draft idea sketch model of our automatic cat litter box, then we would need to spend a thorough amount of time creating the visual. Resources such a Blender or other graphic software might be needed to create a realistic and outline blueprint for our design. With the help of ChatGPT, however, our group could request it to make a concise blueprint without having to do the manual labor of producing the blueprint ourselves. By giving ChatGPT the parameters and features, the AI could make us a nice blueprint/proto-model for our project. This would help our group's learning experience as we would learn how to make efficient basic models without needing to expend excess time.

The last example of how ChatGPT can benefit our group's learning experience in Senior Design is by using it to provide important research sources online. If our group purely researches by scouring the internet for information, our research may take a long time, which may delay our PCB and other components of the project. By using ChatGPT for finding educational resources, our group can rapidly speed up our research rate and find critical information faster. By asking ChatGPT for credited research pertaining to our inputs, we can cut down on the research time and still find credible information. The great part is that our group would not need to worry about misinformation because we are asking for the paper itself, rather than ChatGPT's interpretation and preference response.

Once ChatGPT lists the paper, our group can independently view the paper and gain the information we desire for the project. ChatGPT would help our group's learning experience by helping us research more efficiently and learning how to parse data from

the internet quickly. We can also check sources much faster as there are less suggested resources compared to using web browsers such as google or bing. Big search engines provide a plethora of material, but often overwhelm the user with a massive number of related search outputs. Using ChatGPT can filter out websites that don't quite match the desired material for research. Essentially ChatGPT serves as a better version of traditional engines because of its predictive behavior and advanced human based preferences.

Our group must ensure that, if ChatGPT is used for any research or design purposes, we verify all outputs to verify the information and avoid misinformation or inaccurate outputs. For a project such as an automatic cat litter box, design is critical and all of the measurements and data points must line up. Using ChatGPT can prove beneficial to our group, but not be solely relied upon.

Alternative platforms to ChatGPT include a wide variety of options. A main alternative is Bing Chat, which comes with a set of pros and cons to ChatGPT. ChatGPT is a free and purchased resource, which costs roughly $20 per month for the exclusive version and free for the basic version. Bing Chat, on the other hand, is always free. Bing Chat and ChatGPT premium both run off of OpenAI's GPT-4, while the free version of ChatGPT uses GPT-3.5. Both come with a variety of features such as AI art generation using the DALL* E 3 program. ChatGPT is limited by its training data and cannot access information in real time, unlike Bing Chat which is integrated with the bing search engine. Bing Chat provided real time results and attempts to make inference suggestions for future searches. ChatGPT is considered better at generating content than Bing Chat is generally considered the most concise chatbot. Bing Chat offers more features but performs worse on average with its features than ChatGPT premium.

Chapter 6: Hardware Design

This chapter is all about putting our ideas into the real world through hardware design. We'll break down the subsystem block diagram, schematic diagram, architecture, and structural illustrations that make up the physical parts of our automated cat litter box. This chapter dives deep into why we chose a certain design for the PCB and wire connections, how all the peripherals and PCB are going to be combined with the cat litter box, and what we expect from each component. At the end of this chapter, a computer-aid design is used to illustrate the physical prototype of the product.

Overall Schematic

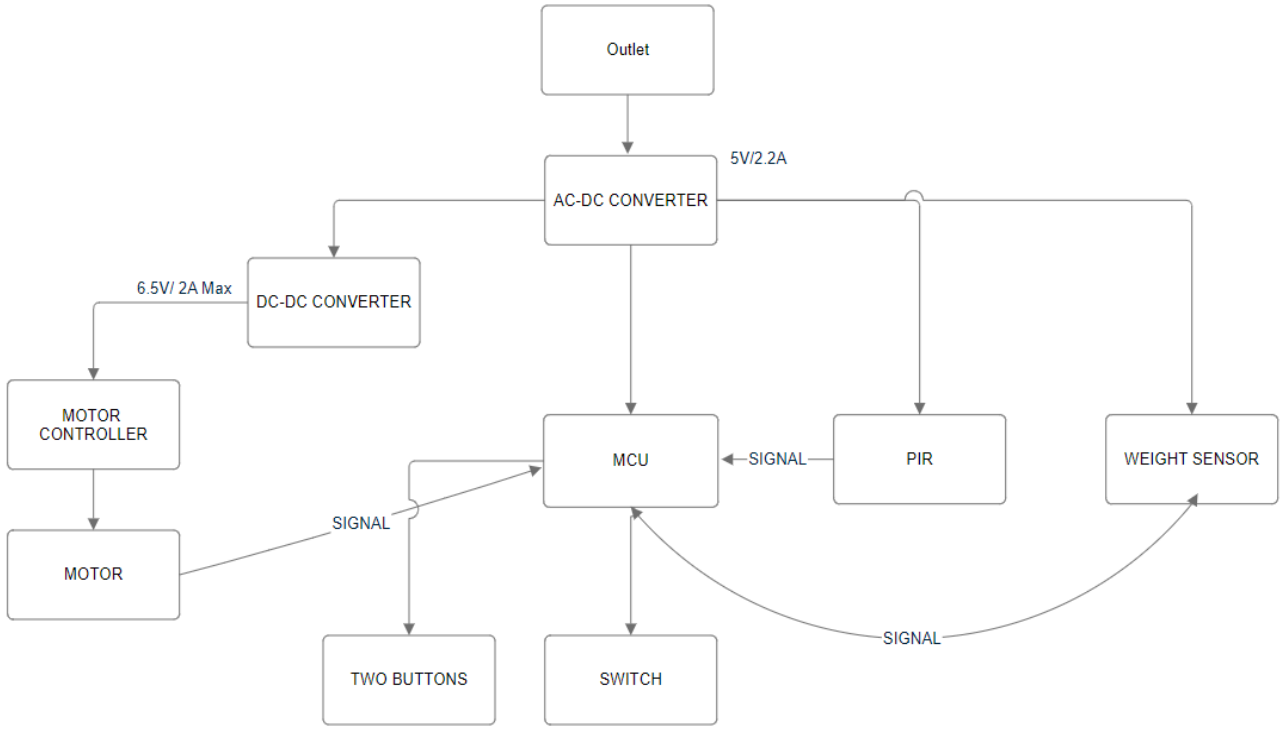

Figure 6A Hardware System Schematic

In Figure 9A, it shows the hardware schematic of the system. The self-cleaning cat litter box consumes power from the outlet, then the 120 AC voltage coming from the outlet is converted into 5 volts DC voltage with a 2.2 Amps current. From the AC to DC converter, the voltage is split 4 ways, it goes to a 5V-6.5V DC-DC converter, the MCU (ATMEGA328P), PIR Sensor, and the weight sensor. Because the motor needs a supply voltage of 6 volts, a 5 volts - 6.5 volts DC-DC converter is chosen for minimum voltage

supply purposes. For the other peripherals like the PIR sensor, weight sensors, buttons, and the switch, they have a wide range of operating voltage, a 5 volts supply voltage should be enough.

For wiring purposes, the power supply for the weight sensors and the PIR sensors are supplied directly from the AC-DC converter, but the outputs from these peripherals are connected to the input of the ATMEGA328P. The other peripherals like the buttons and the switches are connected to the ATMEGA328P chip directly. They don't require a lot of power and are simpler than the other peripherals.

WEBENCH® Circuit Designer

In Junior Design, we were introduced to WEBENCH® Circuit Designer from Texas Instruments that allows us to customize our power supply. WEBENCH® Circuit Designer is a software tool that helps users create customized power supply and active filter circuits. It simplifies the design process by allowing users to input their requirements and selecting appropriate components based on these inputs. The tool then generates complete circuit designs with all necessary components and values, which saves a lot of time and effort. Additionally, it provides analysis capabilities and integration with PCB design tools like Altium Designer, CadSoft Eagle, etc. We are using this software tool to design our DC-DC converter and AC-DC converter.

AC-DC Converter Design

In this section, we discussed the AC-DC converter design. AC is the type of electrical power that comes from outlets in homes and businesses, where the current periodically changes from positive to negative and vice versa. On the other hand, DC is a type of electrical power that flows consistently in one direction, commonly used in batteries and electronic devices. AC-DC converters are used in many electronic devices and power supplies because most electronic components and circuits operate on DC power. By converting AC to DC, these converters enable the use of AC power sources to operate DC-powered devices.

For our product, it takes in power from the outlet, since the power coming from the outlet is AC Power, and every component that is used for this product operates in DC voltage. The purpose of this AC-DC converter is to convert 120 AC voltage to 5 DC voltage. By consulting Dr. Wei's professional experience. He advises us to purchase an existing AC-DC converter from the market. Therefore, refer to Chapter 4 Parts selection to see the AC-DC converter we chose (it is a charger block).

However, if we do have the spare time in Senior Design 2, we can design an AC-DC converter and implement it into our PCB. By using the *WEBENCH® Circuit Designer,* the below schematic is generated. It demands 110-120 RMS AC voltage and outputs 5 DC voltage with a max current of 2.4 amps.

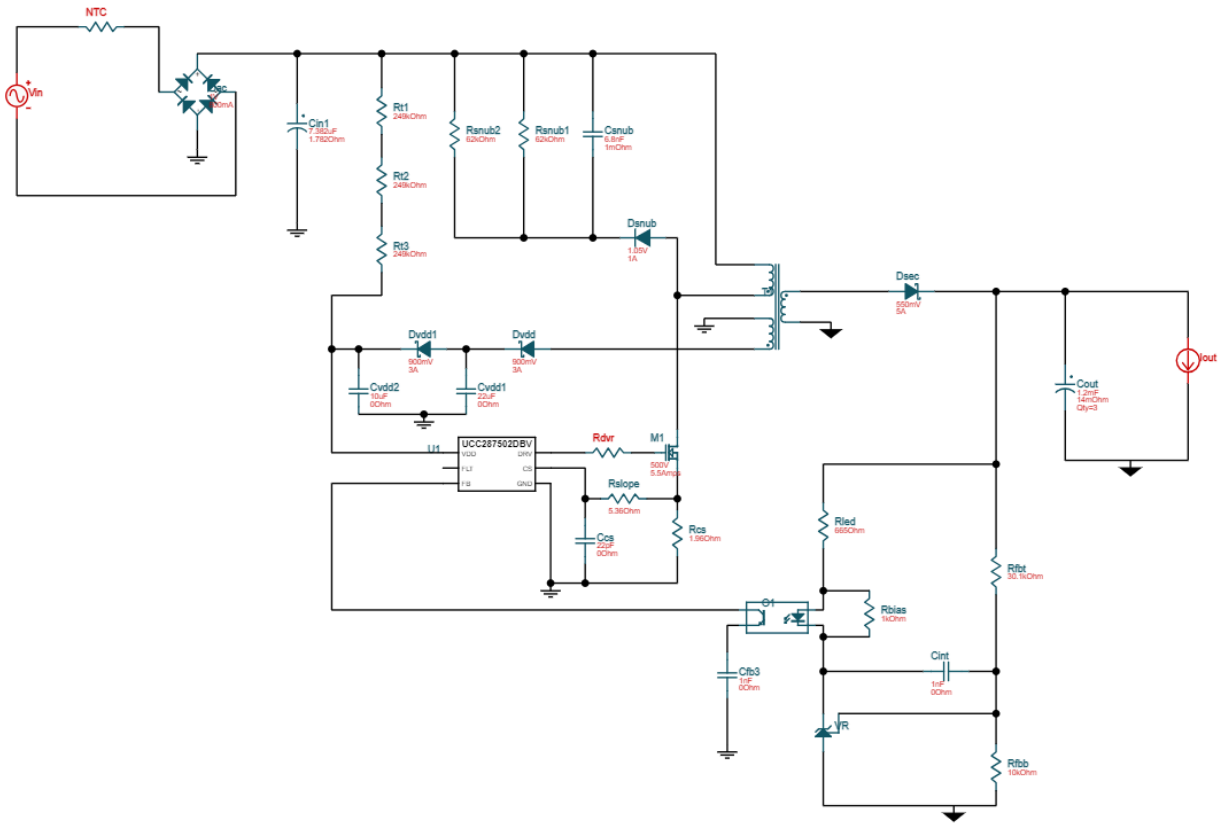

Figure 6B AC-DC Converter Schematic

DC-DC Converter Design

In order to supply voltage to the motor, a DC-DC converter is needed. Because the voltage level coming from the AC-DC converter is at 5 volts, and the motor operates at a minimum of 6 volts. Unlike the AC-DC converter we discussed in the previous section, there are no existing DC-DC converters that are in the market that meet our requirement. Therefore, we have to create our design by using the *WEBENCH® Circuit Designer* software tool.

As prompted from the software tool, the input voltage from the converter is around 5 volts and the output of the voltage is 6.5 volts with 2 amps maximum output. After the above specifications are entered, the software tool returns multiple converter designs. We compared the cost, efficiency, and footprint area factors for all the designs and decided to go with the one shown below.

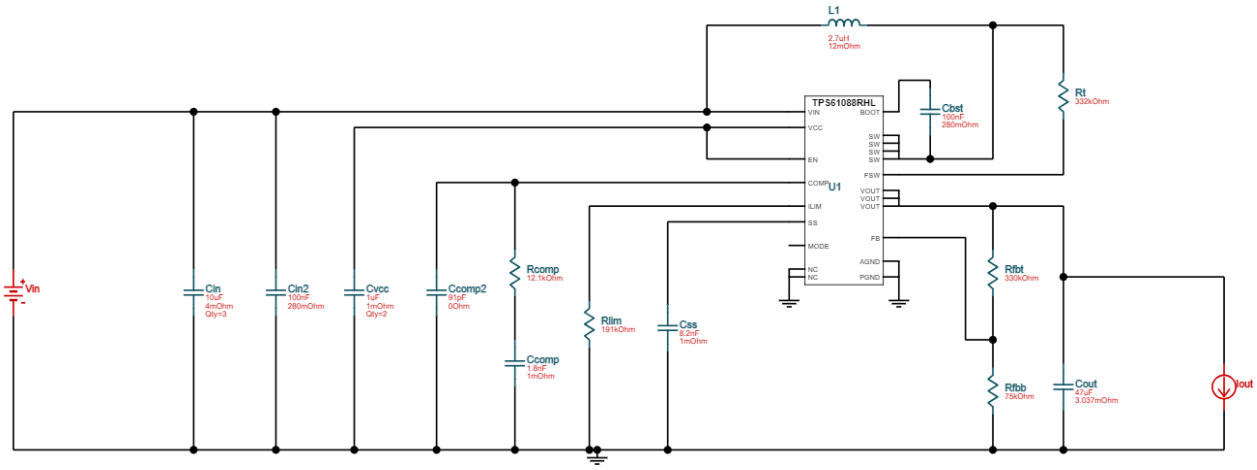

Figure 6C DC-DC Converter Schematic

Figure 6C shows the schematic of the DC-DC converter, as you can see, this converter not only includes the basic electrical components like resistors, capacitors, and inductors, it also uses the analog chip TPS61088RHLR from Texas Instruments. This chip is a synchronous boost converter featuring low-resistance switches for high efficiency, it also offers overvoltage, overcurrent, and over-thermal protection. Figure 6D shows the bill of materials of the DC-DC converter, the total dissipation is around 0.44 watts, which is acceptable. However, the input current for this converter is at 2.6 amps, which is way over the current that is coming out from the AC-DC converter.

Theoretically, when the motor is in operating condition, it demands 6 volts and 0.4 amps with rated load (5 kilograms). Compared to the stall current 1.8 amps, the difference of the current intake might cause a problem in the motor function. Considering the waste for the cat litter isn't going to be heavy, the motor might not need to operate at stall mode. Therefore, this DC-DC converter is the best solution for most scenarios. We do have to test the DC-DC converter with the motor thoroughly in Senior Design 2.

Name	Value	Category	Description
Efficiency	96.70%	System Information	Steady state efficiency
IC Tj	43.66 °C	IC	IC junction temperature
IC Pd	352.11 mW	IC	IC power dissipation
Pout	13 W	System Information	Total output power
Iin Avg	2.69 A	IC	Average input current
IC Ipk	3.1 A	IC	Peak switch current in IC
Mode	BOOST CCM	System Information	PWM/PFM Mode
Vout p-p	42.42 mV	System Information	Peak-to-peak output ripple voltage
FootPrint	290 mm^2	System Information	Total Foot Print Area of BOM components
Vout Actual	6.5 V	System Information	Vout Actual calculated based on selected voltage divider resistors
Vin	5 V	System Information	Vin operating point
Iout	2:00 AM	System Information	Iout operating point
Total BOM	$1.46	System Information	Total BOM Cost
Total Pd	441.13 mW	Power	Total Power Dissipation
BOM Count	18	System Information	Total Design BOM count

Figure 6D: DC-DC Converter BOM

PIR Sensor Testing Schematic

The schematic that we used to test the PIR sensor is shown on Figure 6E. We are using the Arduino UNO development board to test this component, Arduino UNO uses the ATMEGA328P chip. By referring to the PIR sensor datasheet, the 3 pins from the sensors are voltage input, output, and ground. The power supply from the microcontroller is 5 volts which is within the operating voltage of the sensor (4-12v). The ground pin from the sensor is connected to the ground pin on the microcontroller. Since the output pin from the sensor is either high or low (the actual value of the output pin isn't important), we decided to connect the output pin to the digital input pins on the microcontroller. For testing performance evaluation please refer to Chapter 9 System Testing and Evaluation/PIR.

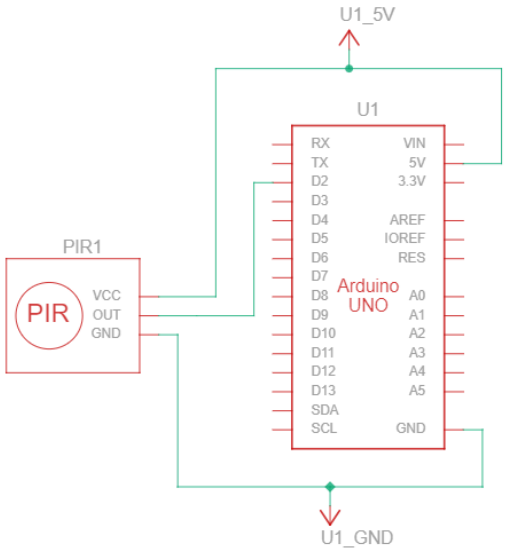

Figure 6E: PIR Testing Schematic

Weight Sensor Testing Schematic

One of the benefits of using the ATMEGA328P as our MCU is the amount of libraries the platform provides. The NEXTION Strain Gauge Weight Sensor comes with a load cell amplifier which is also an analog to digital converter. The HX711 is a module used for electronic scales, operating by converting alterations in resistance values into electrical output through a conversion circuit. There are 2 columns of headers on the HX711, one column is connected to the 4 weight sensors that are placed at each

corner of the cat litter box. The other column header interacts with the microcontroller, in this case, it is the Arduino UNO.

There are 4 pins: voltage input, ground, Serial Data Output, and clock source. Just like the PIR, the HX711 chip gets power from the microcontroller, ground is connected to the ground pin on the microcontroller. The “Serial Data output” pin outputs values of what the weight sensor is reading, the “clock source” pin generates a pulse to work with the “Serial Data output” pin to send values to the microcontroller. Both of these pins are connected to the analog input pins on the Arduino UNO because the HX711 provides analog values of the weight sensor feedback. The connections are as shown in Figure 6F.

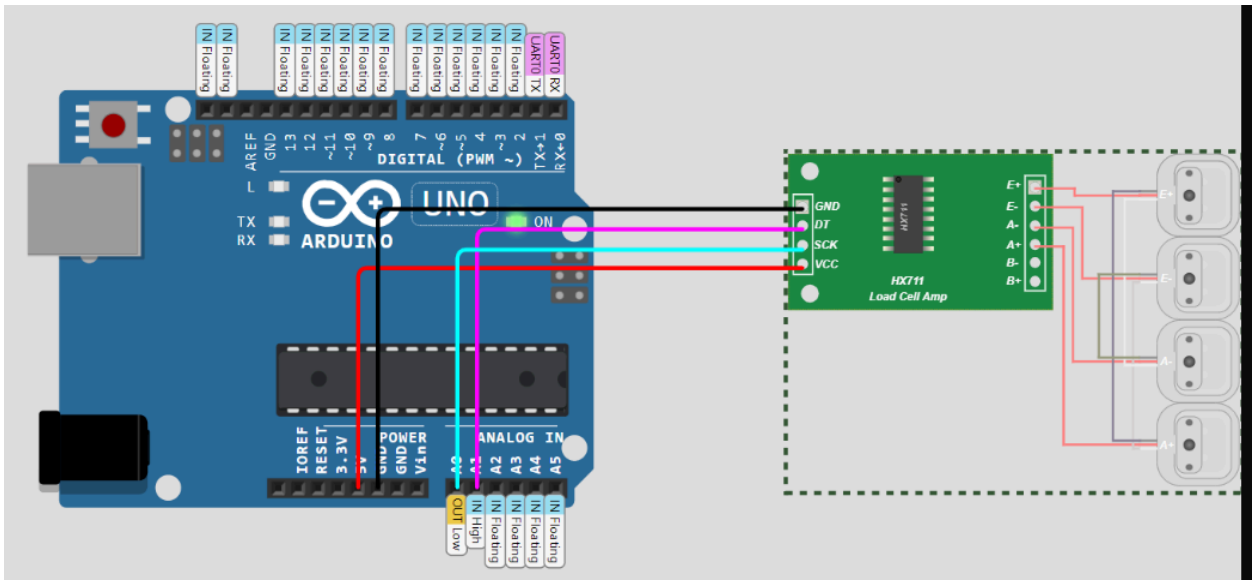

Figure 6F: Weight Sensor Schematic

Buttons / Switch Testing Schematic

The buttons and switch are the simpler peripherals compared to the other ones. The purpose of the buttons is to put the product in different operating modes. One button is to put the product in sanitizer mode which the cat litter box stays on but stops operating. In this mode, it allows customers to clean the cat litter box manually. The purpose of the Rocker Switch is to control the power of the cat litter box, when the switch is on, the circuit is closed and power goes through, when the switch is off, the circuit is opened, therefore no current going through.

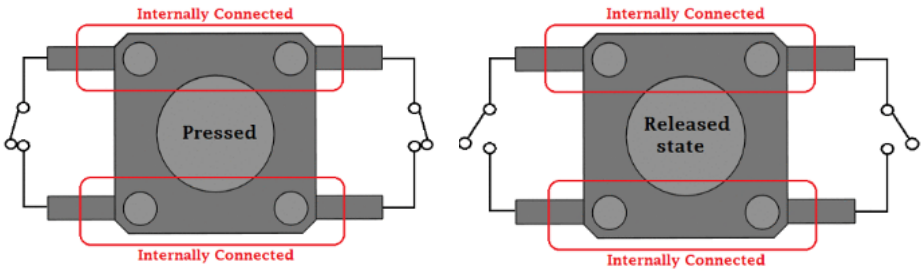

Figure 6G: Push Buttons Schematic

In Figure 6G, it shows the schematic of the buttons, there are 4 pins on the buttons, two of them are internally connected as shown, which means they are the same node. When the button is pressed, it forms a closed circuit letting the power source from the input of the button leave the output pin. When the button is not pressed the circuit is open.

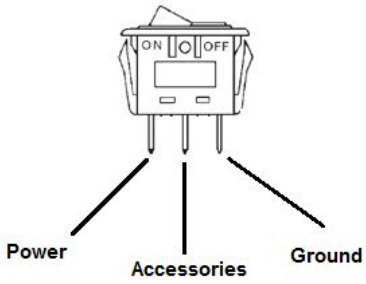

Figure 6H Rocker Switch Schematic

Figure 6H shows the schematic of the rocker switch, this component has 3 pins: power, accessories, and ground. The accessory pin, which is the middle pin, is a central pin that either connects to a "normally open" or "normally closed" pin. With Arduino UNO, the accessory pin can connect to the input pin of the microcontroller, and the microcontroller can read the state of the switch.

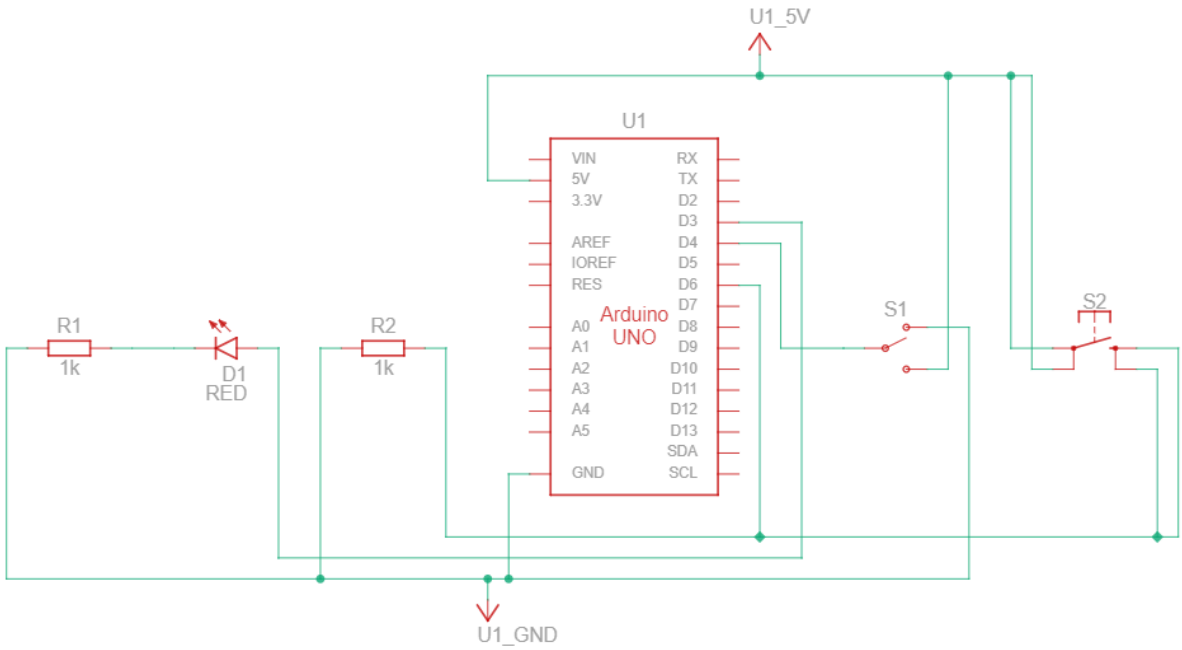

Figure 6I: Button/Switch Testing Schematic

In Figure 6I, It shows the schematic that is used to test the functionality of the switch and buttons. The LED is used to test the output of these components. For the performance of the buttons and switch, it can be found in Chapter 9 System Testing and Evaluation/button/switch testing.

Motor Controller Schematic

The motor that is used in the project is going to be attached to the filter and applies a one-dimension motion that pushes the filter back and forth. The motor used in this project is the Worm Gear Motor (for more details of the motor, please refer to **Chapter 3 Gear Motor)**. There are two wires coming out from the motor, one is for power the other one is for ground. Since there is no wire that can communicate with other peripherals, therefore, it requires another electronic component that can act as a switch to control the state of the motor. We can achieve this by implementing a BJT or MOSFET. As shown in **Figure 6J**, the circuit uses a N-P-N bipolar-junction-transistor, the voltage supply to the collector is 6.5 volts, and the voltage from the collector to the emitter is going to be the same voltage when there is specific voltage supplied to the base of the BJT.

The resistance value for the collector resistor and the emitter resistor are to be determined. The ultimate goal of implementing this BJT is to act as a switch, if there's specific voltage applied to the base of the BJT, the emitter voltage or the collector-emitter voltage is close to the voltage supplied to the collector. And if the voltage applied to the base of the BJT is zero or a small voltage, the voltage supplied to the motor is zero.

Figure 6J shows the basic circuit for the motor controller. With the current design, it is unlikely to have the capability of achieving the goal described above based on bipolar-junction-transistor physics. The development of this motor controller are completed in the beginning of Senior Design 2 with the assistance of Dr. Chan and Dr. Weeks.

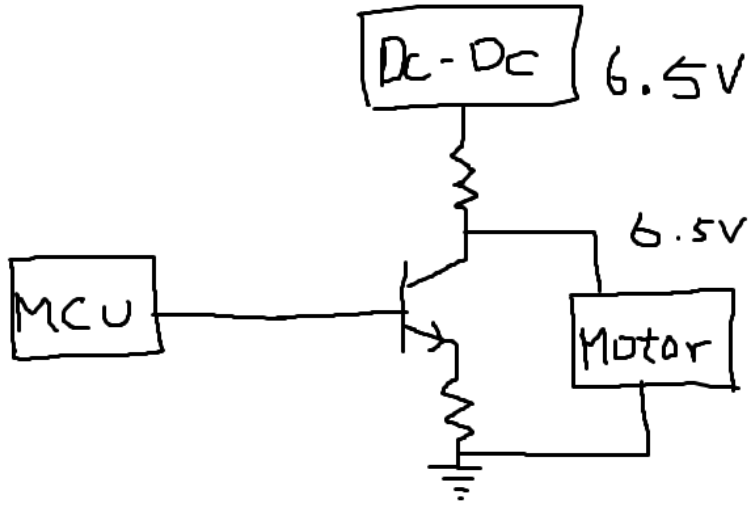

Figure 6J: Motor Controller with BJT

After consultation with Dr. Weeks, we decided to use a NMOS instead of a BJT. They have the same logic when used as a controller and dissipates lower power. Additional to the NMOS, Dr. Weeks also suggested using a flyback diode for current protection when the NMOS is switching. The circuit is shown in Figure 6J.

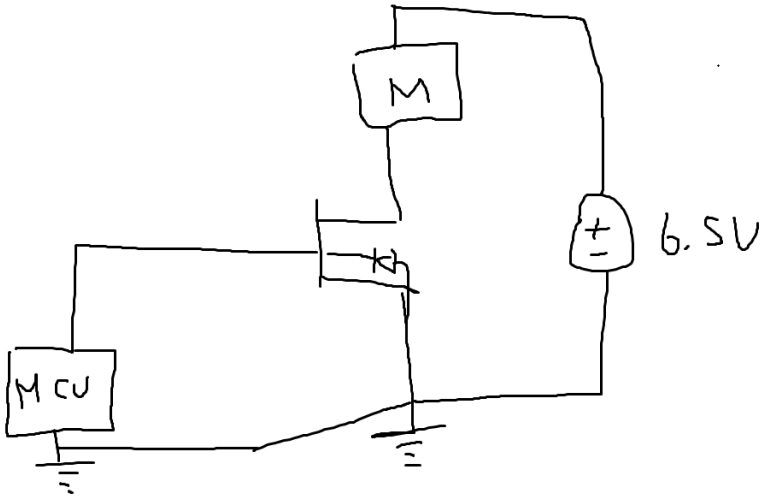

Figure 6J1: Motor Controller with NMOS

Structural Illustration

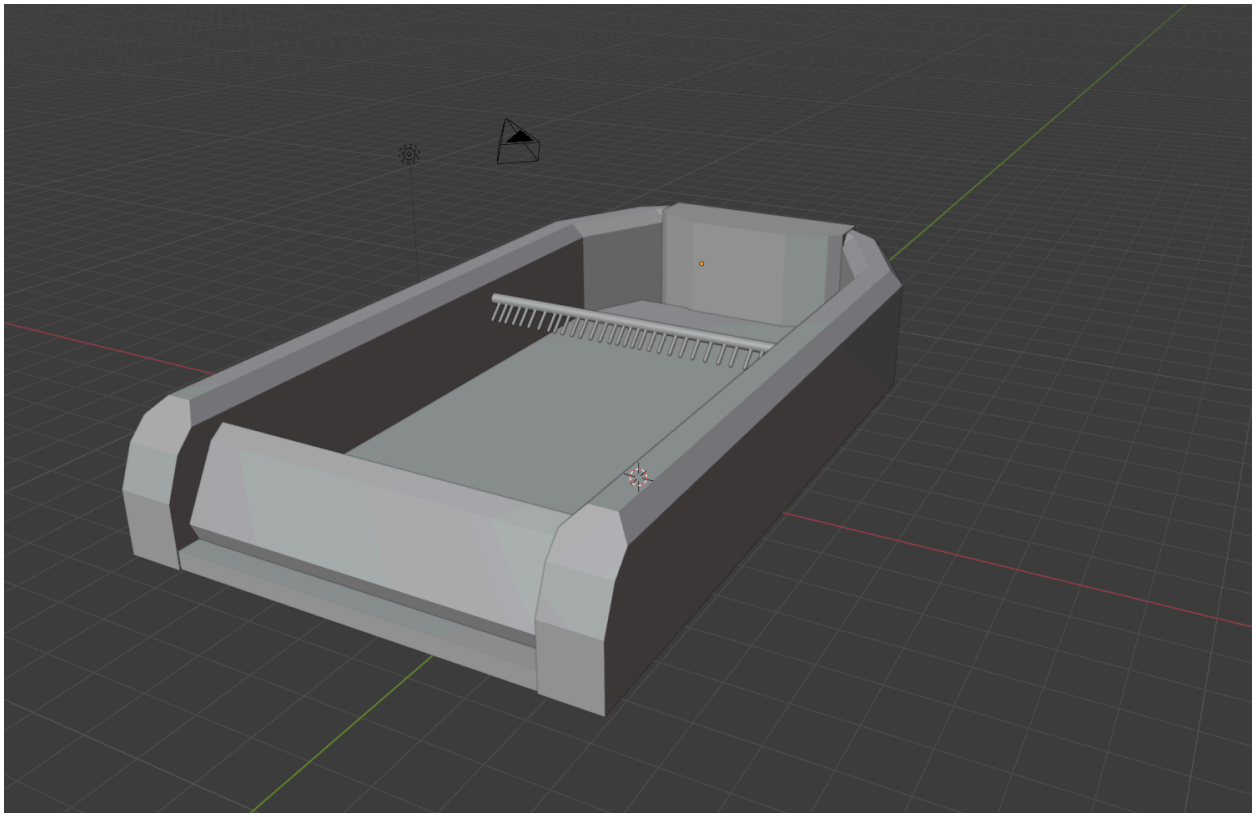

Figure 6K: Hardware System Blender Model(Traditional)

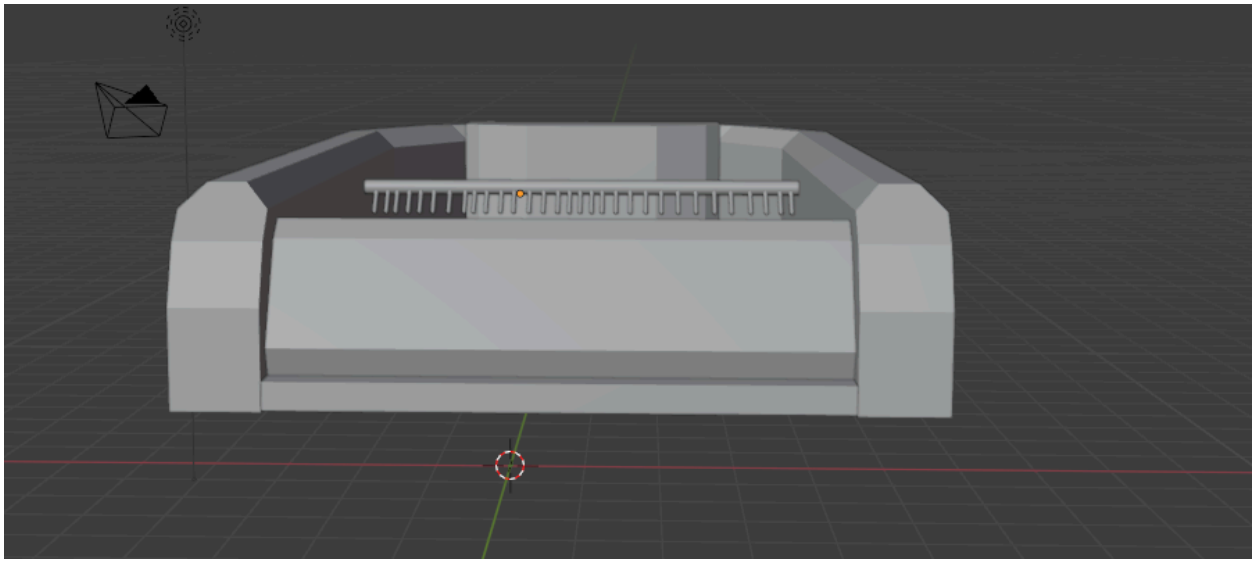

Figure 6L: Hardware System Blender Model(Front)

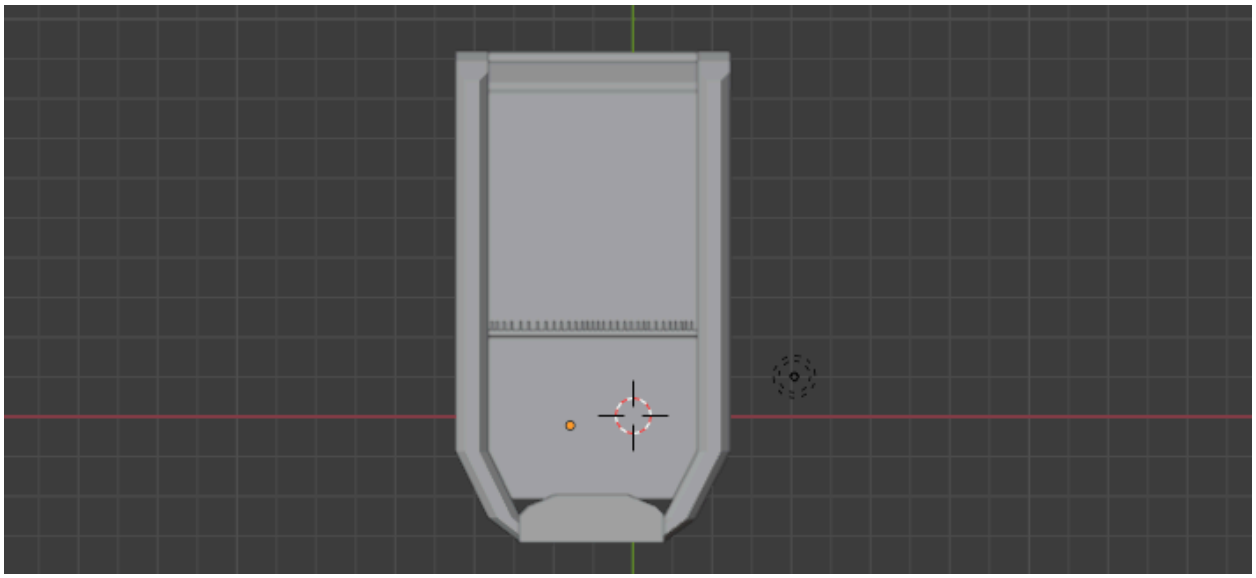

Figure 6M: Hardware System Blender Model(Birds-Eye)

Figures K-M were created in the virtual model generation tool Blender. The application allows for realistic 3D model designs. When designing the structural illustration for the automatic cat litter box I began by formatting the base. Blender allows for the manipulation of base objects such as squares, circles, triangles, etc. I initially used one square to design the base. Blender is considered industry standard for modeling designs and our group has decided to choose this software for our litter box design. The modeling software is incredibly advanced and allows for 3d printed

After constructing the initial bottom base, I moved on to constructing the box perimeter by adding 4 more squares, which I transformed into different rectangular shapes. Using the directional feature tool I was able to ensure precision to avoid asymmetrical sides to the box. Once the walls of the box were scaled to size. I attached them to the original base using the conjoin feature in Blender. This feature allows different separate objects to be joined by connecting their node points and reclassifying as 1 object.

For the detachable base I used two mesh rectangles to form an L-shaped design. I then beveled the front of the base to give a curved structure. Additionally, I used the bevel tool to reshape the walls of the box to create a more aesthetic design. Beveling is very important for rectangular structures as it not only boosts the aesthetic design, but also minimizes unnecessary mass from the structure. Minimizing structure size decreases the weight and cost of the box as there is less material overall.

Next the sifting comb was constructed by creating a mesh cylinder as the base and then making multiple smaller cylinders to serve as the comb's teeth. Of course, to make the teeth have an ideal structure I beveled the ends of the teeth down to near points. For the automatic cat litter box smaller teeth allow for finer feces filtering. However, the ends of the teeth were not actual points because that structure may prove hazardous to the cats. To ensure a safe design none of the teeth are sharp enough to penetrate the skin of a cat or person.

To create a drop hole for the feces, I used the cutting tool in Blender to remove a rectangular section from the original base. The cutting tool has many features. The feature used to create the rectangular hole was the bridge edge faces tool. This tool allowed for a precise cut based on the input values. The resulting base contained a perfectly symmetrical hole of 4"x18" hole across.

Finally, the bevel tool was used again to further smooth out the rough edges of the base box model creating an aesthetic and optimized box design.

Figures K-M show a 3D virtual model of the Automatic cat litter box with traditional, front, and birds-eye screenshots. The model represents the base structure for our group's litter box. The base structure allows for all parts to be inserted under and in the sides of the box, allowing for protected and hidden electronic placement. The motor is contained inside the wall of the box, which when activated by the MCU pushes the sifting comb through the litter.

The weight sensor is placed underneath the bottom floor flare, which detects the change in weight on the box plate after the litter has been added. The rectangular base is sized 20" x 8", which supports cats of varying sizes up to 19" in length. The height of the box is 25". This choice in height is low enough for the majority of cats to access without a stepping feature being required.

The front of the box contains a detachable base, which holds the cat poop stored during the scoping process. This base allows the user to clear all of the cat feces without needing to physically touch a waste bag or pile.

The back of the box contains a simple UI interface for the user to manually start the scoping process. Specially, the top of the back box contains buttons and and leds to allow the user to push to start the scoping process with leds signifying the scoping process. Additionally, there is a standby led on the top, which flashes if the box goes into standby mode. The MCU triggers standby mode if the cat is detected in the box by either the weight or motion sensors.

Note that the illustrations are a rough outline for the cat litter box. Further additions to the design are added and revised during Senior Design 2. Our group has considered multiple editions to the box design. Of course, the main focus of any project should confirm functionality over aesthetic design. However, a pleasing artistic design can greatly increase the appeal of a product. Our group intends to finish the functionality and then implement artistic features later.

Additionally, there is a simple instruction sticker posted on the back end of the box showing a simple-to-use guide. The sticker can be peeled off and serves a tutorial for the device to inform users on proper use and maintenance.

Architecture

The cat litter box is an essential item in cat comfort and relief. Significant design considerations aimed at providing comfort and privacy for cats while accommodating the maintenance preferences of owners should be focused on. Our group's design aims at achieving this area of focus while still maintaining a low price and essential features.

In the past cat litter boxes maintained an incredibly simplistic and primitive design. Users would be required to manually scoop the feces from the box, resulting in displeasing situations. Additionally, earlier cat litter box designs did not contain inherent hygiene considerations, often resulting in poor odor if left unchecked. Since the first cat litter box designs the concept has been greatly improved and innovative. With the progression of automatic cat litter boxes, owners no longer require manual scooping to filter the feces from litter. Primitive designs often used hard plastics that were not odor or stick resistant leading to nasty residue buildup over time.

The architecture of a cat litter box is designed to support the natural behaviors of cats. A well-designed litter box is inviting and secure, offering privacy and ease of access to accommodate cats of all ages and conditions. Standard litter boxes are crafted in simple shapes such as rectangles or ovals with precise measurements, ensuring sides are high enough to contain litter while allowing easy entry for kittens and elderly cats.

Material selection is essential as most boxes are constructed from durable, non-absorbent plastic to allow easy cleaning and minimize odor retention. We intend to use a form of BC plywood material for the exterior. The smooth interior surfaces are specifically designed to prevent litter from adhering, promoting a clean and hygienic environment. Our group focused on smooth BC plywood in the interior with slanted walls allowing for displaced litter and material to fall to the bottom of the litter box. We also intend to have small slits for the displaced material to fall through so it lands on the waste tray that is cleaned when the feces are disposed of. Furthermore, the choice

of plastic must be resistant to scratches and abrasions since cats often exhibit digging and scratching behaviors. The plastic should be of a high-quality type that does not release harmful chemicals or retain smells even after prolonged use. We are considering materials like high-impact polystyrene (HIPS) or polypropylene due to their robustness and long-term durability. These materials also offer the benefit of being recyclable, which could appeal to environmentally conscious consumers. In addition to structural considerations, our design incorporates a slight gradient in the base to facilitate the collection of waste into the designated area, simplifying the cleaning process and enhancing overall user convenience.

The functionality of the litter box determines its size and shape, which must allow cats sufficient space to turn around, dig, and cover their waste comfortably. Properly sized litter boxes help prevent accidents outside the box and make cats feel less enclosed, promoting their likelihood to gain comfort in the litter box. To achieve this functionality, our group is using an average standard size referenced by models sold on Amazon and other online vendors. Specifically, our box contains the following parameters: 20” x 8” x 25” (Length x Width x Height). Our group believes these parameters properly allow any standard cat to freely move in and out of the box without cramming. Additionally, the ergonomic design ensures ease of access for older cats or those with mobility issues. A slightly lower front entry and raised back and sides can help contain litter and provide necessary support for the cat while it covers its waste. Our research into cat behavior suggests that the visibility provided by a semi-open design can help reduce anxiety for the cat, as it allows them to survey their surroundings while still feeling secure. The dimensions and shape are specifically calibrated to balance the needs of space-saving in modern homes while ensuring enough room for the cat to behave naturally. This approach ensures that the litter box is not only functional but also fits aesthetically into various home environments.

Design innovations also focus on owner convenience. Features such as built-in sifters or double-layered trays streamline the cleaning process, while designs that include lids or flaps maintain privacy for the cat and control odors effectively—a key consideration for indoor environments. Our group intends to have an automatic sifter that periodically or manually filters the cat feces from litter. The feces are pushed off of an edge into a designed chute with a collection bag at the bottom. The sifter is made of a 3D printed filament material, which can be easily cleaned and maintained, while still holding a robust form for multiple uses. The collection bag is an odorless plastic bag.

Advancements in technology have significantly impacted the design of cat litter boxes over the years. Automated models, equipped with sensors, detect the cat’s entry and exit, activating a cleaning mechanism that automatically sifts and disposes of waste. This not only maintains a consistently clean environment for the cat but also simplifies the maintenance routine for owners.

Additionally, developments in odor control are increasingly common, with systems utilizing carbon filters or air purifiers integrated into the litter box to improve the ambient air quality of the surrounding environment. Some models even offer health monitoring capabilities, tracking usage patterns to provide owners with insights into their cat's health, which can be crucial for early detection of medical issues.

We intend to provide a potential innovation by capitalizing on the weight sensors of the litter box. Using the weight sensor in conjunction with the motion sensor, our group can determine the weight of the cat every time it goes into the litter box.

Our sensors allow our group to also determine how many times the cat uses the bathroom each day. By storing this data on a server, our group can give important statistical feedback to the user, which may help inform them on their cat's health and diet.

For example, our weight sensors could have their data sent to a server, which gives the user a detailed report of the cat's change in weight over the last 30 days. Storing the cat's weight can help if the owner desires the cat to diet and change weights. Furthermore, tracking the number of bowel movements daily from the cat can give insight to the owner if the cat may be sick or having GI issues. Users may find these features exceptionally useful for older cats or cats prone to illnesses. Due to the mobile features of the project a message or alert could be sent to the users phone notifying them of any abnormalities in the data collected. The integration of mobile devices with household products is a new field of integration in quality of life improvements.

The significance of mobile integration with cat litter boxes allows greater access by the user as data and controls are now available to the user. Regardless of distance, any user who can connect to the internet are able to access the litter box giving extra levels of comfort for the user’s experience. For example, assume a user forgot to clean the litter box and also forgot to turn off standby mode. Let’s also assume they realize their error during lunch break at work. Instead of potentially coming home to an overfilled litter box, the user can simply pull out their phone and click the “clean now” button starting the sifting process immediately.

Mobile integration for household devices is a future advancement that cannot be undervalued. Applying this concept to our project’s automatic cat litter box demonstrates the innovative feature of mobile integration.

The thoughtful design of cat litter boxes has a profound impact on both cat behavior and owner satisfaction. A box that aligns with a cat’s instinctual preferences tends to be used more consistently, reducing behavioral issues related to elimination. For

owners, the benefits of a well-designed litter box extend beyond functionality to include aesthetic considerations, with contemporary designs that seamlessly integrate into home décor, reflecting a blend of practicality and style. Our group intends to design an automatic cat litter box that not only serves as a function and efficient self cleaning device, but also contributes to any home design. Though focusing on the aesthetic of the litter box is second to functionality, our group intends to finish the project early to allow for artistic additions.

The architecture of a cat litter box embodies a blend of strategic design, functional necessity, and innovative technology, tailored to meet the intricate needs of both pets and their owners. As the understanding of cat behavior advances, litter box designs continue to evolve, promising advancements that enhance both the comfort of the cat and the convenience of the owner. Our group seeks to win on both fronts of this objective giving the best experience to all parties.

This ongoing evolution underscores the importance of thoughtful design in pet care products, striving to achieve a harmonious living environment for all. Our group hopes to serve to contribute to the automatic litter box design and provide our own unique additions to the product line. We believe we can make an impact to the design by adding new features such as cat weight monitoring and irregular cat bathroom trips. Our group places a premium on cat and user experience and we believe these potential additions allow the concept to further develop.

Chapter 7: Software Design

The main topic of this chapter is the discussion of the software components of our product. This includes the many tools and resources we used to design the code for the weight and motion sensor that would include the functions and libraries provided by Arduino's integrated software environment. There is also a section for the software designs of the mobile application for our Purrfect Cleaner that would go in depth about the resources we used for the server, database, and the preferred stack we decided would work best for our app. The mobile application was one of our stretch goals and we were not able to get it done in time for the demo.

MicroController Software Design

Motion Sensor Code Functionality

When designing the code for the motion sensor, we wanted to have a straightforward design so that there won't be any possible unseeable errors when it came to testing in both simulation tests and real-world tests. It uses the digital pins of the Arduino, D2,D3,D5, D12, and D13, to read the status of the motion sensor and to turn on the LEDs. Below is the procedure in the case of a moving object being brought into view of one of the sensors.

Procedure:

1. Reads the state of the motion sensor.
2. Check if the sensor pin is set to High (A moving object came into the view of the sensor).
3. If the sensor is High, then the LED is turned on and continue to step 5.
4. Else keep the LED off and return to step 1.
5. If the cleaning cycle has already started, stop the motor until the object is out of the view of the sensor.

Weight Sensor Code Functionality

Similar to the motion sensor code structure, the weight sensor has a straightforward design as well. The main difference between the two sensors is that the weight sensor used the analog pins instead of the digital pins. Most of the functions and variables used in the code were from the Arduino Hx711 library which was very helpful for getting accurate readings from the weight sensor. Below is the procedure of the weight sensors in the case of reading the current weight being applied to one or more of the sensors.

Procedure:

1. Initialize the scale at the pins A0 and A1.
2. Receive readings from the scales and set a delay for 1000 milliseconds for accurate readings in case more weight is applied.
3. Return to step 2.

Software Flowchart

The software flowchart shows that the users would have 2 inputs which are the cleaning Mode (input 2) which activates the manual cleaning and standby mode (input 1) which pauses all sensors and the timer with one press and the user would have to press it again to resume the timer and sensors. But in the case that no buttons were pressed, the timer would start and the weight and motion sensors would detect if anything has entered the box. If one has detected anything the timer would be paused and the LED on the PCB would turn on signaling that the timer is paused until the moving object is removed. Once cleaning mode starts, the motor would run and the weight sensor would be the only sensor operating to make sure the cat is not inside while cleaning. Once cleaning ends the timer resets and the process starts over.

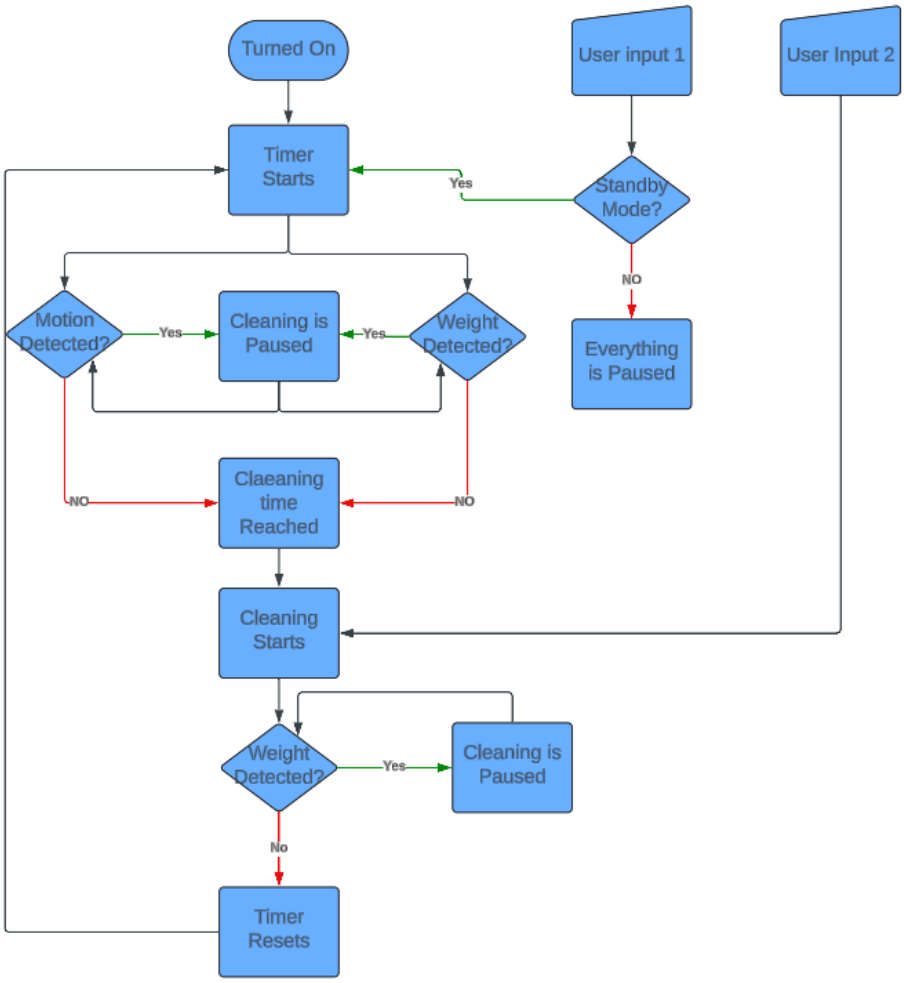

Figure 7A: Software Flowchart

Mobile Application Software Design

Use Case Diagram

This section covers the details of how users of our mobile app would be able to create an account and be able to access their personal information. We decided that a use case diagram would be the best to illustrate how our application can be accessed and what it can offer for our potential users. If it is the user's first time going on our app then they would have to create their own account with a username and password. They would also have to register a valid email address in order to be able to be sent any alerts about their Purrfect Cleaner. Once the email address is considered valid,

then username, password, and email address are then recorded in the database along with a personal customer identification number.

Once the user has created their own account then they can access any personal information related to their own Purrfect cleaner. They would be able to view data on the weight of their cat when they enter the litter box on a chart and be able to view alerts that may have been sent to their email address. All of the data comes from the database on the server which holds the information of all different users while each set of user data is assigned a customer identification number so that no unauthorized user has access to another user's information.

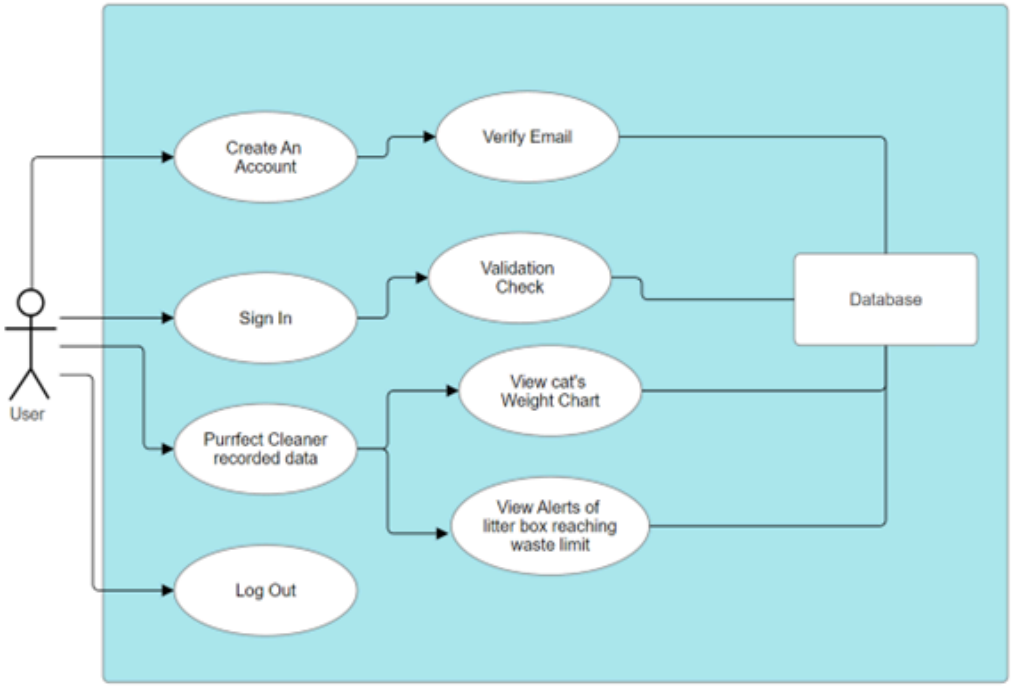

Figure 7B: Use-Case Diagram

Database Structure

Since we decided that we would be using Mern Stack for our application, we used MongoDB for our database. As discussed in chapter 3, MongoDB is a NoSQL server that utilizes a JSON format, JavaScript Object Notation, to store its data instead of using tables like in MySQL. The JSON format consists of key-pair, wide-column, or graph format for storing information. The information is stored as an object for better readability and results in a more simple method of extracting user information from the database.

In order to be able to have a good visualization of how our database would hold the user's personal information we decided to make an Entity Relationship Diagram or ERD for short. An ERD is basically a diagram that shows the relationship between multiple entities in an environment. Each entity may share elements within each other that could form a dependent relationship between them in order to access each other's information.

The ERD below is based on the structure of the database that would hold the information of users who own a Purrfect Cleaner. There are four entities which are the users, their own litter box model, the cat, and the sensors of the Purrfect Cleaner. Each entity would have their own attributes, in this case the attributes are data objects. The first entity holds the user's personal account information and their unique user identification number. The user's identification number has a PK label that stands for primary key which means the identification number identifies a specific instance of an entity since multiple users can have a unique ID number. This primary key can then link to another entity that requires that information to form a relationship with that entity which would be the Litter Box entity in this case. The user's ID number would now be labeled with FK which stands for Foreign Key in the Litter box Entity since it came from another entity. Then the litter box entity can form a relationship with its ID number with the Cat entity and the cat entity can do the same with the sensor entity.

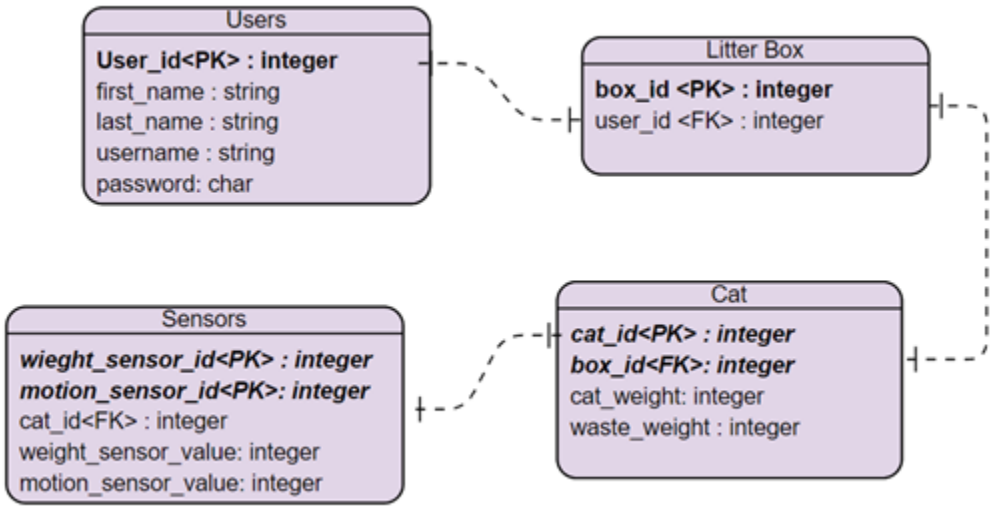

Figure 7C: Entity Relationship Diagram

Mobile App Structure

For our mobile application, we need to have the appropriate number of pages in order for the user's of the Purrfect Cleaner to be able to view their cat's weight and receive and view email alerts informing them that the waste limit has reached in their own account. We decided that we would have a total of 7 pages. The 7 pages are in the table below where the descriptions would be about each page's purpose and functions.

Mobile App Pages	Description
Access Page	This page would have two buttons that would lead to the sign up and login page once the app is opened.
Sign Up Page	Allows the user to create a new account. Users would have to input all relevant personal information.
Login Page	Allows the user to login to their existing account. With the requirement of inputting their unique username and password.
Home Page	Gives the user the option to view the weight chart of their cat or be able to view the alerts they have been sent to their email.
Alerts Page	Lists all alerts that user has received over email with a scrollable panel.
Cat Weight Chart Page	Shows the user's cat weight on a chart over a 1-week time frame.
Settings Page	Gives users the option to edit their personal information such as cat name or email address and log out of their account.

Table 7A: Mobile App Pages

Mobile Pages Design

As discussed in the Mobile App Structure section, we planned to have a total of 7 pages for our mobile application. The 7 pages would be the access page, sign up, login, home, alerts, cat weight chart, and settings page. We thought it would be best to create some mock pages to better visualize what our app may look like during the final stages of our project. We wanted our application's design to go with the theme of cats since that is what our product caters to. The designs of apps are important when trying to get people to use them as well as the features it offers. That's why we used the UI designer website called uizard.io to make these mock app pages below. With the tools provided we can make a visually appealing app with modern designs that we can implement later during Senior Design 2.

The first two pages below are the access page and the Sign-Up page. The access page would be the first page that our users see. It gives the users the option of choosing whether to create an account or to login into a pre-existing account with the two buttons. We have also used free copyrighted images for both the background and logo to not have any issues with copyrights. For the sign-up page, there are some input boxes where the user can type in their personal information, username, and password. There is also a bars icon for the case that the user would like to access settings or to redirect back to the access page.

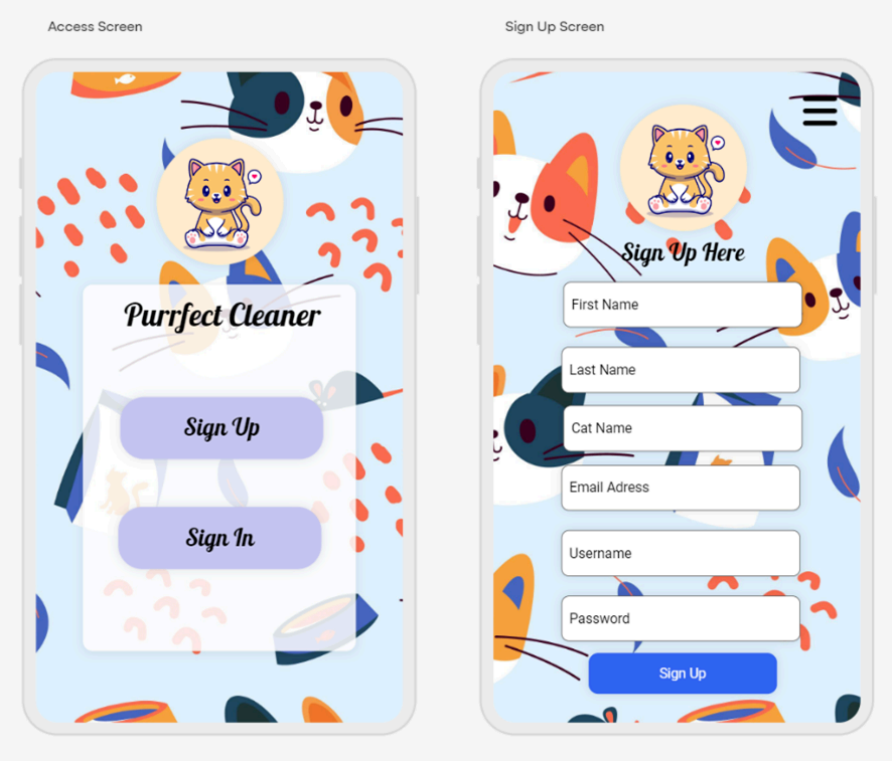

Figure 7D: Access and Sign-Up Pages

Next, we have the home page where users are redirected here after they have logged into their personal account. It's a simple format where the user can decide whether to check the tab of alerts they have received in their email or to view the weight chart of their cat with the cat's name they have inputted to give a more personalized feel. This page also has the bar icon where it would direct them to the settings page where they are given options regarding editing info or logging out of their account.

To go into more detail about the setting page, it offers users the choice to change their password, sign out, edit any personal account information, and redirect to the home page. Normally setting pages would only have options that would allow users to edit personal information such as password, in the case of our application we decided to also include additional options to better the experience of those who use our app since it is all in the same place. When users click on the sign out button they are directed to the access page, so there would be no need to add buttons that would redirect to those pages on the settings page.

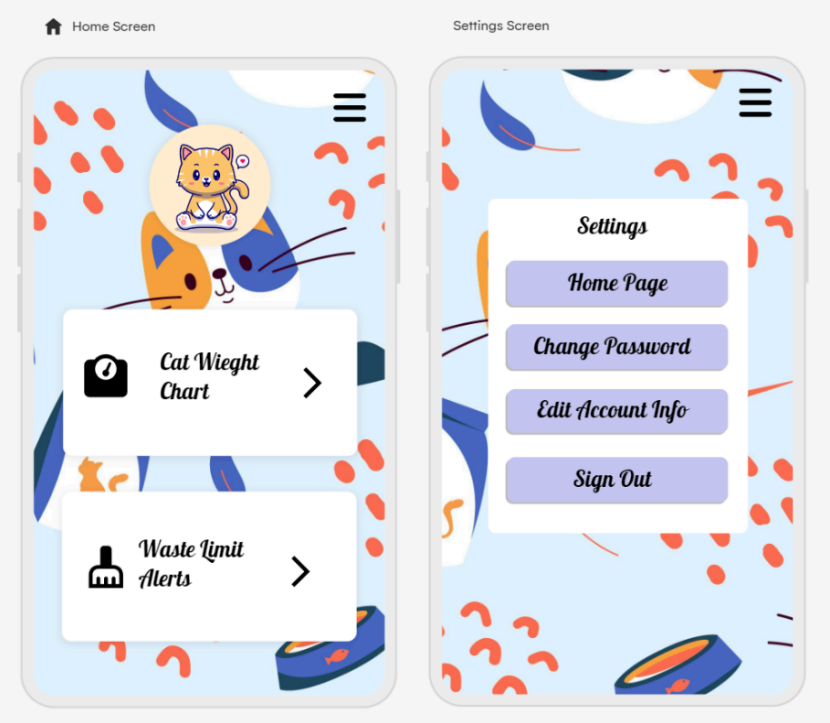

Figure 7E: Home and Setting Pages

Lastly, we have the cat weight chart and alerts pages. For the cat weight chart, we wanted to do a line chart where the x-axis would be the date of when the current weight of the cat was recorded and the y-axis would be the actual weight values.

Unfortunately, uizard didn't have a line chart so in the mock page a graph chart had to be used. The chart would be updated every day during the time that the cat has entered the litter box to get an accurate reading of the cat's weight. The motion sensors would indicate that the cat was near when new weight was applied on the weight sensors and that is when the cat's weight would be recorded. This is to prevent the case of the sensors recording the weight of the cat's waste instead of the cat itself.

For the alerts page there would be a list of alerts with the date and time it was sent to the user's email address alerting them of the waste bin being full. It also has a scroll bar where it can hold more than four alerts. We felt that it would be good to include an alerts page in our app to help the user keep track of all the alerts sent for the case that it could get lost in the user's numerous emails in their email address. It can be common for people to get a lot of emails in one day especially if they have a job, so we thought it would be a helpful inclusion in our application.

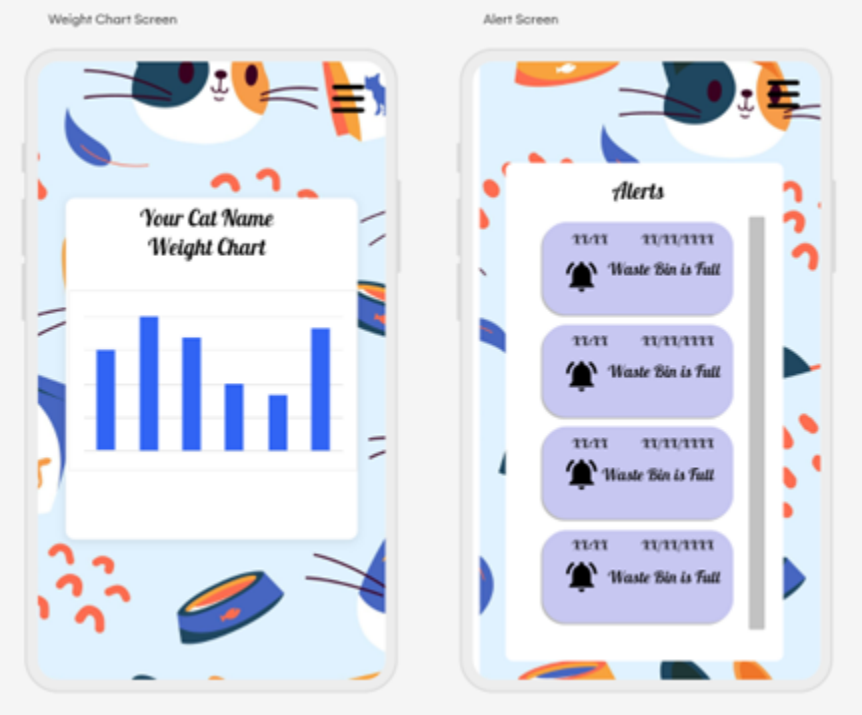

Figure 7F: Weight Chart and Alert Pages

Email Alerts Method

Two of the features of our mobile application include email verification and having alerts being sent to the user via email. Email verification is important to make sure that the user has input a valid email address in order to receive alters and to make sure when they first make an account that a message from our server was successfully sent

before continuing. In order to be able to have these two features we have decided to look at different services that provide the capabilities of performing them.

As discussed in Chapter 4, the two services that provide email verification services would be Google and Microsoft. Google has a Google Sign In service that can be implemented in the backend code of our Server that would allow users with a google account to instead sign in with that account. This would then allow our server to create a new account based on their google account where an ID would be made for it. While having all the necessary personal information of the user. We would just need to qualify for a client ID that requires us to make authorization credentials.

For Microsoft's alternative, it is very similar to Googles where it requires a Microsoft external tenant similar to Google's client ID but does include a free trial. The main difference is that after the user creates a new account a code is sent to their email address, and they would have to input the code in the app to be able to login in. The process for making this method work involves signing into Microsoft's Entra Admin Center and enabling the Email OTP settings after creating a conditional access policy. In the end, we have decided to go with Google's Sign in software because we felt that Google's method was that it had straight forward method of using the user's google account that already had a register email address to send all of the information to the server which would make creating an account for another service a quick and simple process for the user.

For the method of sending waste limit alerts to users of the Purrfect Cleaner, we have researched two services that are SendGrid and MailerSend. Both of these services offer programs that make our app capable of sending emails to our users. When users create an account on our app, our servers would have access to the Purrfect Cleaner model and then record weight data from the weight sensors to see if the cat's waste has gone over the maximum limit. Once the limit has been reached an email is sent to the user's email address informing the user that the waste limit was reached and that the waste bin must be emptied. The app also has a page of all waste alerts sent to the user's email address. So, when researching these two services, we decided MailerSend would be the best choice.

Starting with SendGrid, it is a cloud-based service that provides web and mobile applications with the ability to send emails to their customers. The types of emails it offers are sign up validations, advertisements, and shipping alerts. It has its own Mail Transfer Agent and a cloud-based architecture that both better the performance and speed of the emails they send to many of their clients per day. SendGrid on average sends 90 billion emails per month while maintaining a sending speed of 1.9 seconds for each email sent. They also ensure that emails reach their designated destination by having their Mail Transfer Agent having management development tools help with the inbox placement.

MailerSend, similar to SendGrid, also provides applications with the ability to send emails to their users. It also provides most of the features that SendGrid offers such as sending email validations, the capabilities of sending thousands of emails per month, and providing many safety and performance protocols to make sure users are able to get their emails fast and efficiently. MailerSend, however, allows 3,000 emails to be sent free per month whereas SendGrid only allows 300. MailerSend also offers onboard assistance if there are any issues with setting up its service.

Chapter 8: System Fabrication

This chapter of the paper outlines the physical components and its layout in our system that are used for ordering its fabrication from a PCB assembly vendor, such as JLCpcb. It includes a detailed description of the Printed Circuit Board (PCB) design and the schematic layout of how each individual resistor, capacitor, button, sensor, motor, LED light, and power supply connect to one another.

PCB Schematic

The PCB schematic is the starting baseline for how each component should connect to one another. It is an easy to understand drawing meant to give the reader a quick understanding of what each thing is supposed to do. **Figure 8A** shows our system's PCB schematic that incorporates the ATMega328P microcontroller, two buttons, header for the infrared motion sensor, the weight sensor, and the motor, an LED light, the USB-C connector for delivering 5V power to the entire system, and the 6.5V DC/DC Converter Circuit to run the motor.

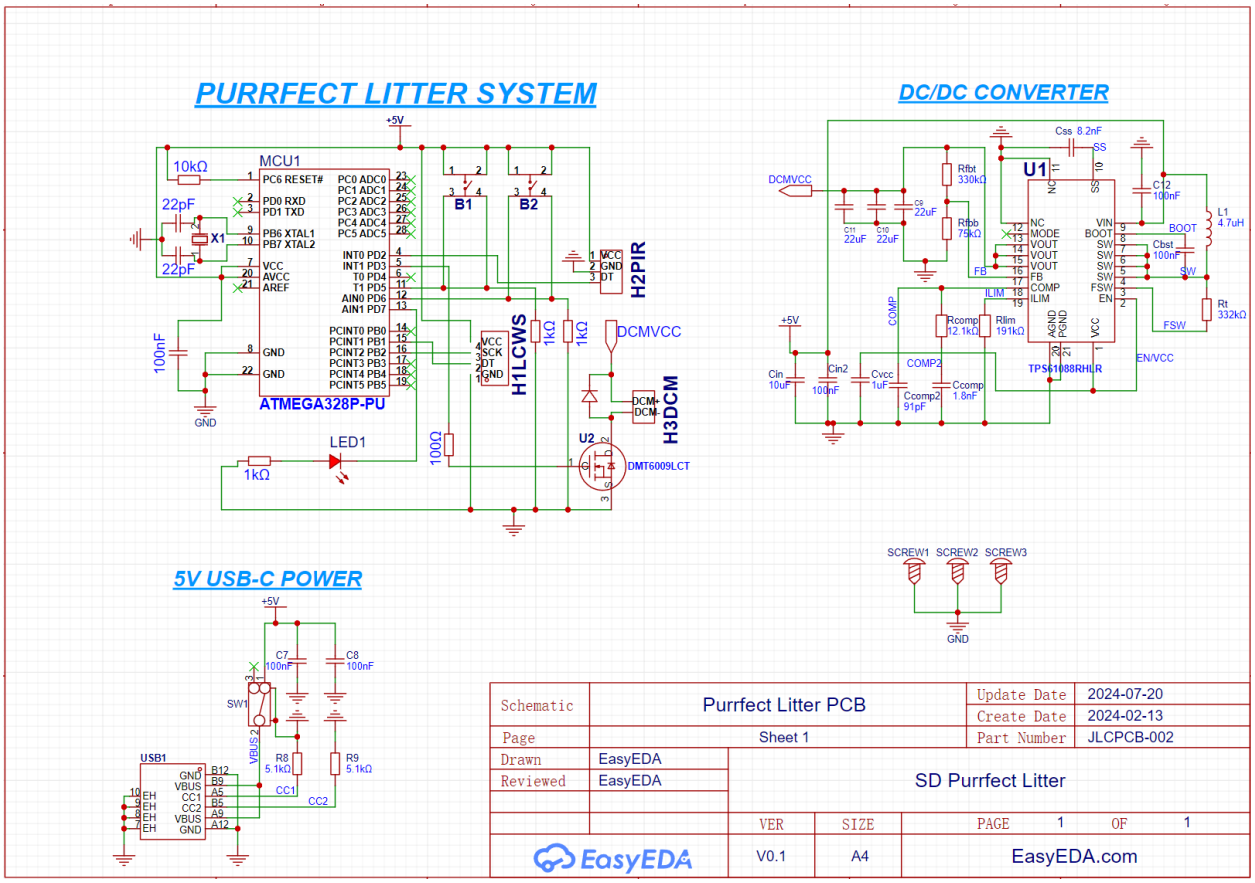

Figure 8A: PCB Schematic

The schematic was designed to operate the automatic litter box with the specifications lined out in this document. While this schematic was created from the ground up, the understanding of how each component connected started with the understanding of the datasheets for each individual component. For example, the Arduino R3 is a developer board that uses the ATMega328P microcontroller, and is the same board that we used in testing our system, more info about this is detailed in **Chapter 9: System Testing and Evaluation**. Because of this, the data sheet for the Arduino R3 was referenced in order to determine which pins were meant for certain peripherals. This strategy was followed similarly for the other components in the system, and it is discussed here as to what each pin on the components mean. Additionally, pins labeled as V_{BUS}, V_{CC}, and GND are not discussed for every component unless it is deemed important to do so. These pins are almost always the pins for input power for the component (V_{CC}/V_{BUS}) and connection to ground pins (GND).

USB1

USB1 is the component on the far left side of the schematic, it is the USB type C connector that connects the power supply to the board in order to receive power. It provides 5V power to the system efficiently and safely.

EH: These four pins on USB1 are known as the shield of the connector. This part is meant to protect against Electromagnetic Interference (EMI) if the USB connector is also handling data signals, like how a mobile phone can connect to a computer to send photos. This connector is usually connected straight to ground for the best EMI protection.

CC: These two pins on USB1 are the configuration channel pins of the connector. These pins are meant to serve as protection against supplying too much power to the system. Before it supplies 5V power on the V_{BUS} pins, it uses the resistors on the CC pins as a pulldown, reading the voltage division value between the input source connector on one side of the wire, and the output source on the other [32]. These CC pins are the output side of USB1, Figure 8B shows an example of the CC pins on a USB-C to USB-C cable. The typical resistor values for Rd are 5.1K Ohms, which are the values we are using for these pins.

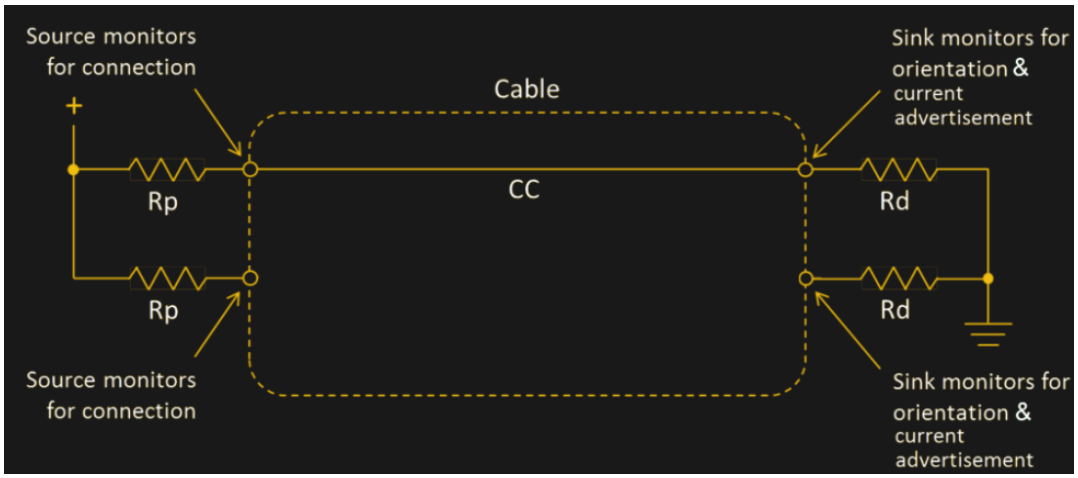

Figure 8B: Example of CC Pins

H1LCWS

H1LCWS stands for Header #1 Load Cell Weight Sensor and in its name it is meant to connect the weight sensors that we used in order to monitor the litter box to the MCU. The weight sensors are located separately from the PCB, so headers are used in order to solder wires for connection.

DT: This pin on the H1LCWS header is the Data Out pin, it is the signal that the MCU uses in order to determine the current weight present in the litter.

SCK: This pin on the H1LCWS header is the Clock In pin, and it connects to the ADC module pin on the MCU, where the clock is defined.

X1

X1 in the system represents the 16MHz crystal oscillator that is used to keep the timer of the system. It also allows the ATMega328P to be a standalone Ardunio without the need for an actual Arduino Uno board and the need to configure the internal 8MHz oscillator in the MCU. It is connected to pins 9 and 10 of MCU1, the ATMega328P XTAL clock pins, with two 22pF capacitors on each lead connecting to ground.

MCU1

MCU1 stands for Microcontroller #1, in this system it represents the ATMega328P microcontroller that is the center for traffic of all the signals in the system. Every peripheral: the weight sensor, motion sensor, motor, button, and LEDs are connected to this component. The datasheet for the MCU details the specific functionality for each pin, so it was referenced for this section.

PB0:7 (Pins 9, 10, & 14-19): PB stands for Port B, and it is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low source current if the pull-up resistors are activated. The Port B pins are tristated when a reset condition becomes active, even if the clock is not running.

Depending on the clock selection fuse settings, PB6 can be used as input to the inverting Oscillator amplifier and input to the internal clock operating circuit. Also, depending on the clock selection fuse settings, PB7 can be used as output from the inverting Oscillator amplifier. If the Internal Calibrated RC Oscillator is used as chip clock source, PB6...7 is used as TOSC2...1 input for the Asynchronous Timer/Counter2 if the AS2 bit in ASSR is set. The various special features of Port B are elaborated in ”Alternate Functions of Port B” on page 91 and ”System Clock and Clock Options” on page 36 of the ATMega328P datasheet in the references chapter [5].

PC0:5 (Pins 23-28): PC stands for Port C, and it is a 7-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The PC0..5 output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low source current if the pull-up resistors are activated. The port C pins are tri-stated when a reset condition becomes active, even if the clock is not running [5].

PC6 (Pin 1): If the RSTDISBL fuse is programmed, PC6 is used as an input pin. If the RSTDISBL fuse is unprogrammed, PC6 is used as a reset input. A low level on this pin for longer than the minimum pulse length generates a reset, even if the clock is not running. The minimum pulse length is given in Table 28-4 on page 261 of the ATMega328P datasheet in the references chapter. Shorter pulses are not guaranteed to generate a reset. The various special features of port C are elaborated in Section 13.3.2 “Alternate Functions of Port C” on page 68 of the ATMega328P datasheet in the reference chapter [5].

PD0:7 (Pins 4-6 & 11-13): PD stands for Port D, and it is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, port D pins that are externally pulled low source current if the pull-up resistors are activated. The port D pins are tri-stated when a reset condition becomes active, even if the clock is not running. The various special features of port D are elaborated in Section 13.3.3 “Alternate Functions of Port D'' on page 70 of the ATMega328P datasheet in the references chapter [5].

AV_{CC}: AV_{CC} is the supply voltage pin for the A/D Converter, PC0:3, and ADC6:7. It should be externally connected to V_{CC}, even if the ADC is not used. If the ADC is used, it should be connected to V_{CC} through a low-pass filter. Note that PC4...6 uses digital supply voltage, V_{CC} [5].

The remaining pins of MCU1, which are pins 2-3, 6, 14, 17-19, 21, and 25-28, are shown with an “X” symbol on the connector. This is a No Connect Flag for specifying that no connection on this pin is required for our system, and it is important for the PCB vendors to know that these connections are not needed when ordering.

B1

B1 stands for Button #1, and in its name it is one of the two buttons that are implemented in the system. B1 is responsible for issuing a stop signal to the motor and keeps it stopped until pressed again. Terminals 1:2 are connected to the 5V bus of the system, and terminals 3:4 are connected to port PD5 of component MCU1 with a ground connection through a 1 kOhm resistor. When the button is pressed, the port PD5 reads a High value, and issues the stop signal. When the button is not pressed, it reads a Low signal from the connection to ground through the resistor. The signal to the motor stays constant until the button is pressed again, and the High output is read on pin PD5.

B2

B2 stands for Button #2, and in its name it is one of the two buttons that are implemented in the system. B2 are responsible for issuing a start signal to the motor to allow user interaction for scooping the motor, should the owner deem necessary to do so. Terminals 1:2 are connected to the 5V bus of the system, and terminals 3:4 are connected to port PD6 of component MCU1 with a ground connection through a 1 kOhm resistor. When the button is pressed, the port PD6 reads a High value, and issues the start signal. When the button is not pressed, it reads a Low signal from the connection to ground through the resistor. The signal to the motor does not stay constant and only causes the motor to do one sweep when pressed.

H2PIR

H2PIR stands for Header #2 Passive Infrared Sensor. This header is where the E18-D80NK Motion Sensor that is implemented into this system connects to on the PCB. The motion detector is used to issue a stop signal to the motor should any movement inside the cat litter be detected, a safety feature inorder to protect the feline. The data sheet of the motion sensor is referenced and it can be found in the references section of the document.

DT: The DT pin of the H2PIR header is the Data (Out) pin, it is the signal that the MCU uses in order to determine if motion is present in the litter, and then issue the stop signal to the motor when necessary.

H3DCM

H3DCM stands for Header #3 DC Motor, it is the header in which the DC motor that we used in the system connects to. The DC motor that we used can use a wide range of voltage levels, with its max capability being 12V power. The pins on the header only encompass the voltage source for the power pins (DCM+ and DCM-). This is because the motor we are using is able to rotate both clockwise and counterclockwise, all that needs to happen in order to change directions is to change the polarity of the voltage input.

Our solution for controlling the motor that we have implemented is to use a MOSFET as a digital switch (U2), specifically, we chose to use the DMT6009LCT MOSFET. By connecting the Gate side of the MOSFET to the MCU using a 100 Ohm resistor and using the pin as an output source, we can use the MOSFET as a digital switch to power on and off the motor, giving the system control over when the motor should run. Because the MOSFET is an N-Channel MOSFET, the motor is connected to the Drain side of the MOSFET, followed by the Source side being connected to ground.

U1

U1 stands for unit #1, and it is the 6.5V Regulator Chip that we are using to supply 6.5V power to the motor. The chip is the TPS61088RHLR from Texas Instruments, and the circuit made for this chip was laid out as specified in the datasheet for the Texas Instrument Chip found in reference [56] on page 14 to ensure the chip functioned as intended. The output of the circuit for the chip is connected to the motors DCM+ pin, and in which the other end of the motor, DCM-, is connected to the Drain side of the MOSFET that is used to allow power to flow through the motor.

PCB Layout

This section of the document details the physical layout of the Printed Circuit Board that was ordered from an assembly manufacturer for our prototype testing, and eventual purchase to make our final product. **Figure 8C** and **Figure 8D** show the layout of where each component on the circuit board is, along with the runs for each connection on the component that was detailed in the PCB schematic section. Additionally, **Figure 8E** shows a 3D model of how the PCB looks like when constructed, a useful feature courtesy of the EasyEDA PCB design software.

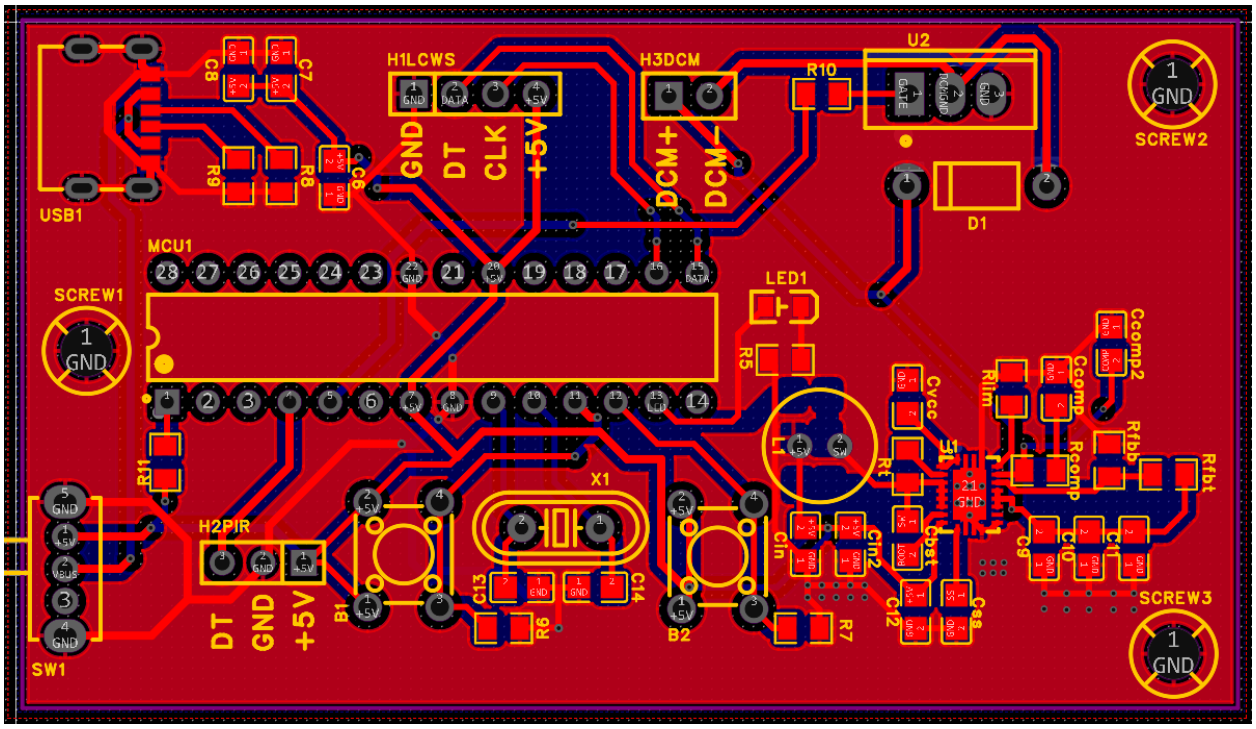

Figure 8C: Physical PCB Layout Design (Top Layer)

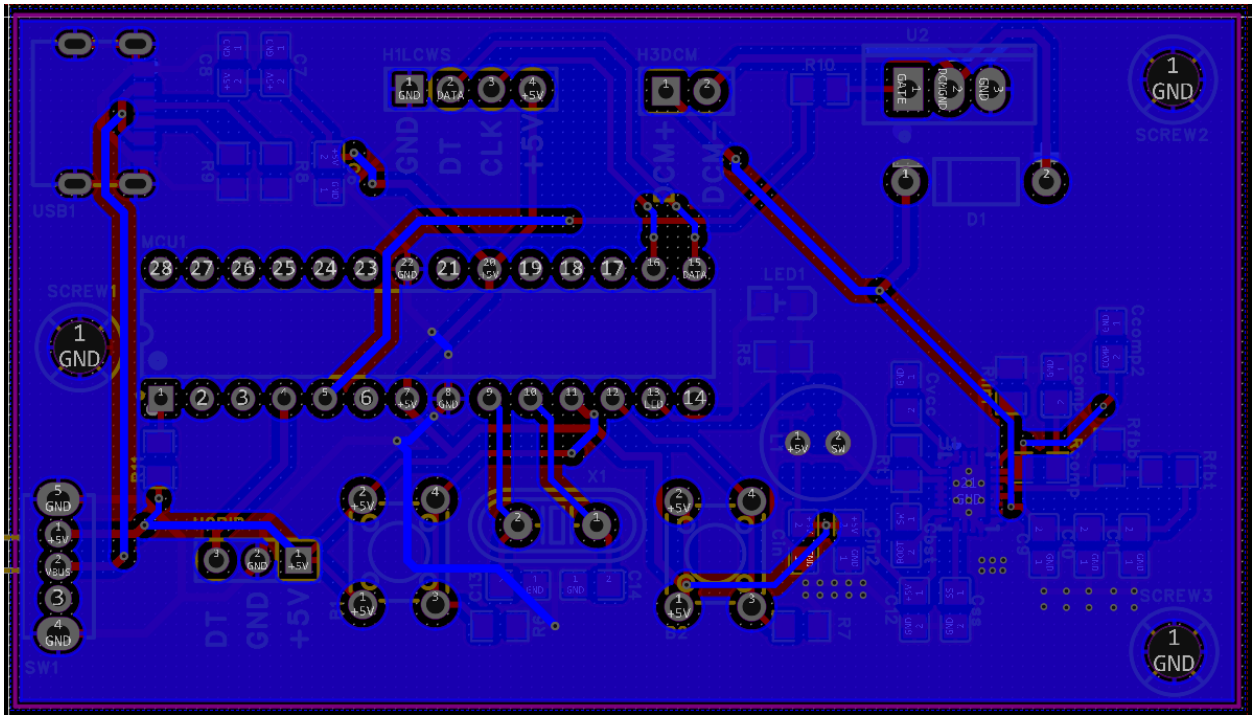

Figure 8D: Physical PCB Layout Design (Bottom Layer)

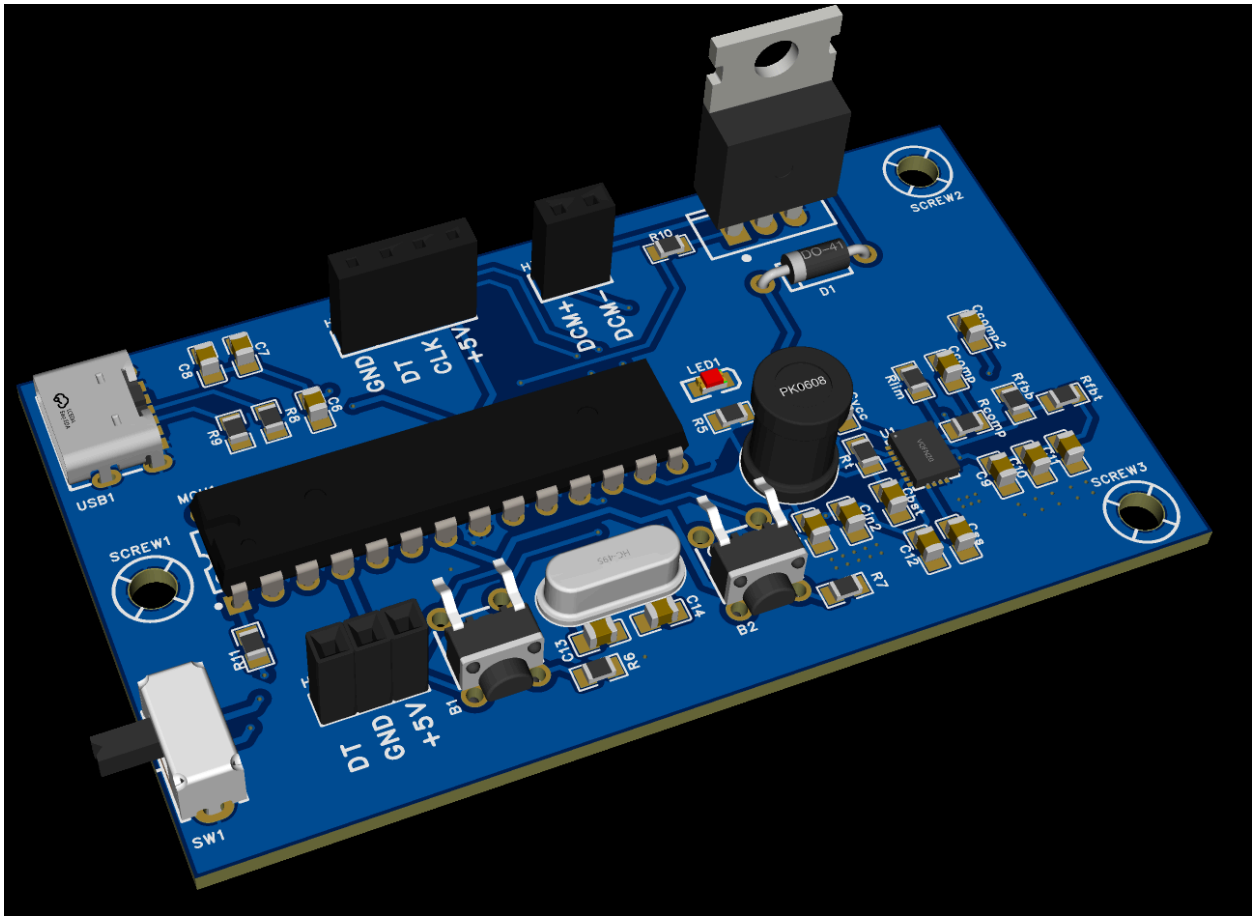

Figure 8E: 3D Model Depiction Of PCB Layout

As said earlier, the software used for these designs was the EasyEDA PCB Design Software, it allows for easy creation of this layout by allowing immediate porting of updates based on the schematic. Essentially, if we add a new component to the schematic and connect it to the system, EasyEDA has a quick update function on the PCB layout that ports the new component and connections to the layout without changing your previous progress. It also removes components or connections if it was removed in the schematic, allowing for quick and easy addition or subtraction of changes that were implemented when we tested our prototypes in Senior Design Two.

The red connections on the layout represent connections made on the Top Layer of the PCB, these connections can be seen in the 3D model **Figure 8D** on the top side. The blue connections on the layout represent connections made on the bottom layer of the PCB. Some connections on the top layer prevented a straight route from one component to another, therefore, VIA points were utilized for some components to route its connections through both the top and bottom layers, bypassing any other connections that prevent it from reaching where it needs to go. Each VIA point was

made with a NET label attached to it, this is to tell the EasyEDA software which connections the VIA point should be looking for on the layout.

For example, in the PCB layout, R6, or Resistor #6 found near the bottom left side of the layout connected to terminal #3 on the button B1, required its ground connection to reach the GND pin #8 on the ATMega328P MCU1. This connection was already being prevented from the connection of terminal #1 on the button B1 to the 5V pin on H2PIR. In order to bypass this, a VIA point was placed next to the resistor R6, and a top layer connection was made to the VIA. Then, a second VIA point was placed near pin #8 on MCU1, in which then the two via points were connected with a blue bottom layer connection line that allowed it to bypass existing top layer connections. Finally, the VIA point close to the GND pin on MCU1 was connected together using a top red layer connection, completing the resistor R6 connection to ground.

The left side of the PCB is shaded in red, this indicates a copper area ment for the ground network, all components with a ground connection connect to this copper area, its area can be changed in the software The PCB used the ATMega328P microcontroller (MCU1) that handles all the signal traffic in the system. Three separate sets of header: One 4-Pin header (H1LCWS) that is used for connecting the weight sensors of the system to the MCU, one 3-Pin header (H2PIR) that is used for connecting the motion sensor of the system to the MCU, and one 2-Pin header (H3DCM) that is used to connect the DC motor of the system. Also, Two TS02-66-60-BK-160-LCR-D push buttons (B1 and B2) to allow user interface with the system, and LED light to indicate when the motion sensor detects motion in the litter, and any accompanying components such as capacitors, resistors, and transistors for connection to each component. The PCB is powered using a USB type C connection (USB1) that provides a 5V power source to all the components in the system.

Additional components may need to be added (or removed) to the design during the testing phases of Senior Design Two, and updates to this document have been made. Once updates are made, it must be sent to the PCB vendor, JLCpcb, in order to receive a new quote and make a new order as soon as possible to continue with PCB testing. Pricing, component choice, component values, and PCB design and layout is a must to be updated in this document when changes occur.

Chapter 9: System Testing and Evaluation

This chapter in this document details processes that were used in testing and evaluating the system components, both individually and in unison. The importance of equipment adequacy is highly emphasized in order to ensure that the system performs exactly as expected and in a safe manner as to not injure any felines of the consumer.

Simulation Testing

In addition to physically testing the components we used in our system, we used simulation software that is able to use the exact components we have chosen. The simulation is an added testing procedure for allowing us to make sure that our components can and should work as intended. Of course, these simulations do not take into account the environmental aspect of how we would test these components physically, and so this testing procedure is more to be used as confirmation that the components *should* work with one another.

The simulation software is called **TinkerCad**, an example of the simulation is shown in **Figure 9A**. In the example, it is using an Arduino Uno R3 with the ATMega328P, the same MCU we used in our system. It is also using the HC-SR501 PIR Motion Sensor, the TS02-66-60-BK-260-LCR-D Mechanical Button, and a couple of LED lights, all components that we used in our system. The simulation also allows us to write test code into the Arduino to interact with the different peripherals.

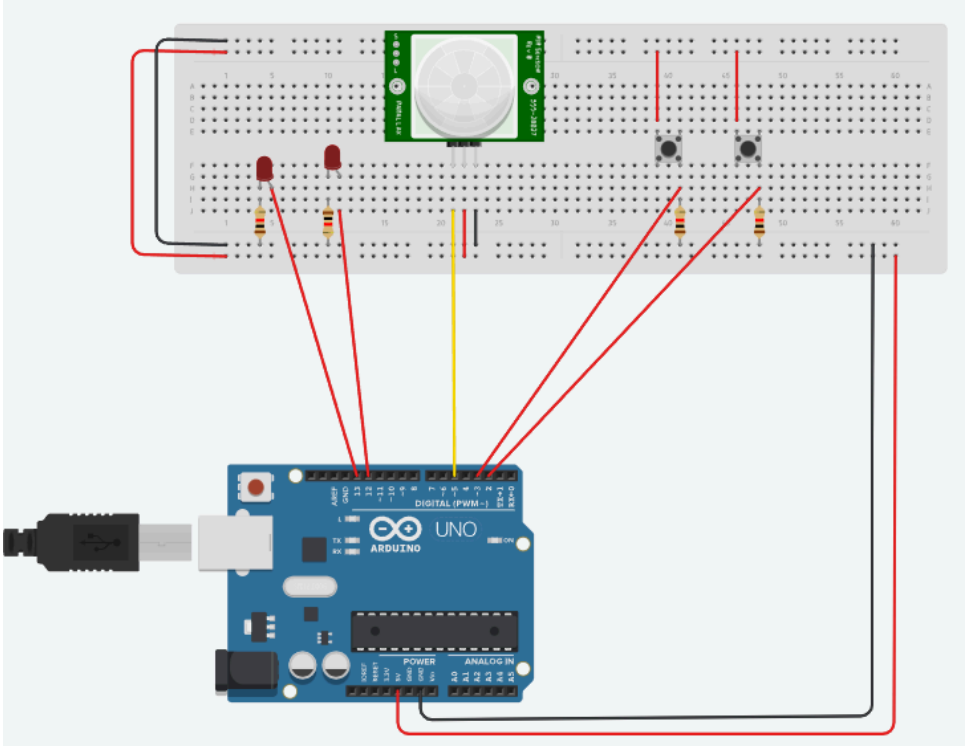

Figure 9A: Tinkercad Simulation Example

After writing test code and connecting the peripheral together on the simulated breadboard, we can then “physically” interact with the components. We can press the buttons on the breadboard, move an object in front of the PIR sensor, or disconnect the power cord from the Arduino, and watch as to how the system reacts. This simulation allows for an easy way to test components in a safe environment that would prevent breakage, and can confirm with this simulation how we should connect components together.

Prototype Testing

The prototype used to ensure all components meet our requirements for producing the Purrfect Litter automatic cat litter box. The following section gives every necessity that each component must meet in order to receive a green check of acceptable performance. Each sensor, motor, MCU, and power supply was tested and evaluated according to these guidelines. The vendor for our PCB was ordered from JLC PCB, in which we provided a schematic capture that they can use to build it for us. We ordered multiple PCBs in order for us to do extensive testing to our system.

PIR Sensor

The PIR Sensor used to detect the presence of a cat in the litterbox, this is a key factor on whether or not the scoping process starts. The motion sensor collaborates with the weight sensor to ensure the safety of the customer's cat.

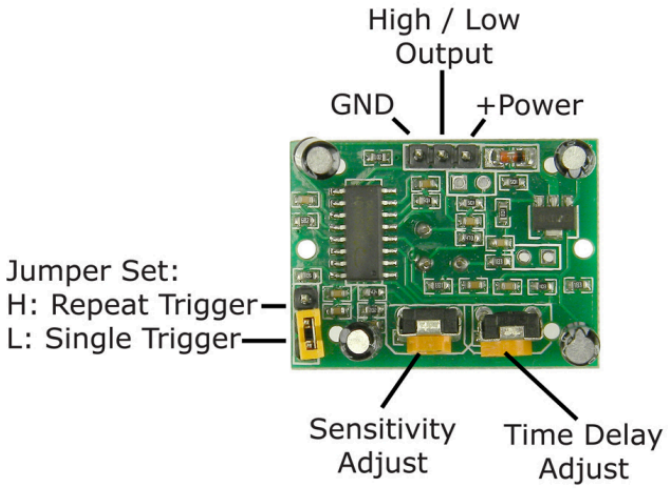

Figure 9B: PIR Sensor Features

Figure 9B shows the features that the PIR sensor offers, the 3 pins that you see on the top are the inputs and outputs of this component. The main goal of this test process is to test the high/low voltage of the output pin. When this sensor detects an object moving, it would output 3.3 voltages from the output pin. The Sensitivity adjustment is a potentiometer that you can modify the range of detection, and the time delay adjustment is to adjust how long the output signal lasts.

There are two modes that can be used in different scenarios:

- Non-repeatable trigger: Sensor output changes from high to low automatically after delay time is over without human activity affecting the output.
- Repeatable trigger: Sensor output remains high if there is human activity in its sensing range, and the delay period extends automatically with each new human activity until there is no activity detected for the delay duration, causing the output to change from high to low.

We operated the sensor in repeatable trigger mode for the project.

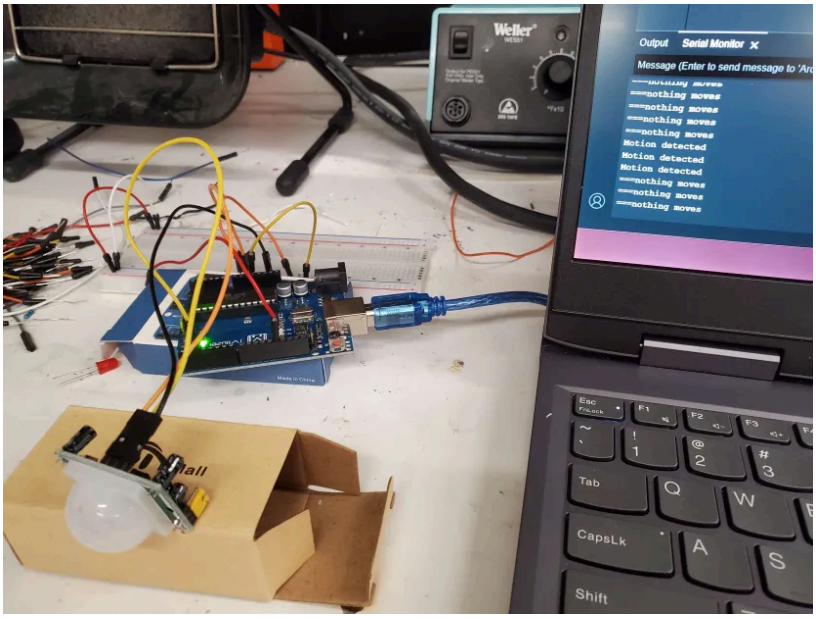

Figure 9C: PIR Sensor Testing

Similar to the set-up used in the simulation testing, we downloaded the Arduino IDE platform to test the set-up with Arduino UNO. This Microcontroller uses the ATMEGA328P chip and ATMEGA16U2. The features from the chip ATMEGA16U2 won't be used in our final PCB.

After uploading the code to the Arduino IDE and loading it to Arduino UNO, we tested the sensor on a non-repeatable trigger. The sensor was pointed at an open area, after we initialized it we tried to minimize movement and the output pin from the sensor is LOW which displayed "nothing moves" in the feed-back channel. After we made sure that it was able to send the correct output when no motion was detected, we waved our hand about 1 meter in front of it. The output pin pulled high for about 1 second and pulled low, which works as intended.

Lastly, we jumped the first two pins on the left-hand side of Figure 9B, and changed the operating mode of the sensor from non-repeatable trigger to repeated trigger mode. After initialization, we repeated the same test process when nothing was moving. Then, we kept waving a hand about 1 meter directly in front of the sensor and the output pin was able to output a high voltage constantly when the hand was moving. After the movement stopped, the high output state lasted for about 1 second and pulled low. With the above performance, the sensor is working as intended.

Buttons

The buttons on the Purrfect Litter are used for user interaction on the system. Two buttons are utilized, one for putting the system on standby to prevent the motor from

going off, and one for immediately starting the scoop motor. Both buttons read on the rising edge of the signal input, and once read should immediately begin the associated action. The buttons should be able to withstand multiple pushes in a 8 hour time frame to simulate regular use in a household. Four buttons are tested to ensure that the one we use for our system is not faulty. All four are compared with one another to ensure that all meet the same functionality.

MCU

The MCU in our system is the brain of operations, controlling the traffic of signals from one component to the next, and as well as some power delivery to some of the other peripherals. The software code is written in the C language and uploaded into the MCU. The MCU must be able to handle all peripherals that we used in the system, this includes: two buttons, a motion sensor, a weight sensor, a motor, and (possibly) an internet adapter. The code and MCU work together to ensure the signals to each of these peripherals are in a timely manner, occur when appropriate, and store values when necessary.

With the code, the MCU should operate accordingly with each peripheral. When the weight sensor detects weight in the litter, the appropriate triggers occur, the MCU receives the signal from the sensor, and the MCU sends the appropriate signal to one of the other peripherals, such as the motor. The MCU is the traffic for all these signals, and it must be able to handle all traffic to each one without fail. The test for each component in the system also applies to the MCU, since to interact with the peripheral would need to be through the MCU. The green check of approval for the MCU would come when all peripherals have been tested individually and together at the same time in different trials.

The MCU should also keep track of a timer in order to plan the moments for sweeping. The system is programmed to run once every 3-4 hours, and in order to achieve this requirement the system must keep track of the time. The ATMega328P has an 8-bit and 16-bit timer installed that we can utilize to achieve this. At the high end, 4 hours constitutes 14400 seconds, which can easily be handled by the 16-bit counter on the ATMega328P with its max integer limit of 32767. The 8-bit timer can only hold an integer limit of 255, which is far below the needed time for a four hour time interval. The MCU is tested with an interval of ten minutes in order to ensure the timer works properly, and to determine its accuracy. If deemed acceptable, the intervals are increased by ten minutes and retested again, until the intervals reach one hour. After this testing is done and found the accuracy and workability of the time to be in perfect condition, a final test with either a three or four hour interval can be conducted to receive a green check of approval for the timer in the MCU.

Weight Sensors

The weight sensors in the system are used for both activating the scooping motor after the cat has done its business, and for security purposes as to prevent harm to the feline. To be determined in evaluation, the sensor should read and send the correct measured weight of the cat litter with ±98-99% accuracy. This also includes the variability when the weight of the litter changes depending on what goes in or out of it. Multiple objects with varying weights are used to determine the strength of accuracy the sensors produce, the objects vary within the limits of the sensors capabilities. Three separate sets of the weight sensors were used to ensure that the one we use on our system is not faulty and meets our expectations. Each one is compared with one another for comparing functionality, and all three should have the same outcome if they are in pristine condition.

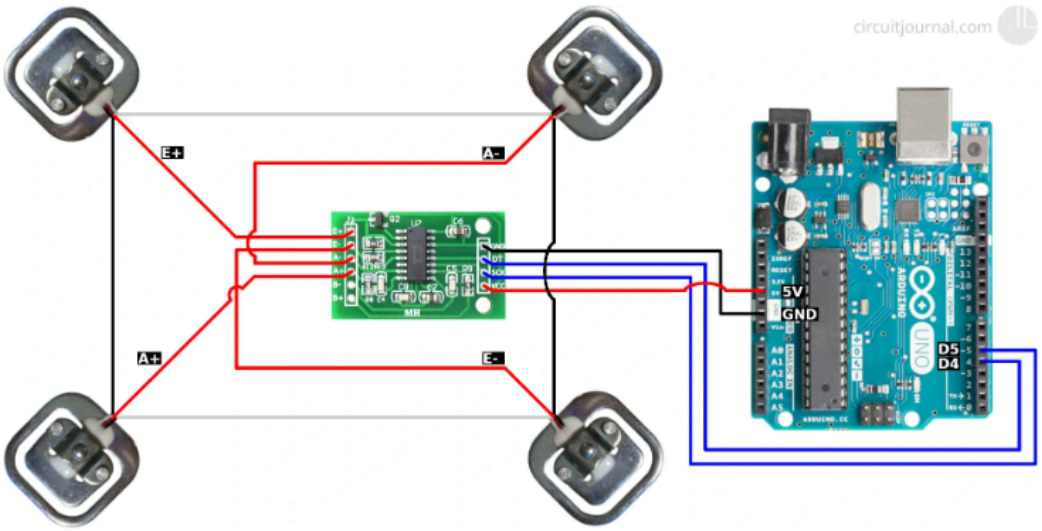

Figure 9D: Weight Sensor Connections

In Figure 9D, it shows the connections between the 4 weight sensors which go to the 4 corners of the bottom of the cat litter box. There are three wires coming out from each weight sensor, the red wire is used to transmit analog values to the Analog to Digital Converter, the black wire and the white wire are used to transmit data in between the weight sensors.

After we connected the weight sensors to the Analog to Digital Converter, we followed the same connections from the chip to Arduino Uno as shown in Figure 9D. There are 4 pins coming out from the chip, two of them are power supply and ground. The other one is the clock and the serial data output pin. These two pins both connect to the digital pin, they work together to send values to the microcontroller.

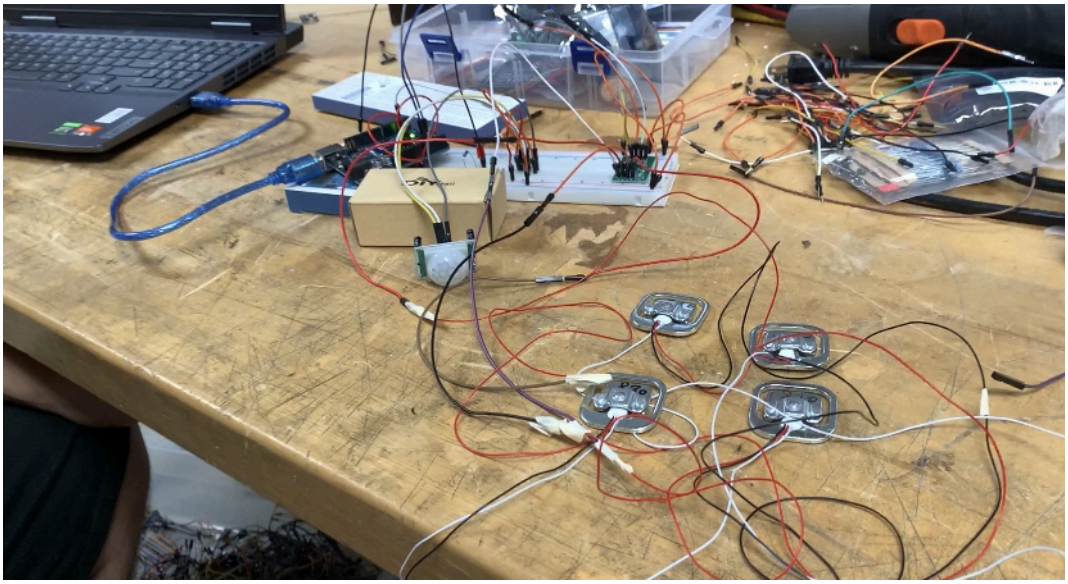

Figure 9E: Weight Sensor Testing

When all the connections were finished, we uploaded the code to the platform. Our results are not ideal, the weight sensor was returning garbage (random) values, we made sure that all the wires are connected to the same pin and the code seems to be fine. The only possibility of this outcome is that some of the corrections between the thin wires from the weight sensors are not connected properly.

Therefore, we decided to move on to another type of weight sensor, the digital load bar weight sensor. With the digital load bar weight sensor, the main body is a bar of metal with 4 wires coming out from it instead of having 3 wires coming out from 4 different weight sensors. This is less complicated, and secured connections. The new weight sensor also uses the HX-711 analog to digital converter, the connections from the HX-711 to the microcontroller are similar, two pins for power and ground the other two are clock and data output. Additionally there's no need to wait for settling after initiation compared to the previous one, the only down size is that the weight capacity is 20 kilograms, which is less than 50 kilograms.

Figure 9F illustrates the experimental trials conducted on the load bar weight sensor. Our findings revealed that the side closer to the wire has higher sensitivity to variations in weight, whereas the opposite side demonstrates lower sensitivity. This discovery holds significance as it guides us in determining the optimal placement of the load bar within our prototype design, ensuring accurate weight measurement.

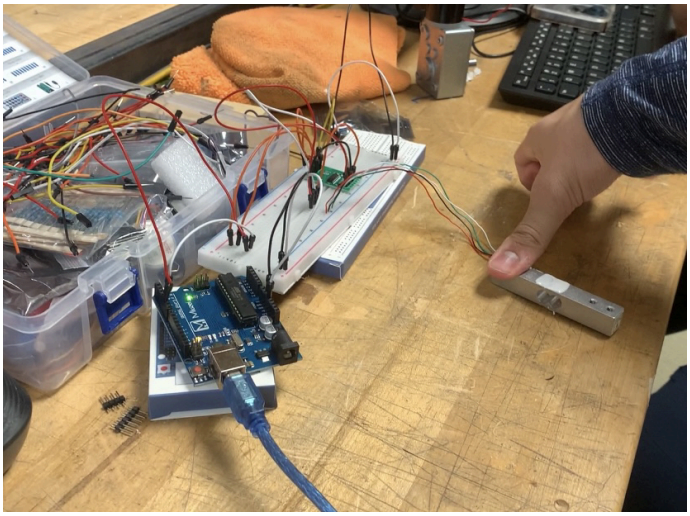

Figure 9F: Load Bar Weight Sensor Testing

Motor

The motor in our system is used to scoop the cat feces out of the litter box and transport it to the trash bin that is made for storing it. The motor itself is a worm gear motor, where it can be connected to a rail installed in the litter and extend or retract along the rail in one direction. The motor spans the entire length of the box in order to sweep all the litter. To be determined for evaluation, the motor must activate or deactivate after at least one of its three triggers occurs from the MCU.

The first trigger is after the cat has done its business, leaving cat feces in the litter that must be sweeped. Once the MCU gives the trigger that the cat feces are in the litter and the cat itself has left the litter, the motor must wait for an additional three seconds before beginning to sweep, this is an additional safety feature that must be met as an extra precaution to make sure the cat has left the litter completely to prevent injury to the feline. Once the three seconds are done, the motor must begin extending, sweeping the entire length of the litter and picking up any feces in the litter, and then dumping the feces into the trash bin at the end.

The next trigger to the motor is the standby button. In its name the button is to be used to prevent the motor from running until the owner chooses to release it from standby. Once the button is pressed, the motor must NOT under any circumstances be able to activate, even when additional weight has been detected in the litter that may be indicated feces inside it, until the owner of the system chooses to release it from its standby mode.

The last trigger for the motor is the run button. In its name the button is used to have the motor immediately start running, this can be used if the owner decides that the

feces in the litter may be a problem, such as too much odor, and can use this feature to eliminate the problem. Once the button is pressed, the motor must immediately run, sweeping the entire litter box and returning to its original position in one run. Subsequent presses of this button while the motor is in action is considered redundant, the motor must finish the entire cycle of its run before it can be used properly again. The motor must also move at its rated speed of 1.2 to 210 revolutions per minute (RPM) depending on the amount of load on the motor, and draw power at or below its rated capacity of 1.6 to 4.8 Watts depending on load to ensure it is free of any defections.

The Motor in our system is one of the most important components for safety that needs strict testing for safety requirements, as this part of the system can very easily cause harm to the feline. An additional safety feature is implemented to the motor while it is running. During any sweep of the litter, the system constantly checks the weight to ensure it has not fluctuated while sweeping the litter. If any amount of weight enters the litter while it is running the motor must come to a complete halt in the span of one second. This is to ensure the cat did not reenter the litter during the sweeping process. This weight limit for the motor to stop is as low as 0.2 pounds to ensure that a baby cat did not enter the litter. Baby cats on average weigh about 0.22 pounds, so even this small of a weight change in the litter must be taken with tremendous importance.

Figure 9G shows the connections used to test the motor. With insufficient measuring equipment, we were not able to measure the torque and the speed of the shaft spinning. There are two wires coming out from the motor, the power and ground. We first supplied 6.5 volts to the motor, the motor is turning at a lower speed (about 45 rpm) with unknown torque. Then, we tried to stop the shaft spinning when it was operating to test its stall current. When the shaft is stopped the power supply shows that the motor is consuming a little more than 1.8 Amps, which matches with the datasheet.

We do observe that the higher the voltage supplied to the motor, the faster the motor spins and consumes higher current. However, we do have to resolve the following concern in further testing:

1. How do we determine the motor’s turning speed?
2. How to control the motor’s rpm?
3. How to set the turning ratio?

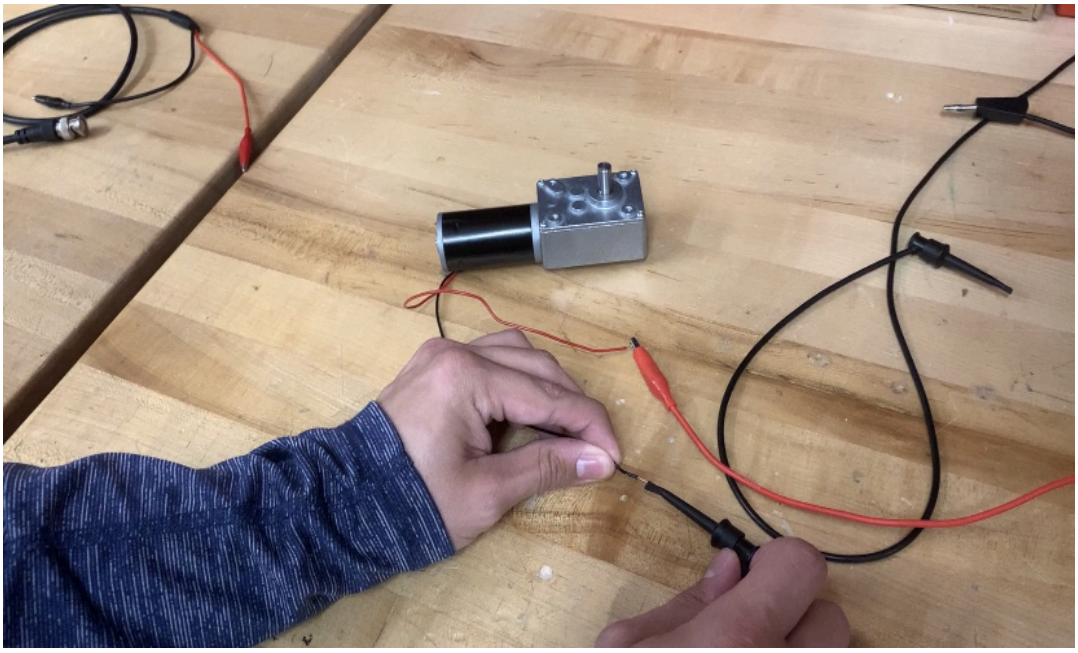

Figure 9G: Motor Testing

Power Supply

The power supply in our system is the most important part of the system and is under stricter testing conditions to ensure it can handle the load it experiences during use. The power supply we used in the system is a USB-C type connection to power the PCB for our system. Because of this, the power supply must follow the USB type C standard for power delivery, and the pinouts on the connector should match the appropriate process for 6 pins, 16 pins, etc. An AC adapter, similar to the ones used for phones, is also made for converting the AC power drawn from the wall into DC power for the components in our system. The adapter should have the appropriate protection ratings for supplying the correct amount of power for our system in a safe manner.

The power supply is first tested with just one of the necessary components being powered. The voltage is measured with this singular component to ensure it meets the standard voltage regulation of +5% or -5%, and the current is measured to ensure that the component is receiving power within its limits to ensure the protection of the equipment. Using these two measurements we can also determine the amount of power being consumed by the component, and delivered by our power supply. The power being delivered to the component must remain within these parameters over the course of 15 min per trial to ensure proper power delivery. Once the power supply has been deemed adequate with one component connected, an additional component is added, and the voltage, current, and power draw of the system is once again measured to ensure proper delivery. This process is repeated until all components

drawing power at the same time is deemed adequate, and the power supply receives a check of approval to be used in the product. Should the power supply not pass the test and receive approval for use, additional safety features and rechecking the designs of the power supply have to be conducted.

Enclosure

The enclosure in our system is the housing for all the components we used. The PCB, external sensors, motors, and power supply are all protected inside the enclosure to prevent damage from any outside sources. With many of these parts being sensitive to ESD, or ElectroStatic Discharge, the material of the enclosure should not exhibit any form of ability to conduct electricity to protect these components, such as glass or porcelain. However, along with being non-conductive, the material must also be sturdy enough to withstand hefty weight, around 30 lbs or more. This is because both a cat and the cat litter is present in the container at certain times, and the enclosure must be able to support both of these weights to protect the cat from harm.

The enclosure must also be able to have a certain resistance water. As we all know, water is toxic to electrical components, and can damage the PCB or any sensor in the system if it comes into contact with it. Therefore, the enclosure should possess an Ingress Protection rating of at least IPX4, which is a protection against any splash of water from any angle, common scenarios in which this can happen is if a cup of water is accidentally spilled on the floor, and the splash from the water hits the cat litter. The enclosure must meet these ratings while also having cutouts for the interactive buttons on the PCB. A small section of the enclosure can be made to house the PCB, and also include the appropriate cutouts for the buttons. The PCB is also mounted to the top side of the enclosure with the appropriate cutouts for the buttons, this is to allow the customer to be able to see and reach the buttons that they can use for the litter.

Software

The software is composed in the Arduino IDE software application for the ATMega328P microcontroller. The software allows for easy bootloading of the code into the microcontroller, and well as easy rewrites for smooth testing parameters. Format of the code should be structured in a way that should be legible and easily understood with the use of indentation and comments. The comments in the code should clearly describe what the line or lines of code is meant to be doing or be a label for what a variable means. This can help during troubleshooting the code when errors occur. Should an error pop up with the number of the line of code causing the issue, the format with indentations and comments can help review it to ensure it is working as intended, or if any typos/misspelling occurred during its creation. The code should compile without errors or issues during its creation, and the code should also remain error free throughout the testing of the code.

Each part of the code for the MCU should properly execute depending on the action that needs to be completed. The MCU should send a signal to the motor when the three hour timer is up to begin a sweep, when an interrupt from one of the two buttons occurs, or when an interrupt occurs from the weight sensor or motion sensor while the motor is in action. The code should also know what to do with the signals from each of the sensors in the system, as well as the two buttons, and each signal should not cause an error to occur in the system. Errors should also not occur when multiple signals occur simultaneously, the code and MCU should handle each signal appropriately and determine which one is more of a priority. The code should also implement a low-power mode for when the system is in an idle position until either a button is pushed, a sensor is tripped, or the three hour timer for the periodic sweep causes the system to come back on.

Trials

Each one of these components must adhere to these specifications in order to receive a pass of approval. The components undergo these stress conditions in 5 separate trials EACH, meaning we test each individual component separately to ensure functionality. Once each one has been determined individually, they then undergo a trial when operating simultaneously, in which they would need to once again pass 5 trials while working all at once. The components are also tested in different temperatures to ensure they work in all manners of customer housing climate, in around the range of 65-74°F.

The design of such extensive trials is to ensure every error or fault in any of the components in the system has been accounted for. The trials are meant to find the errors to allow us to correct any mistakes that have happened because of us, or the manufacturer. With manufacturer mistakes being very important to catch in the early stages of production to have a call back for a replacement to be shipped.

Plan for Senior Design II

In Senior Design II, parameters of the project may change throughout the course and updates to the system may need to occur. During Senior Design II, the way we test the components of the system is dependent on what products we chose to combine in the system, should these change, our parameters for testing may change. Our plan for Senior Design II was to ensure that any changes we need to make to our system be addressed quickly, so that the testing and evaluation of these parts be started immediately to give it a green check of approval to be used in the system. Our methods of testing were changed and updated with any upcoming changes in senior design II.
We have our initial PCB schematic and layout for Senior Design 1 (please refer to **Chapter 8: System Fabrication** for more details). However, with the current schematic, it is missing the DC-DC converter and the USB-C port headers. The reason why we haven't finalized these items is that we need guidance from Dr. Wei and Dr.

Wei. For the DC-DC converter, the output is 6.5 volts and 2A max current, but the current consumption for the motor when it is running at rated load is still undetermined due to the lack of datasheet. The datasheet from the manufacturer doesn't provide sufficient engineering specifications. Lastly, the USB-C port is placed with a 5 volts power source until further instructions.

Chapter 10: Administrative Content

This chapter of the paper contains the content needed for administrative understanding of the content discussed, meaning how the project was planned and executed. The following sections detail the budgeting and bill of materials (BOM) of the project, project milestones for both senior design one and two, and the division of work that details what each contributor worked on in this project.

Project Milestones for SD1 and SD2

This section details the important assignments that either the class, or ourselves set that helped us to complete this project. Dates for starting and ending these assignments are for the strict purpose of incentivizing proper work ethic on this assignment, and to avoid falling behind on the target date in which this project must be completed.

Task	Description	Start Date	Tentative End Date
Forming a Team	Finding 4 teammates for Spring/Summer semesters	**1/8/2024**	**1/11/2024**
Brainstorming Project Ideas	Discussing potential ideas	**1/11/2024**	**1/21/2024**
Individual Research	Each member conducts their own research on chosen idea	**1/21/2024**	**2/2/2024**
Divide and Conquer Document	Writing and finishing 10-page D&C Document	**1/21/2024**	**2/2/2024**
Divide and Conquer meeting	Having a meeting with advisor about D&C document	**2/5/2024**	**2/8/2024**
60-page Report Milestone	Starting to write and finalize the 60-page draft	**2/2/2024**	**3/29/2024**
60-page Report Meeting	Having a meeting with advisor about 60 pages draft	**4/3/2024**	**4/3/2024**
Final Report	Writing and finishing the final 120-page report	**3/29/2024**	**4/23/2024**
Final Report meeting	Having a meeting with advisor about our final document	**6/7/2024**	**6/7/2024**

Table 10A: SD1 Project Milestone Table

Task	Description	Start Date	Tentative End Date
Prototype	Creating a prototype to be used for testing and evaluation	**3/25/2024**	**5/26/2024**
Ordering PCB	Ordering PCB from our chosen manufacturer	**6/3/2024**	**6/14/2024**
Testing PCB	Testing if the PCB works as intended	**6/18/2024**	**7/8/2024**
Putting together all of components	Forming all the parts together to build the product	**7/8/2024**	**7/12/2026**
Practice Demo	Conducting a practice demonstration before presentation	**7/15/2024**	**7/19/2024**
Finalizing the Final 120-page Report	Reviewing and editing the final Report	**7/19/2024**	**7/21/2024**
Final Presentation and Demo	Presenting finished project to advisors and committee	**7/19/2024**	**7/19/2024**

Table 10B: SD2 Project Milestone Table

The two tables above are our project milestones that we had completed for Senior Design 1 and Senior Design 2. We kept track and followed them strictly to be successful in completing our project on time.

Pricing and Budgeting

The estimated price for this system is shown in **Figure 10C**; the prices listed in the table are average prices between multiple websites, such as Amazon and Temu, and multiple brands of parts needed to create the system. For example, button manufacturers can create simple tactile buttons or buttons with a locked switch to keep the button pressed. Each button has a different purpose, but for our system, simple tactile buttons are enough to meet our requirements, and the extra feature for smart locking on the button is unnecessary. Along with the component being priced is the seller that the price was taken from, and the decision to choose the seller was based on the price and time for delivery of the parts. For the PCB assembly, we decided on JLCpcb, a reputable company recommended by past senior design students and engineers currently in the field. JLC was also chosen because it incorporates the software that is used to make the PCB schematic, the EasyEDA PCB

design tool. The motion sensors are a simple Passive Infrared Sensor for reading the status of the litter box, since only a small range is needed to be covered, the PIR is enough for our system needs. The weight sensors we used are four separate weights that were placed in each of the corners of the litter. Along with the weight sensors is an analog-to-digital converter to convert the pressure input from the container to a digital output for the MCU. The MCU in our system is going to be the ATMega328P from Atmel.

Component	Quantity	Vendor	Estimated Price
PCB Assembly	1	JLC	$45
Motion Sensor	1	Amazon	$8
Weight Sensor	1	Amazon	$9
MCU ATMega328P	1	Amazon	$6
TPS61088	1	TBD	$2
Electronics	~	DigiKey	$20
Bags	1	Amazon	$15
Motor	1	Micro DC Motors	$20
Casing	1	TBD	$20
Buttons	2	Amazon	$6
Scooper	1	Amazon	$20
Total	-	-	$169

Table 10C: Price Table

The MCU we chose is a highly reputable, and highly familiar, unit that has many features in its architecture. Our main reasons for choosing it was because of both familiarity with using it in the past, and multiple features with support for multiple I/O devices, such as the sensors we used. The internet adapter is a separate module to handle communication with the internet for our app integration; the price for this

adapter is also an estimate, as it would depend on the MCU we choose. The power supply is labeled “Assembly” because it is a component that must be built according to specific standards, whether we choose the Nema 5-15P or a USB connection. The bags are self-explanatory; they are meant for the garbage container to store the cat feces. The motor and casing depend on one another; how we choose to make the casing affects the type of motor we should use to have it operate the best for scooping the feces. The buttons were explained earlier; we only need simple tactile buttons for user interaction with the system. Finally, we have the scooper with the type of shape, blade count, and curvature that have been made based on the form of the casing, which was put up for discussion along with the casing and motor type.

Our goal for the pricing of the cat litter system is to either keep it below other similar products on Amazon, Temu, etc., or match the price with more features. An example is Nature's Miracle™ Multi-Cat Self-Cleaning Litter Box on Amazon. This litter system is a similar product that we are trying to create, it has a self cleaning motor system whenever the cat is done doing its business on the litter. It has a switch to change the system from Auto to Maintenance, similar to our idea of having a standby button to be able to clean or fix a small problem, and it has a storage system. The difference is that the motor is ONLY for cleaning, it does not scoop that poop for the owner, and the storage system stores a manual scooper. Removing the poop from the litter is still done manually with the scooper in the storage area, but cleaning is done automatically. Our idea is to do the opposite, have an automatic scooping and storage system for feces instead of automatically cleaning the container.

The figure above shows only the estimated prices and predicted vendors of the components we used in our system for this project. Actual prices did of course vary depending on inflation at time of purchase, taxes, and product availability. **Figure 10D** is a bill of material record of the products we have purchased in order to keep track of the exact total cost that the system was worth. Our average price that we planned to stay below is around 200$, this is to stay in competition with other similar products that are currently in the market. Of course however, in order to ensure proper testing and implementation of our system, multiples of each part were purchased as backups and testing dummies. Throughout Senior Design One, as well as Senior Design two, the bill of materials was updated according to what components or PCB assemblies our group purchased for testing and creating the Purrfect Litter Automatic Cat Litter System.

Part Number	Part Name	Quantity	Vendor	Price (Taxes & Quantity Included)	Date Purchased	Date Received
N/A	Miuzei Super Kit, Arduino Project	1	Amazon	$38.33	Sep. 26th, 2022	Oct. 2nd, 2022
HC-SR501	Infrared Motion Sensor	3	Amazon	$7.76	Feb. 14th, 2024	Feb. 15th, 2024
B07B4DNJ2L	50kg Strain Gauge Weight Sensor	1	Amazon	$9.57	Feb. 15th, 2024	Feb. 16th, 2024
S18X2+S19X2	ShangHJ 2pc 20kg Load Cell Weighing Sensor	1	Amazon	$11.90	April 10th, 2024	April 11th, 2024
TPS61088RHLR	10-A Fully Integrated Synchronous Boost Converter	1	Texas Instruments	$1.97	June 6th, 2024	June 10th, 2024
N/A	Electronic Components	N/A	DigiKey	$27	June 10th, 2024	June 17th, 2024
PCB_6-28_Y5	Blank PCBs (Final Iteration)	5	JLCpcb	$12.67	June 28th, 2024	July 3rd, 2024
N/A	Electronic Components	N/A	DigiKey	$12	June 29th, 2024	July 6th, 2024

E18-D80NK	Infrared Motion Sensor	3	Amazon	$15.81	June 29th, 2024	July 1st, 2024
NFP-5840-36ZY-1280	Worm Gear Motor	1	Amazon	$30.00	April 14th, 2024	April 17th, 2024
N/A	BC Plywood	1	Home Depot	$15.00	June 20th, 2024	June 20th, 2024
N/A	Sprockets and Chains	2	Amazon	$5.00	June 20th, 2024	June 24th 2024
Total				$187.01		

Table 10D: Bill of Materials

Division of Work

The following section details the division of work for this project. **Figure 10E** shows each task that went into the creation of the project that was worked on, who was responsible for each task/who was the lead person responsible for creating or designing the task of the project, and who was sub-responsible for each task/who provided support to the lead person construction or designing the task specified. The division of work is meant to give credit to the people in this project who did great work in designing and implementing the parts specified to create the Purrfect Litter.

The Printed Circuit Board Design encompasses **Chapter 8: System Fabrication** of the document. It details the PCB schematic design that gives the connections between each component in the system, as well as the PCB layout, which shows how each component was placed and physically connected on the board layers. Additionally, a 3D model of the PCB design is shown in the chapter to give a physical depiction of how it looks.

Power Supply Design encompassed parts of **Chapter 6: Hardware Design** of the document. It details how each component receives power in order to function. This includes AC to DC design models that were used to convert the AC power from a wall outlet, to a usable DC source for the components. It also details a DC to DC design model that was utilized to power the motor in the system, since the motor is the only component that does not draw power at 5V like every other component in our system, it instead draws power at 6.5V or above.

Software Design encompasses parts of **Chapter 7: Software Design** of the document. It details the creation of each piece of code required for the ATMega328P

microcontroller that we used in our system to communicate with each component on the system. This includes codes to read data from the weight sensor and motion sensor in order to determine when something is currently in the litter, the motor for activating or deactivating when appropriate, and the two buttons for user interaction.

Enclosure Design encompasses parts of **Chapter 6: Hardware Design** of the document. It details the vision of how we wish to create the enclosure that houses all the equipment, and the cat litter, in order to create the Purrfect Litter. It gives depictions that were created in the Blender software showing how we plan to create the enclosure, and the features it needs in order to meet required specification standards.

Project Task	Lead Person	Sub-Lead Person
Printed Circuit Board Design	Eliezer	Junxu
Power Supply Design	Junxu	Eliezer
Code Creation	Kayla	Sam
Printed Circuit Board Testing	Eliezer	Junxu
Power Supply Testing	Junxu	Eliezer
Code Testing	Kayla	Sam
Motion Sensor Implementation	Junxu	Eliezer
Mobile App Design	Kayla	Sam
Weight Sensor Implementation	Eliezer	Junxu
Motor Implementation	Sam	Junxu

Enclosure Design	Sam	Kayla

Table 10E: Division of Work Table

Mobile App Design encompasses parts of **Chapter 7: Software Design** of the document. While creating the mobile app was one of our group's stretch goals, we deemed it still important to talk about because it is something that can be improved upon our system. It details the creation idea for implementing a mobile app to the system, and its use cases for our system. Additionally, examples of mobile web apps were given to show how the app would be implemented.

The remaining tasks in the Division work, the Printed Circuit Board Testing, Power Supply Testing, Code Testing, Motion Sensor Implementation, Weight Sensor Implementation, and Motor Implementation encompass **Chapter 9: System Testing and Evaluation** of the document. It details the parameters that were used to test the components of our system to determine its validity, safety, and robustness to be used in our final product. Each section of the chapter details a specific component of the system and gives in detail how it was tested in the Senior Design Lab/TI Lab at the University of Central Florida. It also gives schematics for each component as to how it was connected and tested in the lab, as well as photos of the members of this group physically testing.

Chapter 11: Conclusion

The creation of the Purrfect Litter system allowed us to present our knowledge and ability to learn about designing, planning, budgeting, and creating a project from scratch. It also allowed us to understand the importance of having a team working together on a project, as one person cannot shoulder such a big responsibility. Each member assisted one another in the creation of this project, and had to learn firsthand how to compliment each other's strengths and weaknesses. Even though we each had our topics to cover in this project, collaborating and sharing ideas helped to complete this project together.

We spent a long initial period formulating ideas and strategies to manage this project. With a team of 4 we divided up the work evenly to allow our team to work efficiently with defined expectations and deadlines. Before we began our project, we made sure that the project was within the scope of a 6-7 month period of work to ensure our project was not too easy or difficult. After long deliberation we agreed that the automatic cat litter box was within the scope of a Senior Design project.

Another aspect of our project we preferred was the scalability of the automatic cat litter box. With the inclusion of a mobile app, our project can support wifi connections allowing users to activate the litter box from a device. Beyond the actual construction of the litter box and all of its physical components, the creation of a data server, database, hosting server, and device to server connections greatly expands the project. We are pursuing the mobile application as a stretch goal that can be adjusted according to how fast we can finish the base litter box.

In Senior Design 2, we were able to better assess how much extra time we can place into setting up a mobile component for the project. After the box was fully constructed and properly tested, the mobile component was a luxury edition to the project.

A key component to our group's ability to meet deadlines was constant communication and updates. During the Senior Design 1 semester our group would regularly hold 2 meetings a week to give important updates and ensure our deadlines were met on time. We used the communication app Discord to host our online meetings, providing an easy means for group messaging and discourse.

During the initial lectures held in Senior Design 1, our group would meet after class to discuss potential ideas and observations during class. After the lectures stopped for SD1 our group switched to biweekly meetings online in addition to planned in person meetings.

Communication has proven a vital aspect to our project's workflow success. The inclusion of agreed deadlines and constant communication kept everyone on pace for work. Looking back, our group's decision to host consistent meetings and discussions greatly helped not only speed up the project's completion, but also allow everyone to be equally informed on the status of the project.

If our group was to do the project again most of the decisions would remain the same. One possible improvement our group could have added would be the inclusion of a gantt chart to further track the sub-deadlines for the project. Though all of our major deadlines were met and clearly outlined by our group, it's become apparent that there can never be too much organization and planning.

We believe a detailed sub gantt chart would have even further boosted productivity, allowing each group member to see their sub deadlines with performance tracking. Our group never encountered the issue of deadlocked workflow, however, looking back this issue could have possibly occurred.

Another possible addition to our group's organization would be a workflow chart paired with a gantt chart. Pairing a gantt chart with a workflow chart allows the group member to better understand all deadlines and preemptively determine any possible workflow complications. For example, if one group member's job was to do parts comparison for the MCU and another member's was to total the parts costs a possible workflow complication could arise.

If the parts comparison is not completed by the timely deadline, the parts total needed to wait until the previous task is completed, slowing the project down. The aforementioned solution to this potential issue tackles the problem and allows for complication free workflow.

For our project's component research, our group spent a long time finding the most efficient parts for the projects. Due to the competitive market for automatic cat litter boxes, price is a major factor in component choice and our group made sure to not only find the most efficient parts for the job, but also ensure their price point was comparable to what is currently on the market. After cross referencing many different suitable parts, we believe our components are very cost effective and reliable for the project.

The majority of automatic cat litter boxes on the market range in price from roughly $200-$500. In addition, automatic cat litter boxes on the lower end of the price point range tend to not include quality of life features such as a mobile component or safecat technologies such as motion and weight sensors. Our project aims to provide a high quality automatic cat litter box at a low end price point.

The system detailed in this document is a constructed variation of the thousands of products for an automatic cat litter system. We seeked to improve on an existing product in order to drive creativity and improve customer service experience using a cat litter system. Purrfect Litter boasts more features that allow customers to feel both at ease with its safe designs, and in control with our physical user interface. Our creation helps to foster that there is always room for improving products to help consumers.

Even our own creation can still use more improvements to its functionality, such as our suggestion for implementing SMART technology and having and interactive web app on mobile devices, allowing for remote access to the Purrfect Litter system with notifications of when something is detected in the litter or even remote control by activating the motor from the mobile device somewhere not in your home. Possibilities for improvement are always present, and our system is no exception.

The designs used for the PCB, communications between the devices connecting, and how powered delivered to the system and protection for the felines made for a compelling product against competitors. This project took our understanding of engineering principles to the forefront in order to create it in an efficient and professional way. We hope to use the experience learned during this project to further our understanding of how engineers work and perform under grander projects. Our experiences here have built and improved on in future endeavors as engineers in the real world.

For Senior Design 2 our group plans on retaining our best qualities from Senior Design 1, while also making improvements from our Senior Design 1 shortcomings. The inclusion of a gantt and workflow chart in Senior Design 2 has greatly helped our group ensure there are no workflow deadlocks. We also plan to host more in person meetings given the need for more physical construction in SD2. Our group has also spent time observing the scope of the project and determining which future tasks require the most time to complete.

Looking forward, our group believes the most difficult component of our SD2 project was the PCB implementation and mobile programming. For the automatic cat litter box the physical design of the box should be straightforward there are many online resources outlining common materials and dimensions used for the box.

Additionally we believe setting up the parts inside the box were also simple as the size and constraints of the box are minimal. We plan to greatly focus on PCB implementation and MCU programming to ensure the most difficult aspects are

completed first. Once we established the logic and physical form of the PCB the remainder of the project was much easier.

If our group can follow the plan we have set up for SD2 and ensure all deadlines are met, we expect our project to be successful and well executed. Our group believes that great communication, clear and concise set deadlines, and a proactive focus on PCB and MCU programming allowed our project to be finished during the SD2 semester. We also plan to finish the project early, accounting for possible setbacks or other unforeseen issues that may cause time delays.

Setting aside extra time as a cushion for future development or needed project corrections ensures a best possible outcome for our project. Based on our group's schedules for the summer, all members should have more time to invest in SD2. We look forward to continuing our project in SD2, producing a well constructed and effective automatic cat litter box.

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