Self-cleaning Cat Litter Box

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Contents

1 Introduction

1.1 Objective

Cleaning the cat litter box might be the most disliked work for people who have cats. First of all, the cat litter box is smelly and hard to clean. While people need to bear the bad smelling, they also need to use shovels to find droppings of the cat. Since the droppings are small, it is usually time-consuming to only remove the droppings. Second, cleaning the cat litter box needs to be done everyday, which makes this job even more tedious.

Therefore, we want to design a self-cleaning cat litter box to help people. As its name suggests, the self-cleaning cat litter box could clean the cat litter box and bag the waste automatically and remotely. People would be able to use an app on devices to control it to save time and effort.

1.2 Background

Self-cleaning cat litter box is an existing product. However, many in the market have some downsides. Some products, like the "ChillX AutoEgg" [1], do not support remote control features. Another product, the "Litter-Robot 3 Connect" [2], is WiFi-enabled and is known as the best smart self-cleaning litter box in the market [3]. However, the cost of the product is nearly $ 500, which is not a friendly price to most cat owners. Most importantly, nearly all products in the market could only deposit waste into a drawer or plastic bag but not fully seal the waste bag, thus the smelling is still bad inside the box and the parasite from cat waste may cause infection [4].

Our design aims to solve these problems. We want to make the Self-cleaning cat litter box to be more affordable for most people. Also, with the auto-bagging and IoT, this design could really save people from the painful work of cleaning the cat litter box.

1.3 Visual Aid

The litter box will be a boat-shape box. We plan to design a comb shape cart to do the filter work. The cart has two modes of motion: one is pushing from one side to another to do the filtering; second is pushing the waste up to pour it into the plastic bag. An open pouring area would be made at the back of the box.

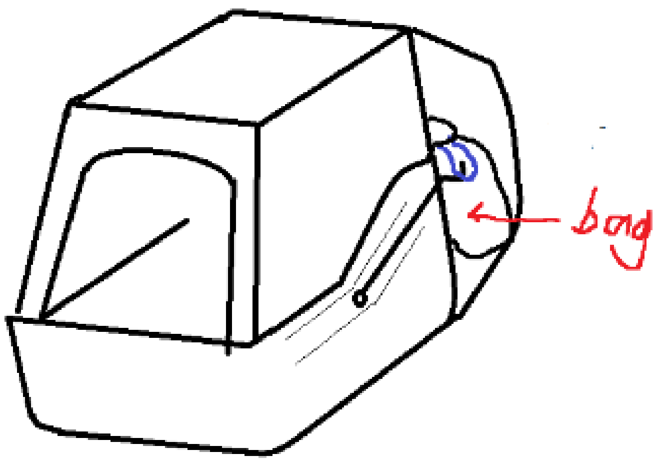

Figure 1: Sketch of Front View with Cover

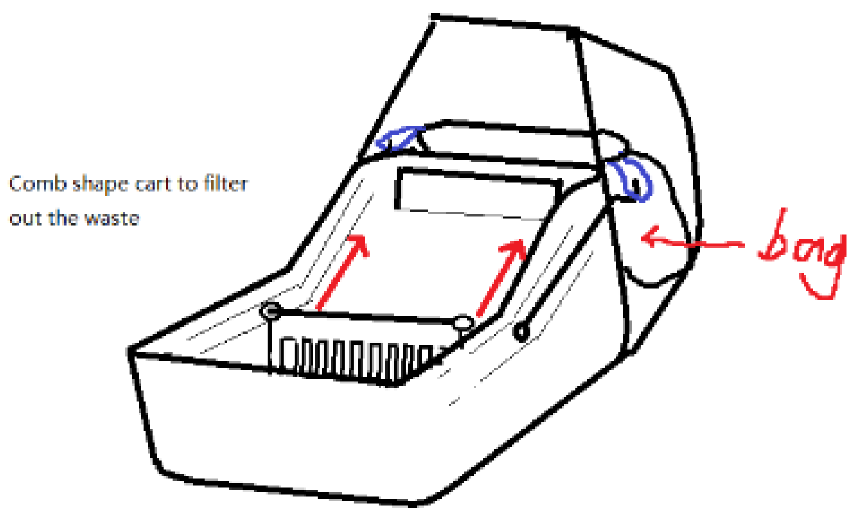

Figure 2: Sketch of Inside View

1.4 High-Level Requirement List

- This system must be able to remove at least 90 % of the waste from the litter box.
- The user must be able to remotely control the system under wifi environment and be able to see the weight data that is updated within 15 minutes.
- The cleaning system must be able to seal the bag after the cleaning process is done.

2 Design

2.1 Block Diagram

The design contains five modules for successful operation: a detection module, a control module, a power module, a motor module, and a user interface module. The power module ensures the system can be powered all the time with proper 5 V for control module and 12 V for motor module. The control module contains an ESP8266-01 Wi-Fi transceiver and an Atmega328 micro-controller from the Arduino board. It would be used to control the motor module for cleaning and bagging, the detection module for noticing the cat's usage of the box, and the user interface module for manually and remotely control the machine.

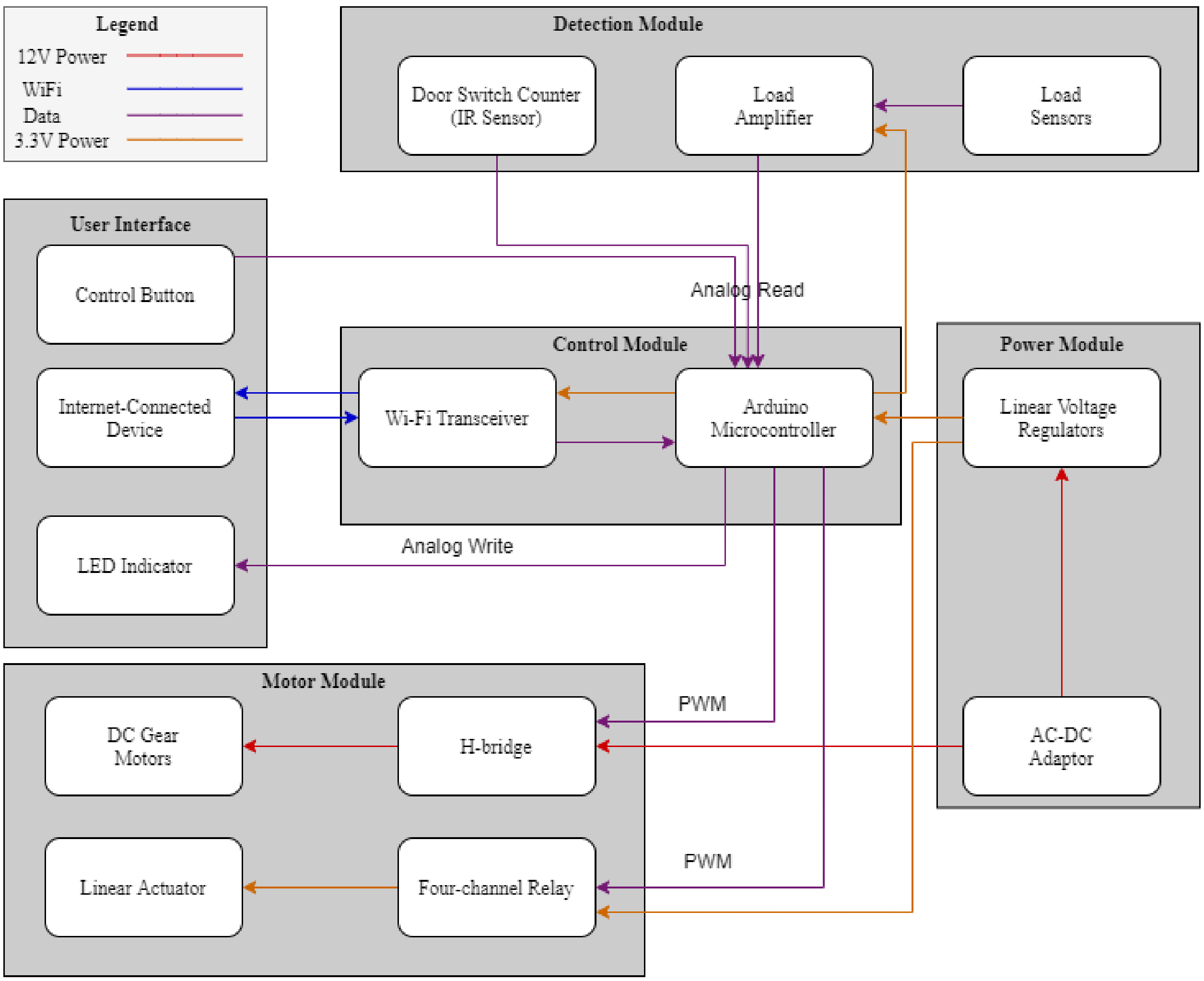

Figure 3: Block Diagram

2.2 Physical Design

The litter box will be a boat-shape box with around 40"(1 meter) in length, 20"(0.5 meter) in height, and 20"(0.5 meter) in width. We plan to design a comb shaped cart to do the filter work. The size of the comb-gap should be around 1 cm which would be sufficient to let the cat litter through but gather the waste. The comb cart is controlled by one motor that can move two folding arms along the sidewall of the box. The cart that moves one side from another can push waste and filter the litter; and it can also push the waste uphill to pour it into the plastic bag. An open pouring area would be made at the back of the box. A funnel shaped pie will lead those waste into the plastic bag. The bag will then be sealed by a heating sealer that is controlled by two motors. One gear motor controls the heating level and the other one would be used as a linear actuator motor in order to push the heat sealer bar to seal the plastic bag.

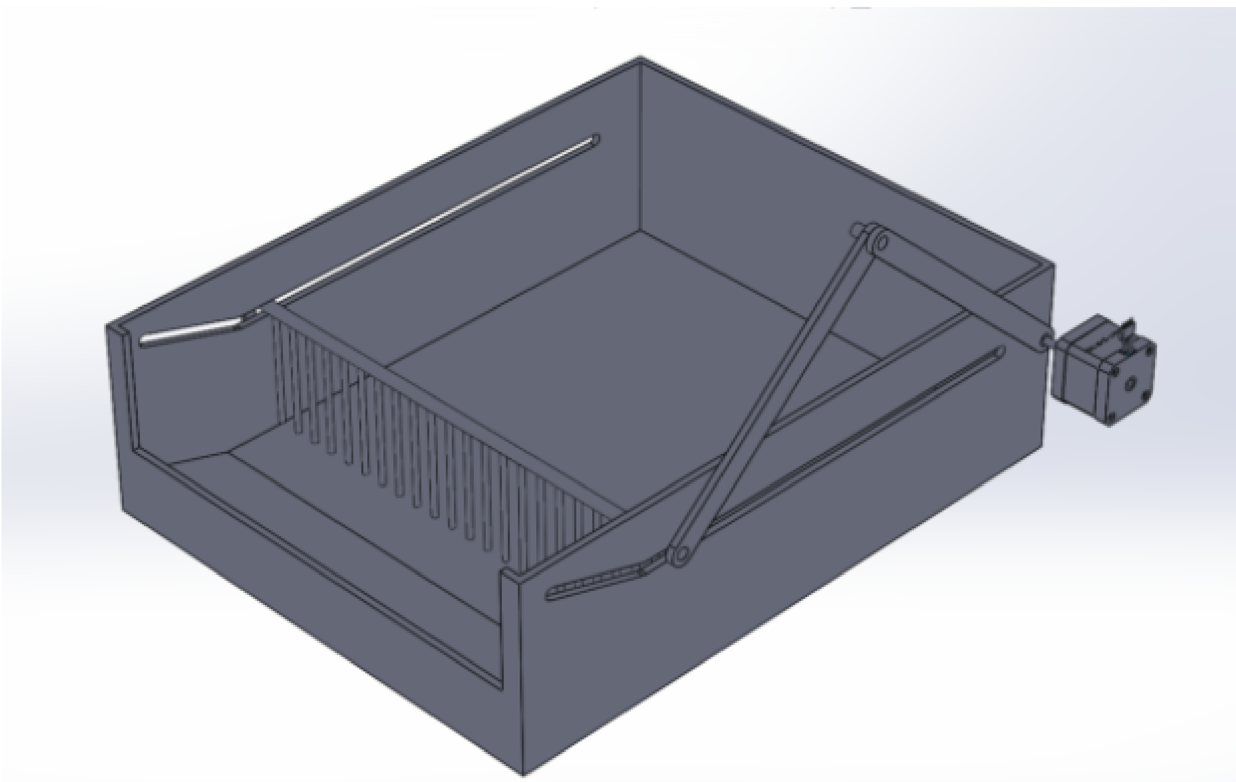

Figure 4: Top View

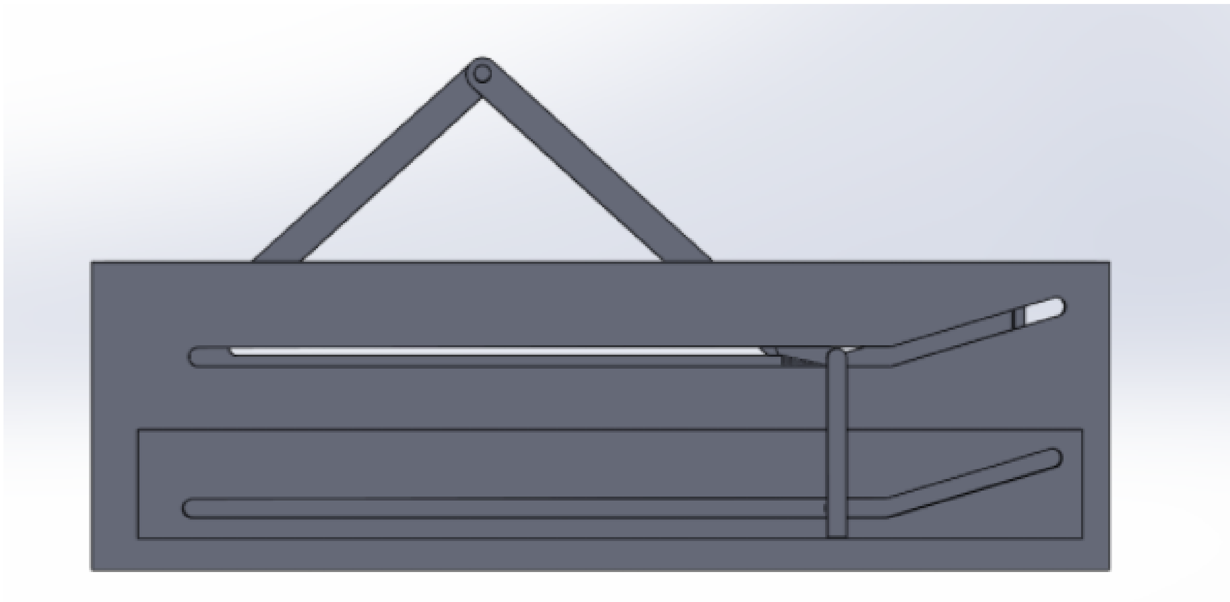

Figure 5: Side View

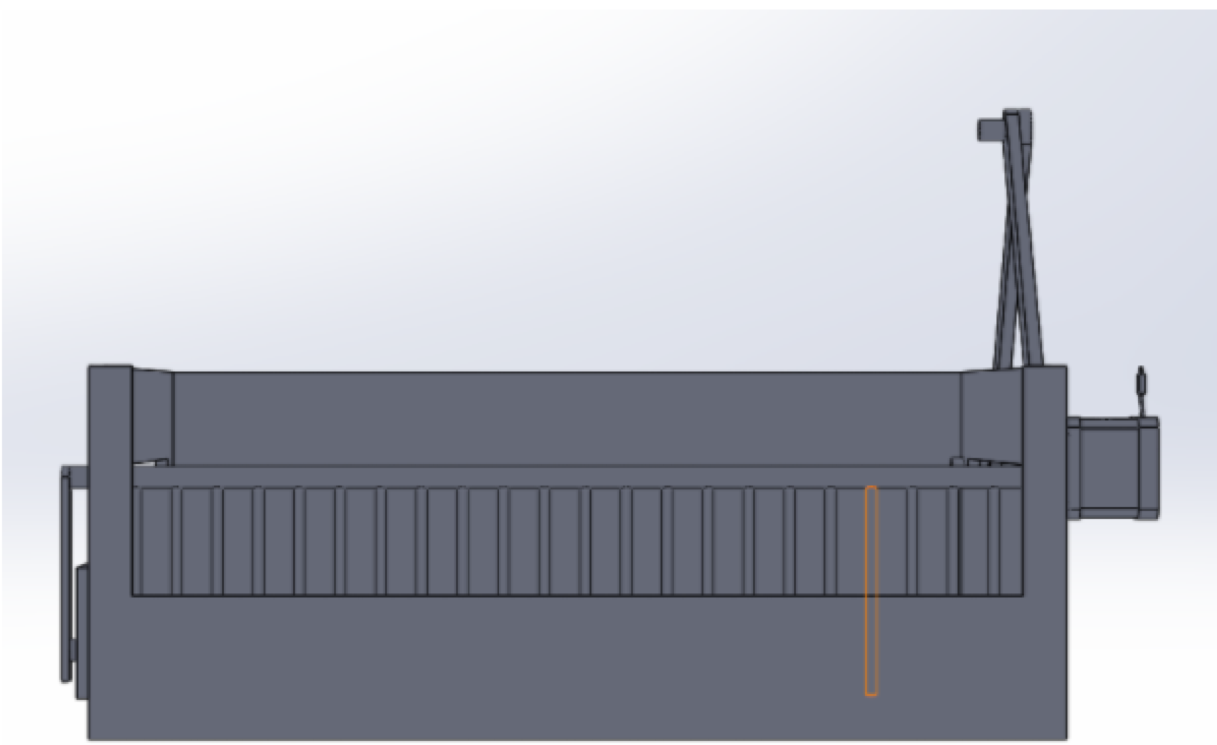

Figure 6: Front View

Figure 7: Heat sealer[5]

2.3 Block Requirements

2.3.1 Detection Module

Multiple load(weight) sensors would be attached at the bottom layer of the litter box and is used to detect the weight change in the litter box. We want to trace the weight of the litter and determine if the cat has left droppings in the box. The weight change of more than 5 pounds (typical weight of the cat) or the weight change of less than 0.2 pounds is marked as outlier data. The data should be collected for every 10 mins and outlier data will be filtered out. There is a reset function that is used when we change the litter in the box.

We harness four weight sensors to measure the change in weight. The weight sensors' resistance will change according to the applied surface pressure. The four sensors form a ring structure. The load amplifier use voltage divider to sense the resistance change and transforms the dedicated resistance change to readable voltage level difference that can be picked up by the micro-controller. The micro-controller will store previously recorded weight and only cares about net weight change.

Table 1: Weight Sensor R&V Table

Requirement	Verification
1. The weight sensor can update data for every 10 minutes and will report weight change within 0.2 - 5 pounds.	1. Collected weight data could be deleted when the dataset receives a reset signal. 2. When the weight sensor detects positive weight change within 0.2-5 pounds, it could send the signal to the control module. If the data collected is outside of the range, it must keep quiet.

2.3.2 Control Module

The control module is an ESP8266 wifi module connected with an ATMEGA328 microcontroller[5] used to control the filter motors to move along the track and the bagging system to seal the waste bag. If it receives the command from remote apps or someone pushes the button, the control module could send signals to the motors and bagging arms so the litter box could start to clean itself.

Table 2: ESP8266 R&V Table

Requirement	Verification
Control module could use ESP8266 WiFi transceiver to connect to an online database.	ESP8266 could recognize the nearby WiFi signal and connect to the Internet.

Table 3: ATMEGA328 R&V Table

Requirement	Verification
Both physical buttons and the remote app can control the machine to start the clean job.	If the start signal from the remote end is received in the database or the start button is pushed, the ATMEGA328 could send signals to enable motors to start moving.
Motors and the linear actuator can work together with correct order to finish the clean and sealing job.	The linear actuator does not move until the droppings are in the bag.
The ATMEGA328 should remind the user to clean the cat litter box when the cat leaves droppings.	When the detection module detects the cat droppings, the ATMEGA328 could send signals to the database.

2.3.3 Power Module

The power module should be able to drive the motors and support other electrical devices involved in our design. The system would be powered all the time with an AC-DC adaptor. A voltage regulator will convert input voltage to voltages usable by the corresponding components. For our project, we need 12V and 3.3V DC power to drive all components. This low dropout regulator would supply the 3.3V from the 12V± 5%

AC-DC adaptor. The LD1117AV33 regulator[2] should be able to handle the maximum and minimum input voltage from the adapter at the peak current draw(50mA).

Table 4: Power Module R&V Table

Requirement	Verification
The adaptor could transform 110V AC power to 12V DC power.	The output of the adaptor is 12V DC voltage.
The linear voltage regulator should be able to provide 3.3V ± 5% from a 12V source and could operate at currents within 0-50mA.	The linear voltage regulator can produce 3.3V DC voltage output and 5V DC voltage output.
The power system should maintains thermal stability below 125°C.	Use thermometer to ensure the temperature stays in range.

2.3.4 Motor Module

The motor module handles both the movement of the comb shape cart and the bagging quest from the heating sealer. The DC gear motors should be able to carry the two folding arms along the sidewall of the box to move along the track smoothly. The linear actuator must be able to have enough force to push the arms of the heat sealer to bag the waste.

1500N Electric Putter	
Input Voltage:	12V DC
Max Push Load:	1500N/330lbs
Max load:	150KG/330lbs
Max Pull Load:	1000N/264lbs
Travel Speed:	0.22 in/sec
Duty Cycle:	20%
Material:	Aluminum alloy
Color:	Silver grey
Operation temperature:	-26~+65°C
Protection Class:	IP54
No-load current:	0.8A
Max load current:	3A

Figure 8: Linear Actuator Specs[6]

The actuator we chose can handle upto 330 lbs load, more than enough to handle cleaning cat litter. The operation distance must be accurate so that the box and heat sealer would not be damaged.

Table 5: Motor Module R&V Table

Requirement	Verification
H-bridge controlled by General purpose IOs (GPIOs) is able to drive multiple motors with desired speed of around 0.1RPM and a maximum desired error of 2%	Connect the motors and H-bridge with an Arduino-Uno microcontroller. Program the duty cycle with analogWrite function to test the control of the speed. Program the GPIO inputs with digitalWrite function to test the control of the direction. When the H-bridge sends signals to control the motors' speed and direction, all the motors could correctly follow the command.
The module must be able to carry the comb shaped cart to move along the belt track without any jam. The sucess rate should be at least 90 %	Run the motors on the track 20 times and to count the times that more than one motor stopped following the track or lose synchronization.
The linear actuator must be able to push the arm of the heat sealer with enough force (15+ lbs). The pushing distance must be accurate to 7.62±0.5 cm	Run the linear actuator control function independently and measure the pushing distance 20 times to make sure it is inside the range. Then run the function and combine it with the linear actuator to operate the bagging feature 40 times.90% fully bagging rate would be define as a success.

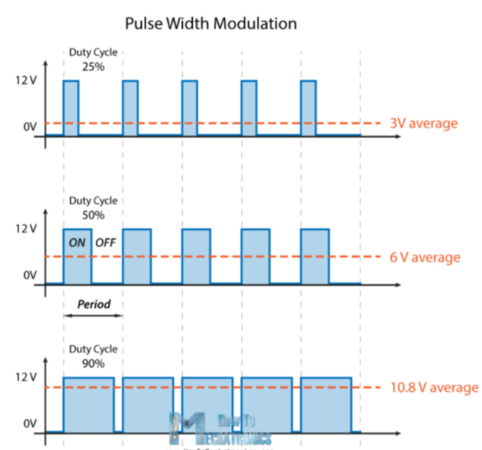

Figure 9: H-bridge Verification of motor speed[7]

2.3.5 User Interface Module

The user interface module is designed to be accessible through the internet in a browser that users can access it on their phone or on their computer. It will have clear sign-in and sign-up options at the beginning and

registered users' data will be store in the database. Users are able to control the machine after signing in. There will be clear icons to be clicked that users are able to initiate the machine and reset the weight sensor. Data from the sensor will also be shown in the same interface.
There is also an actual button on the litter box to avoid accidents. It is covered in the usual time that cats cannot press it when they hanging around.
LEDs on the box will be used to show the status of the machine. If the LEDs are on, it means the machine is still in the cleaning process.

Table 6: User Interface Module R&V Table

Requirement	Verification
The user is able to send signals to litter box to initiate the machine remotely through the internet-connected device	When the user pushes the start button on the remote app, the clean signal could be sent and recorded in an online database.
The user is able to reset the weight data collecting criteria	When the user pushes the reset button on the remote app, the reset signal could be sent and recorded in an online database.
The UI is able to register new users with their email address.	The UI has choices to sign up for the first time and sign in connecting with the database to choose insert data or retrieve data.
The server will send reminders to the user when cleaning is needed.	The user could receive reminders by email when the cat droppings are detected and recorded in the database.
The control button on the cat litter box has a low possibility of being pushed by a cat, but it can be easily pushed by humans.	The button is at the position which is not accessible to a cat.

Table 7: Control Button R&V Table

Requirement	Verification
The control button on the cat litter box has a low possibility of being pushed by a cat, but it can be easily pushed by humans.	The button is at the position which is not accessible to a cat.

2.4 Circuit Schematics

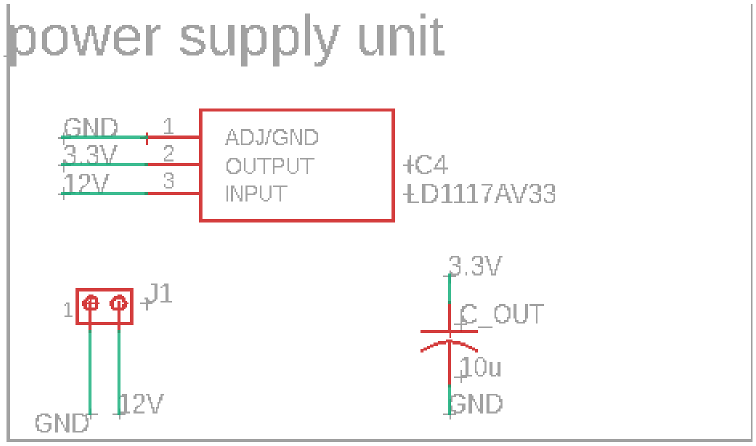

Figure 10: Power supply unit connection

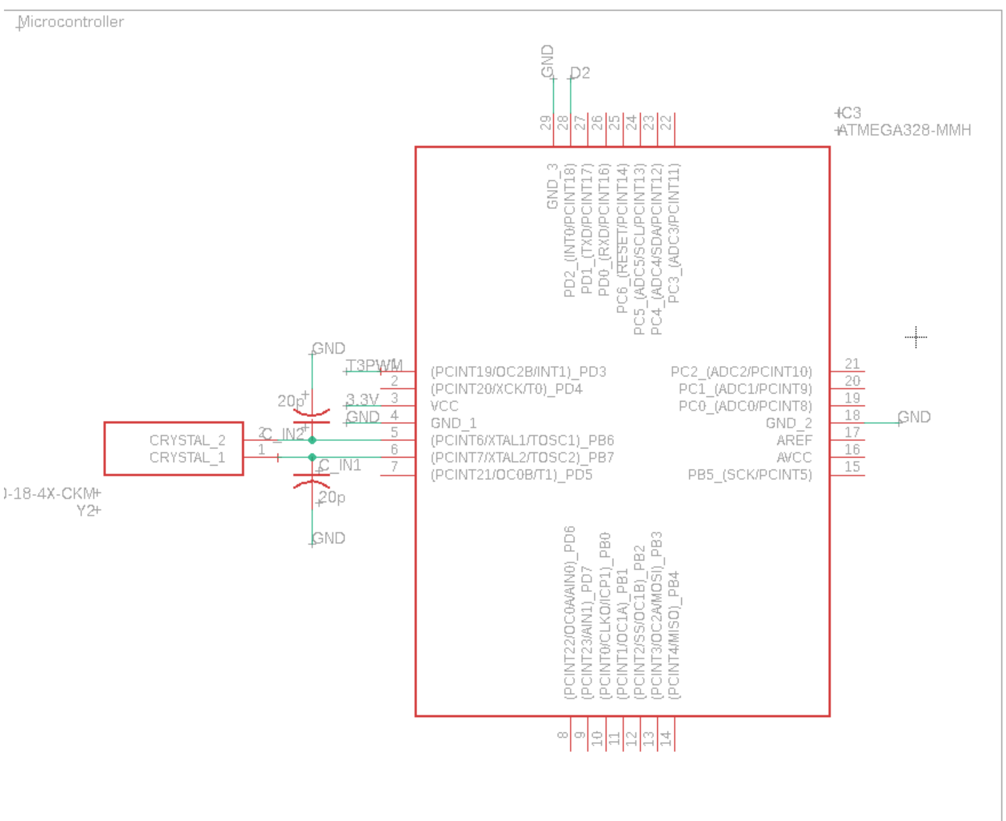

Figure 11: micro-controller circuit

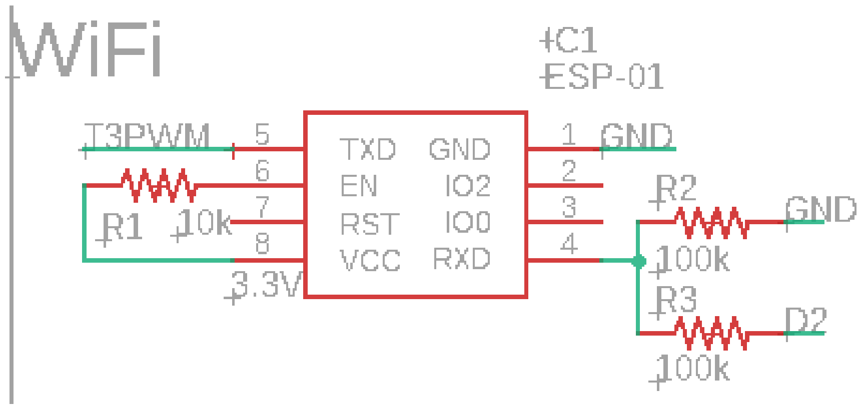

Figure 12: WiFi module circuit

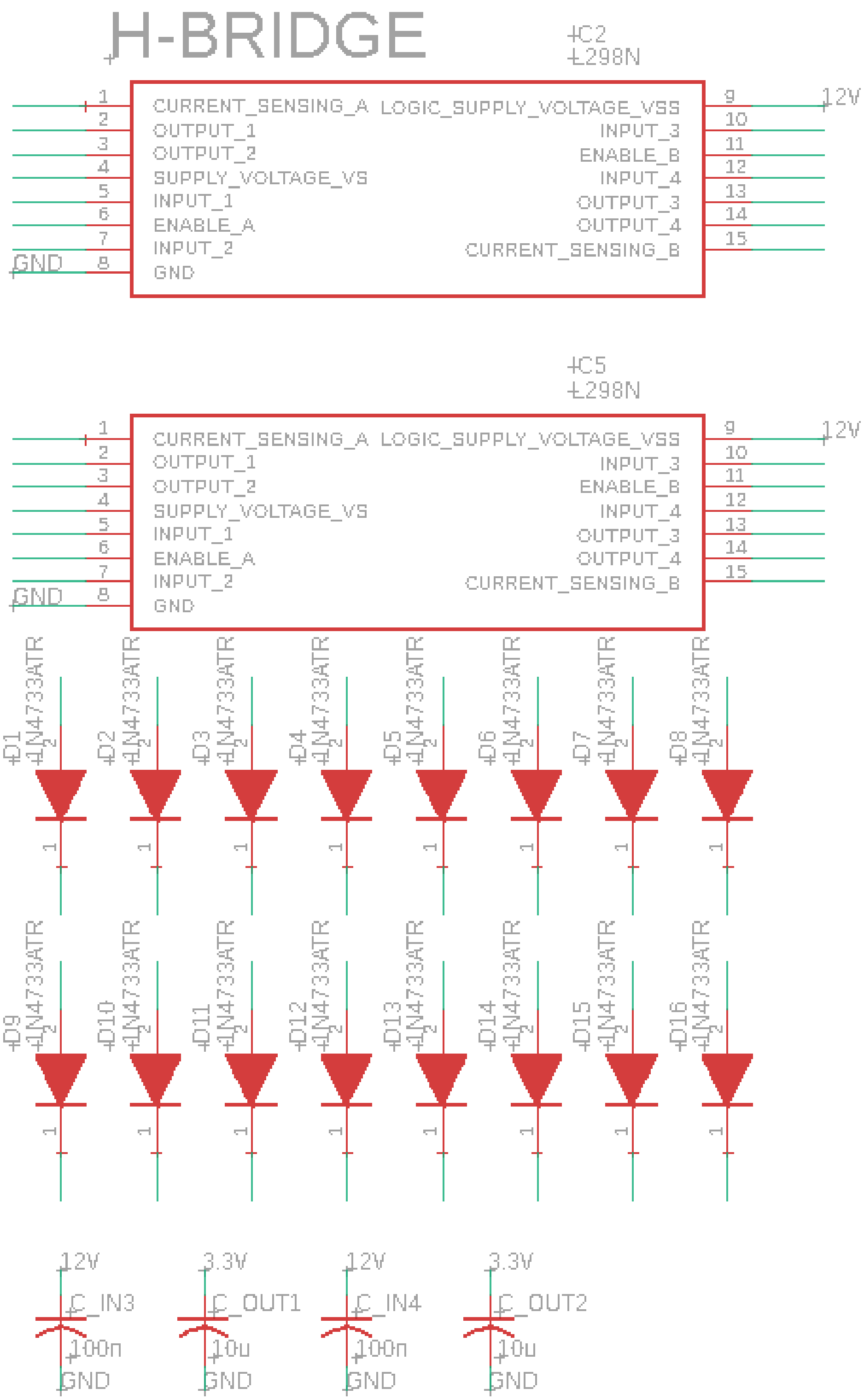

Figure 13: H-bridge circuit

2.5 Risk Analysis

Detection module is the most risky part of the whole project. Since cats usually move fast and it is hard to trace their movements. It is really important that the sensor can detect cats and make a quick reaction to protect their safety. Also, the sensor has to correctly detect that the cats get inside into the litter box instead of just hanging out there. Since we want to notify users when to start the machine to do the cleaning job after a certain amount of time that cats use the litter box. So we have to make sure that it can work efficiently to send the signal to users at the correct time. The major difficulty that we encounter might be the way that we analyse the data collected from the sensors. We are considering using ultrasonic sensors, while the frequency that the ultrasonic sensor generates is often within 25 - 50 kHz and cats can hear frequencies from 48 HZ - 85 kHz. [8][9] It is possible that ultrasonic sensors will annoy cats that they don't want to use the litter box. We could also use IR sensors instead but IR may not have enough accuracy that we want.

The motor module also has a relatively high risk to successfully complete the task. We want to seal the bag up for convenience, and string and heating are methods we are considering. For string methods, the difficulties are the design and movement of the robotic arm controlled by the motor and it is hard to completely block the odour. For heating methods, heating plastic might generate some toxic gas that might hurt cats and have bad smells [10]. We would need long term testing and debugging to find the best solution.

2.6 Tolerance Analysis

2.6.1 Maximum Current Draw

Since our project utilizes three linear actuators which by nature is current hungry when operating in heavy load condition, we need to make sure that at maximum possible load scenario, the AC-DC converter can still operate without overloading. Two actuators will push the cat wastes to the bag and the last actuator will firmly apply pressure to the sealer to make sure it seals well. The AC-DC converter we use [11] can handle 5A maximum current when its outputting 12V DC. The worst scenario happens when the cleaner only dispose the wastes after one day. According to this source[12], an average 8-10 pound cat poops around 2 ounce (60 grams) per day. Suppose the two actuators should also be able to push 1lb of cat litters on its away.

The 12V linear actuator we use has max load of 3A and no-load current of 0.8A. It can handle up to 330lb weights.[6] The current draw in the above described scenario can be estimated using the equation from this website[13]. Because the actuator has a linear I-V relationship, we can calculate the slope of I-V curve and estimate the current.

$$slope = \frac{I_{Max\ Load}(A) - I_{No\ Load}(A)}{Max\ Load(lbs) - No\ Load(lbs)} = \frac{3 - 0.8}{330 - 0} = 6.67\ mA/lbs \tag{1}$$

$$I_{Push\ Waste} = slope\ (mA/lbs) * load(lbs) + I_{No\ Load}(A) = 6.67 * 1.13/1000 + 0.8 = 0.808A \tag{2}$$

The last actuator for pressing the sealer should apply around 15lbs to allow enough margins for the sealing operation. Applying the same equation above, the current is:

$$I_{Seal} = slope\ (mA/lbs) * load(lbs) + I_{No\ Load}(A) = 6.67 * 15/1000 * 2 + 0.8 \approx 0.9A \quad (3)$$

Other modules, for example sensors and microcontrollers, consume less power. The ATMEGA328[14] has maximun power supply current of 2.75mA and ESP8266 Wi-Fi Transceiver[15] consumes 170mA max load. The HX711[16] has 1.4 mA assuming max load.

$$I_{Total} = 0.808 * 2 + 0.9 + 0.00275 + 0.17 + 0.0014 = 2.7A \quad (4)$$

Assuming worst scenario, the max current draw is 2.7 A which is well within the AC-DC converter's current handling capacity. The 2.3A margin allows our system to be more failure safe and robust to unexpected pitfalls that sucks in more current from converter.

3 Cost

3.1 Parts

Table 8: Parts Costs

Part	Manufacture	Retail Cost	Bulk Purchase Cost	Actual Cost
Linear Actuator[6]	ECO LLC	29.99 * 3	9.99 * 3	29.99 * 3
Heat Sealer[17]	METRONIC	34.86	21.22	34.86
Petmate Open Cat Litter Box[18]	Doskocil	5.87	0.79	5.87
Weight sensor with HX711 amplifier[16]	Geekstory	6.5	4.3	0(samples)
Gear motor[19]	Uxcell	33.89	20	33.89
Total	N/A	171.09	76.28	164.59

3.2 Labor

We worked eight hours per weekday and less than four hours per weekend during the whole semester. Considering the hourly wage as \$50 and the period of prototyping as 16 weeks, the total labor cost would be \$115,200.

$$8 \times 5 \times 3 \times 16 \times 50 + 4 \times 2 \times 3 \times 16 \times 50 = \$115,200 \tag{5}$$

3.3 Schedule

Table 9: Schedule

Week	Chi Zhang	Jian Chen	Weiman Yan
3/8	Final check with machine shop about mechanical design and ATMEGA328 control	ATMEGA328 control motors with H-bridge	ATMEGA328 circuit
3/15	ESP8266 Wi-Fi circuit.	ESP8266 server	Design UI with front-end code for users
3/22	PCB design	Build a database and ESP8266 connect with database	UI code and backend code for users
3/29	PCB design final version	Work on weight sensor with HX711 amplifier and send data to Esp8266 server	Combine all software stuff and debug
4/5	Work on ac to dc adaptor	Work on Linear voltage regulator	Finalize software version and make sure it can work.
4/12	Combine the machine and test	Combine the machine and test	Solder Bluetooth to receiver.
4/19	Prepare for mock demo.	Prepare for mock demo	Prepare for mock demo
4/26	Prepare presentation	Prepare presentation	Prepare presentation

4 Ethics and Safety

There are some safety-related issues for this project. First of all, the motors of the cat litter box are controlled by the control module. The movement of the comb-shaped cart and robotic arms could potentially hurt humans. Once the motors start to move, there is no way to stop it. According to the #1 of IEEE Code of Ethics [20], we come up with several solutions to prevent the misuse. We also have an LED indicator to show if the cat litter box is cleaning itself. Visible instructions would warn people not to put their hands in the box when the LED is red, which follows #2 of IEEE Code of Ethics [20].

By communicating with an ESP8266 micro-controller, the remote app will constantly collect data from the cat litter box. Since the box would most likely sit in the house, it is possible to be a threat to the user's privacy. According to the #1 of IEEE Code of Ethics [20], we would notify the user about the data collection and only collect the data if the user-approved. Also, we will encrypt the data to protect the users from hackers. There are sensors on the box to detect the cat. It has the probability to be misused to detect people living in the room. To prevent such cases from happening, we need to make sure that the sensor could only detect the cats around the cat litter box.

One issue we might encounter is that: After testing with simulated waste and cats, we would need to have real cats as users to test our product. Since our circuit or the movement of the comb-shaped cart has the possibility to hurt cats, we would have to address this potential threat according to Animal Protection laws of Illinois [21]. We need to make sure all our circuits are covered by insulation material and not exposed outside. We also have sensors to protect cats from staying around the box while it is working. We would put limits on the speed and the movement distance of our comb shape cart to ensure that even if it crushes the cat, it would not cause much damage.

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