SELF-CLEANING CAT LITTER BOX

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Final Report for ECE 445, Senior Design, Spring 2021

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May 5, 2021

Project No. 48

Abstract

This project aims to create a self-cleaning cat litter box with an auto-bagging system. To accomplish the goal and to make a better product, we came up with many design concepts and considered the corresponding trade-offs in each part. This report will begin with our introduction to our motivation and designs of our project. Next, we will talk about our design by going through each module in detail and the function and verification for each module are then discussed. It followed by our cost and conclusion that consists our accomplishments and future work.

Contents

1 Introduction

1.1 Objective

Cleaning the cat litter box is often the most disliked work for people who have cats. First, 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 is a daily chore which makes this job even more tedious.

Therefore, our plan is to build a self-cleaning cat litter box to help people manage a usually undesirable task. 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

The 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 Wi-Fi 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 an affordable 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 unpleasant odor is still bad inside the box and the parasites from cat waste may cause infection [4].

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

1.3 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 Wi-Fi environment and see the weight data that is updated within every minute.
- 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 powering all systems 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 ATMEGA328P micro-controller from the Arduino board. its use is 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.

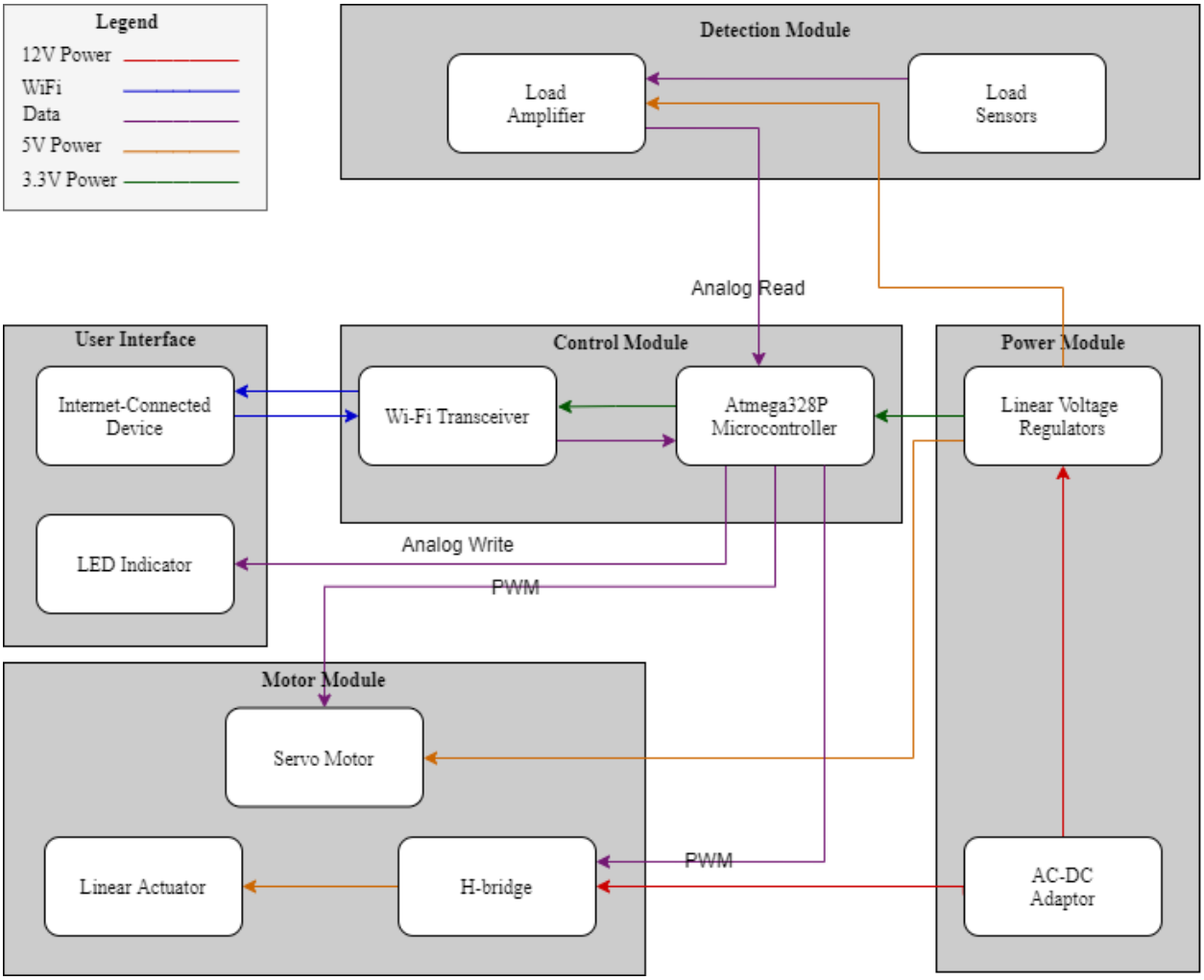

Figure 1: Block Diagram

2.2 Physical Design

The litter box we designed is 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 make a comb-shaped cart to do the filter work. A 1 cm comb gap is considered 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 is planned at the back of the box. A funnel shaped pie will lead those waste materials into the plastic bag. Next is the process of sealing the bag by a heating sealer that is controlled by two motors. One gear motor controls the heating level and the other one would function as a linear actuator motor in order to push the heat sealer bar to seal the plastic bag.

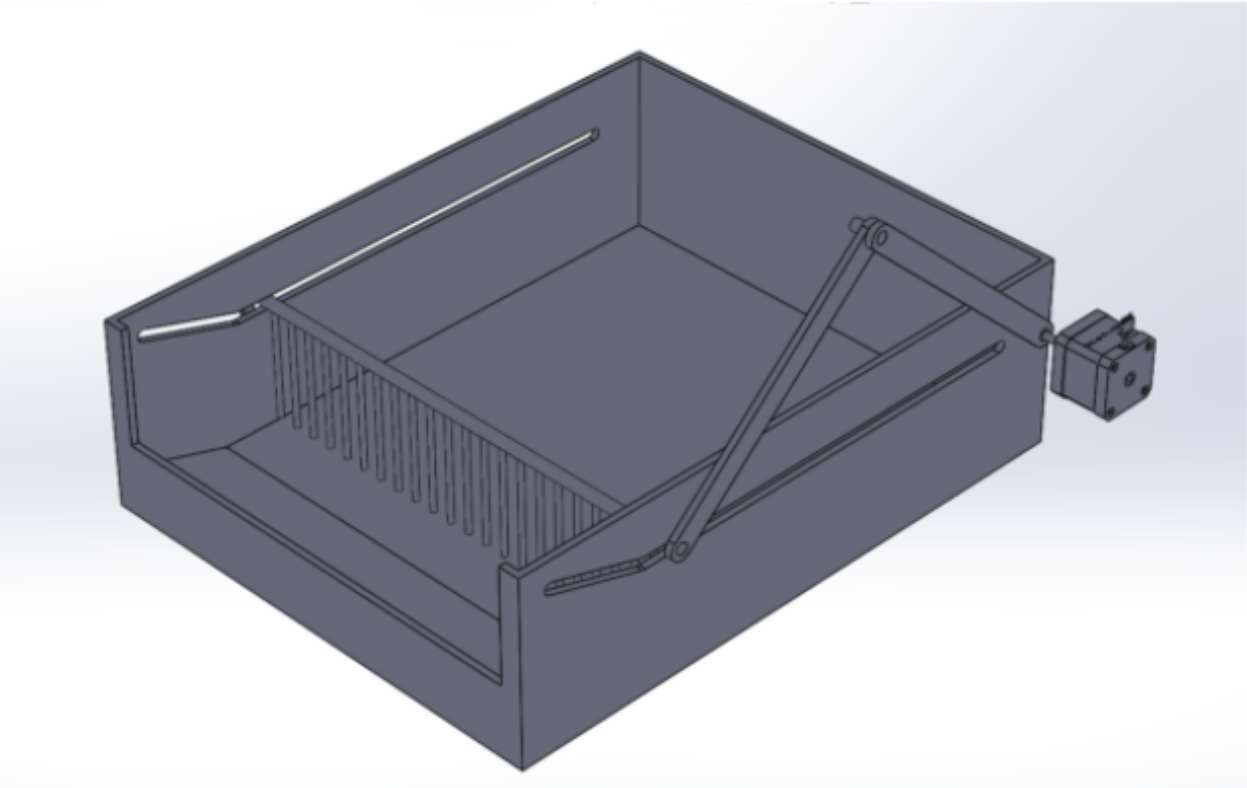

Figure 2: Top View

Figure 3: Heat sealer [5]

Due to the material limitation that we have only wood and metal and they cannot have curve. Here is our sample product image for the demo this semester.

Figure 4: Demo Sample [5]

2.3 Block Description

2.3.1 Detection Module

Multiple load (weight) sensors are proposed to attach 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 to determine if the cat has left droppings in the box. The weight change of more than 4-5 pounds (typical weight of the cat) or the weight change of less than 0.1 pounds is marked as outlier data. The data is collected for every 20 seconds and the outlier data is going to be filtered out. There is a reset function that is used when we change the litter in the box.

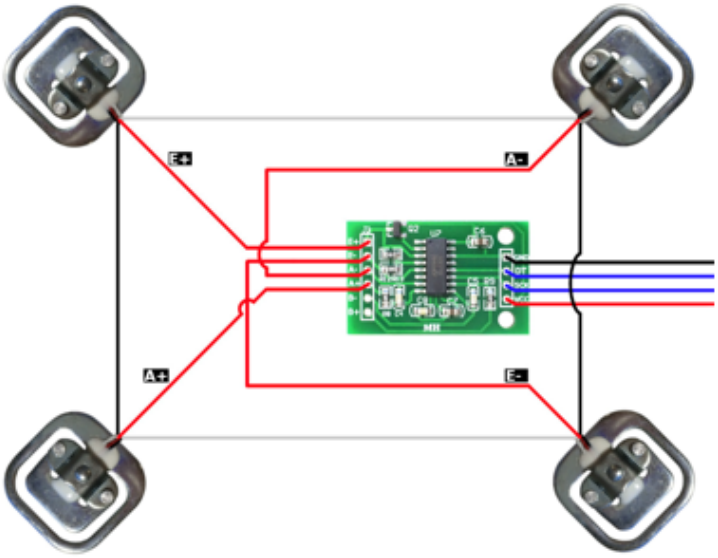

Figure 5: HX-711 amplifier circuit with 4 pcs load sensors [6]

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 a voltage divider to sense the resistance change and transforms the dedicated resistance change to readable voltage level difference that are prepared for the microcontroller.

2.3.2 Control Module

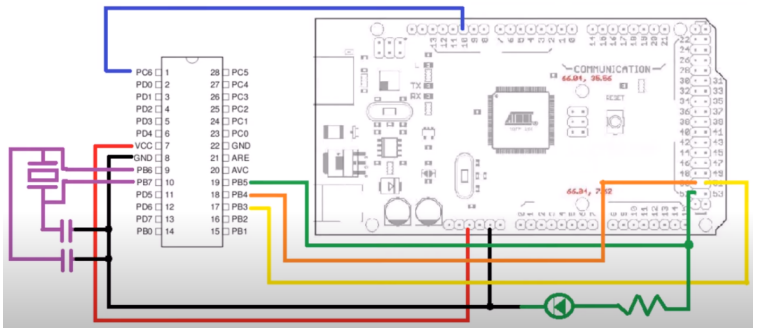

Figure 6: ATMEGA328p circuit

The control module is an ESP8266 Wi-Fi module connected with an ATMEGA328P microcontroller [5] used to control the motor module and it receives data from detection module and commands from users. Considered about safety, if it receives the command from remote apps and the weight sensor tells that there is no outlier data, the control module could send signals to the motor module. If it receives the command from users while the weight sensors give an outlier data which means it is not safe to work, the control module will not send signals to the motor module until weight data gets normal.To program the ATMEGA328P in Arduino IDE, we use the Arduino-Mega 2560 as ISP programmer. And here's the state machine that for control module to control the motors. In the Halt state, the ESP8266-01 writes weight data to the cloud and reads users' command for every 20 seconds.

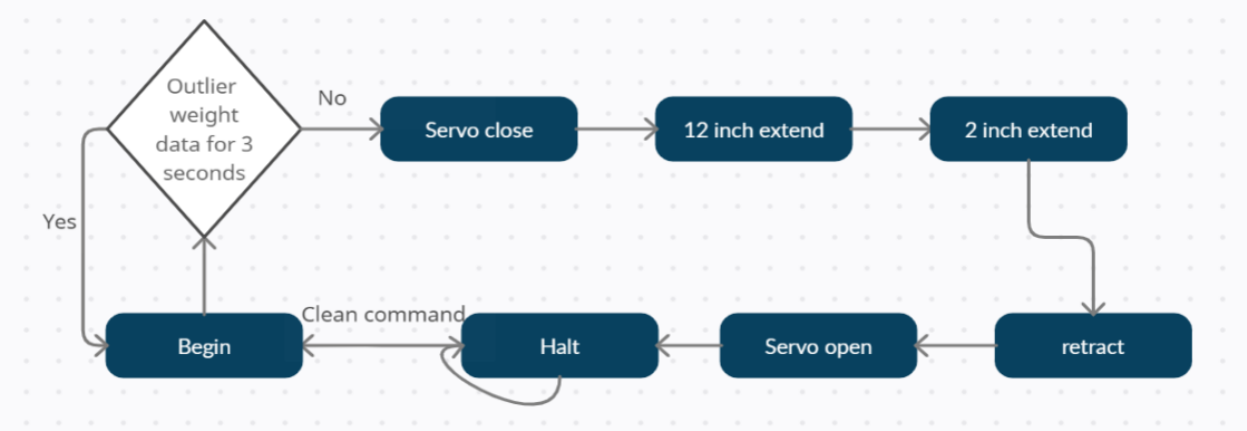

Figure 7: state machine

2.3.3 Power Module

The power module is able to drive the motors and support other electrical devices involved in our design. The system is going to 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 12 V ,5 V and 3.3 V DC power to drive all components. This low dropout regulator would supply the 3.3 V from the 12 V$\pm$ 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).

2.3.4 Motor Module

The motor module handles both the movement of the comb-shaped filter and the bagging quest from the heating sealer. The two 12-inch linear actuators is powerful enough to carry the comb shape filter along the sidewall of the box to move along the track smoothly. The 3-inch linear actuator also has enough force to push the arms of the heat sealer to bag the waste. The servo motor is planned at the front door for safety that it can close and open the front door of the litter box. The two 12 inches linear actuators are controlled by H-bridge to make sure they can move accordingly and we can adjust their speed by changing the duty cycle.

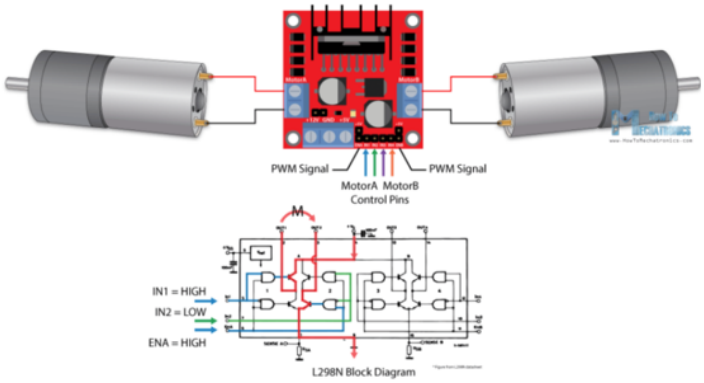

Figure 8: L298N circuit [7]

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 9: Linear Actuator Specs [8]

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.

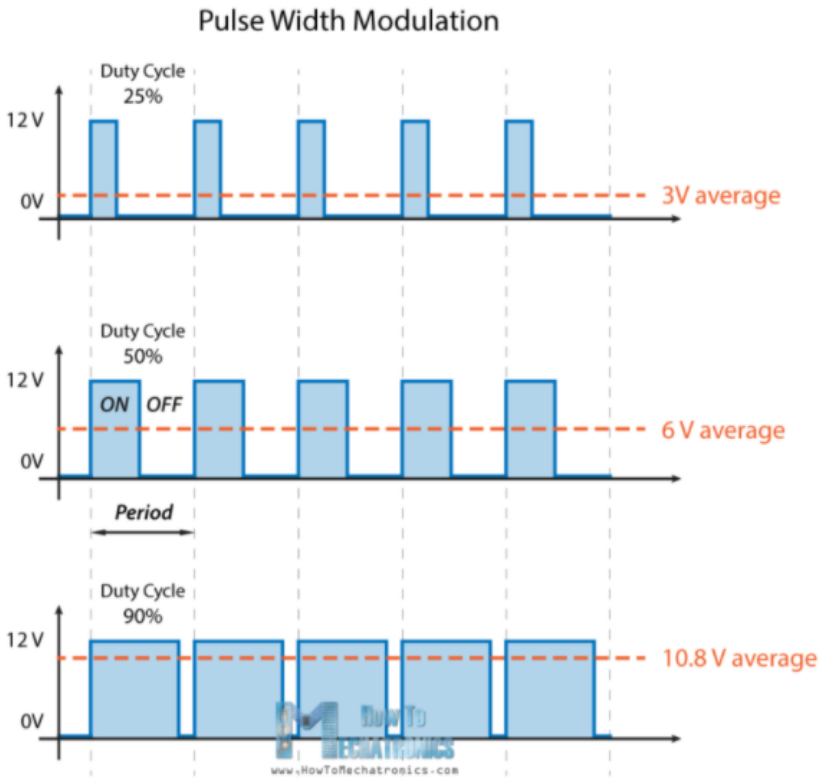

Figure 10: H-bridge Verification of motor speed [7]

All motors should work in a sequence to make sure the cleaning job and the bagging system are successful. As shown in the figure 7 state machine, when it receives signal from control module and there is no outlier data, the servo motor firstly closes the door, and then the linear actuators for the filter begin to work. After the filter pushing waste material into bag, the 3 inches linear actuator begin to push heat sealer. Finally, three linear actuators get back to the initial position and the servo motor opens the door.

2.3.5 User Interface Module

The user interface module is designed for accessibility 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.
LEDs on the box will be used to show the status of the machine. The red LEDs shows that the machine is powered on. The blue LEDs represents that the machine receives command from users and the blue LEDs will blink if the weight sensor detects that the cat is in the box.

3 Design Verification

3.1 Detection Module

The detection module contains a HX711 amplifier and four 50kg load cells. We need to meet the requirement that the control module could receive the correct weight data and upload them to the Thingspeak cloud every 20 seconds. Thus, our verification includes both receiving basic load data from the load cell circuit and processing those data to enable the clean function. The processing logic is that if the past two measurements of the weight have a difference within 0.1, we define the state to be stable. If a measurement is both within the range of 0.2-5 and has a stable state, we would send a start cleaning signal to the control unit.

3.1.1 Load Cell

We connect the load cells with the HX711 amplifier to an Arduino Uno board and use the Serial Monitor to observe the received data. During the first verification test, the data was very unstable. The weight values were changing frequently and sometimes not received. That was caused by two reasons. First reason is that both connections between load cells and HX711 are not stable. We fixed this problem by using different wires and sold connecting points together. Secondly, the floor that we set our test on is covered by a soft carpet, which makes any movement a huge noise to the verification test. We solved this problem by adding four wood pads for each load cells. We also tried to not make movement during the test.

3.1.2 HX711 Amplifier

The test of HX711 Amplifier was initially not in our verification table because it is a commercial product and we expect it to work properly. However, at the 13th verification test of the detection module, we suddenly could not receive the correct load data. After several hours of debugging, we finally decide to replace the HX711 with a new one. The problem then got solved. The reason of the old HX711 broken might be accidentally shorten by other circuit or burned by have 12 V input. After that we added the HX711 verification to our test.

3.2 Control Module

The control module contains a ATMEGA328P microcontroller and an ESP8266 Wi-Fi transceiver. We would verify both parts separately first, and then test them together with the motor module.

3.2.1 ESP8266-01

We test the ESP8266-01 by connecting it with an Arduino UNO. First, we connect TX,RX of ESP8266 to pin 1 and pin 0 on the Arduino and set it to 8600 baud speed and client mode. Then we test it with our designed circuit. We type "AT" in the serial monitor. It returns "OK", meaning that the ESP chip is powered. To verify if the ESP8266 could recognize the nearby Wi-Fi, we then type"AT + CWJAP = 'networkname','password'". The serial monitor shows that the WI-FI is successfully connected.

3.2.2 ATMEGA328P

We connect the ATMEGA328P by a 16 MHZ crystal and two 22pf capacitors. Then we test it by upload the basic blink code to the ATMEGA328P. Because our Arduino UNO was not working, we then used an Arduino Mega board to upload the code according to figure 7.

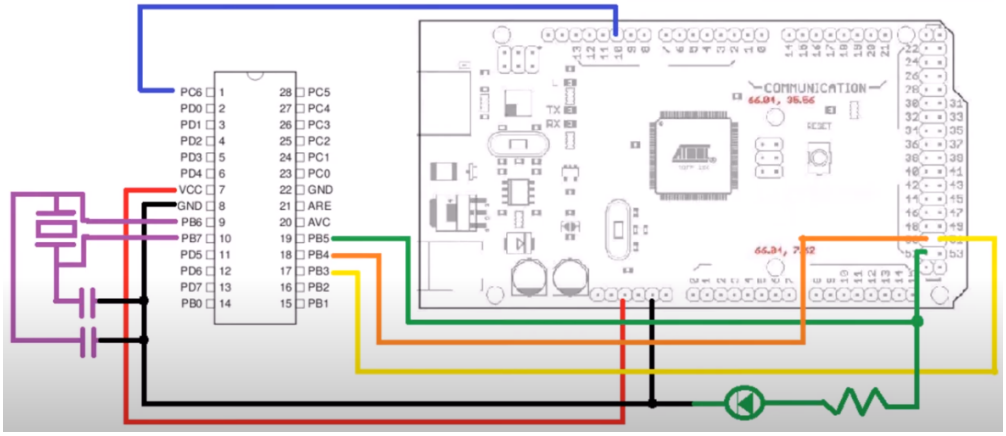

Figure 11: Arduino Mega as ISP programmer

3.3 Power Module

The ECE445 toolbox provides us with the AC-DC adaptor we need. After received the ordered PCB, we tested it with voltmeter and Arduino board. The verification of the 12V to 5V and 5V to 3.3V functions in our PCB was successful. However, we eventually used the 5V from the ECE445 toolbox to avoid any potential current problems because we added multiple motors to our design after ordering the PCB.

3.4 Motor Module

The motor module contains three linear actuators, one servo motor, and one L298N H-bridge. We need to test each parts separately first. It is also important to test them again after the machine shop put them together on the product to verify any potential damage or unexpected design problems during the building process.

3.4.1 Linear Actuator

The verification of all three linear actuators are passed by connecting them to the 12V source. We also found that after the actuator retract or extend to its limit, it would eventually stop and cut off power even when still connected to the source. This verification makes coding and design much easier.

3.4.2 L298N H-bridge

The L298N H-bridge could control two motors simultaneously. During one test of the verification process, we accidentally disconnect one 12 inches linear actuator. The filter was then jammed. This potential problem of our product made us connect the two 12 inches linear actuators to one output of the L298N. This would guarantee both linear actuators have the same speed. It also saved us some space since we only need one L298N now.

3.5 User Interface

3.5.1 Main Page

Users could register new accounts or login using existing accounts on our main page. The user need to enter the email address and click send confirmation code button to start register. Then our system would automatically generate an email containing a 5-digits code to that email address. The user needs to enter the code, password and box id to finish register. The box id is an unique id on each of our product. By entering the box id, the user's account could be linked with the box.

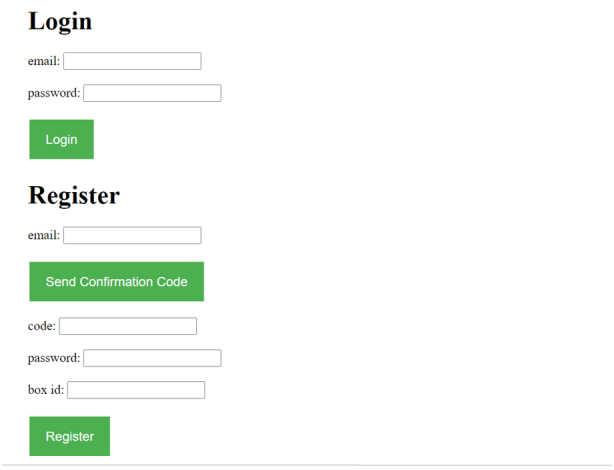

Figure 12: Main Page

3.5.2 Control Page

After login, users could see their individual control page. Here, they could see their boxes' status and control the box. As its name suggests, if the user click on clean, the box will start to clean if there is no cat in the box. If the user pour more cat litter into the box and the current net weight becomes a non-zero number, the user could click on the recalibrate button to reset the net weight back to zero.

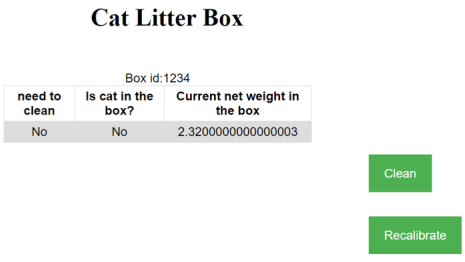

Figure 13: Control Page

Below is how we calculate and determine the values in the three entries.

$$CurrentNetWeight = CurrentWeight - RecalibratedWeight$$

$$CurrentNetWeight > 0.4 \text{ lbs} \rightarrow \text{Cat is in the box}$$

$$\text{Last two Measurements of the Net Weight have the difference within 0.1 lbs} \rightarrow \text{Box is stable}$$

$$(0.2 \text{ lbs} < CurrentNetWeight < 0.4 \text{ lbs}) \;\&\&\; \text{Box is stable} \rightarrow \text{Need to clean}$$

3.5.3 Database

In the backend, we mainly use MongoDB. We store user's email address, password, confirmation code when register and box id linked with this account. For security reason, all stored users' password has been encrypted and stored in binary form. We also store the information of box. We record each box's useful channel ids and API keys on thingspeak. This enables the backend to communicate with the box through the channels.

3.5.4 Email Notification when needs clean

This feature is implemented by running a program independent from the Web App. We want users to receive email notification without opening our website. It is implemented by checking all registered users' the box status and remind them if there is need. This program is multi-threaded so more users will not lower the running time. The calculation and determining logic is same as the Web App.

4 Cost

4.1 Parts

Table 1: Parts Costs

Part	Manufacture	Retail Cost	Bulk Purchase Cost	Actual Cost
Linear Actuator [8]	ECO LLC	29.99 * 3	9.99 * 3	29.99 * 3
Heat Sealer [9]	METRONIC	34.86	21.22	34.86
Petmate Open Cat Litter Box [10]	Doskocil	5.87	0.79	5.87
Weight sensor with HX711 amplifier [11]	Geekstory	6.5	4.3	0(samples)
Gear motor [12]	Uxcell	33.89	20	33.89
Total	N/A	171.09	76.28	164.59

4.2 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.

$$8 \times 5 \times 3 \times 16 \times 50 + 4 \times 2 \times 3 \times 16 \times 50 = \$115,200 \tag{1}$$

5 Conclusion

5.1 Accomplishments

Ultimately, we have achieved all goals that we designed. First, we successfully build a self-cleaning cat litter box that has an auto bagging system, and we have tested multiple times that it can filter the waste and seal the bag. Second, we have done IoT function that the users can remotely control the cat litter box and know the weight data online. Third, we have integrated the microcontrollers with motors and weight data to make sure the safety of the cat litter box. Last, we designed our own web/app UI for users to use the product and receive notifications when needed. Overall, the project was success.

5.2 Improvements

Although our project is considered as successful, there are still something we can do to improve the project. These are something that is not future work but is because time and material limitation we did not do.
The first thing is the mechanical design. Because we only have wood and metal, our demo product is kind of big and heavy and not very good looking. We can build product plastic with design in the Figure 2 to make it lighter. We can also replace the giant linear actuators with gear motors which are smaller and lighter in weight.
The second aspect is about the weight sensors. Our weight sensors on the demo product is too sensitive to the noise that is when people walk around it, the weight data will also change. The reason is that when we build them, they are independent so that their position is not relative stable. And they contact with the soft ground that the pressure will change. We can make this part stable by making weight sensors like a weight scale and make a gap between sensors and ground. In this way, their positions are fixed and the pressure will not change when people walk around them.
The third aspect is about the Wi-Fi module. Although our Wi-Fi module can successfully read and write data for every 20 seconds, and it is enough for our demo product, we have multiple ways to speed it up. We can use more ESP8266-01 chips. Since for each ESP8266-01, it can only read or write at one time. Using more chips can save more time by only do reading or writing job. Besides, we can change ESP8266-01 chip to more advanced Wi-Fi module which is ESP32. Compared with ESP8266-01 ESP32 is much more powerful that it has an extra CPU core, more GPIOs and much faster. [13]

5.3 Ethical considerations

There are some safety-related issues for this project. First, the motors of the cat litter box are controlled by the control module. The movement of the filter and robotic arms could potentially hurt humans. Once the motors start to move, there is no way to stop them. According to the #1 of IEEE Code of Ethics [14], we came 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 [14].

By communicating with an ESP8266 microcontroller, the remote app will constantly collect data from the cat litter box. Since the box would most likely sit in the house, it could pose a threat to the user's privacy.

According to #1 of IEEE Code of Ethics [14], 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 of misuse 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 [15]. 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 filter to ensure that even if it crushes the cat, it would not cause much damage.

5.4 Future work

Since this project is about marketing, to make our product more popular, there are something we need to do in the future. The most significant one is that we have to find some ways to automatically change the bag. For now, our product needs manually change the bag after sealing the bag, which is kind of annoying for users. We thought about using robotic arm to change the bag but that might be too expensive. So we still need to find some new ways to do this job. Besides, we need some more sensors to help users track their cat. Sensors like IR sensor and ultrasonic sensor can help a lot that it help users know about their cats better, and our product will be more functional. Furthermore, we can improve our web/app UI like better appearance and add more functional buttons to attract more consumers.

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Appendix A Requirement and Verification Table

Table 2: System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Detection Module Requirement (a) The weight sensor can update data for every 20 seconds and will report weight change within 0.2 - 4 pounds.	1. Detection Module Verification (a) Connect load cells with HX711 to Arduino Uno to test if we could receive the up-to-date weight data. (b) When the weight sensor detects positive weight changes within 0.2-4 pounds, the cloud could send a signal to the control module. If the data collected is outside of the range, the control unit should not receive anything.	1. (a) Y (b) Y
2. Control Module Requirement (a) Control module could use ESP8266 Wi-Fi transceiver to connect to an online database. (b) The remote app can control the machine to start the clean job. (c) Motors and the linear actuator can work together with correct order to finish the clean and sealing job. (d) It should remind the user to clean the cat litter box when the cat leaves droppings using the weight data.	2. Control Module Verification (a) ESP8266 could recognize the nearby Wi-Fi signal and connect to the Internet. (b) If the start button is pushed and the start signal from the remote end is received in the database, the ATMEGA328P could send signals to enable motors and linear actuators to start moving. (c) The linear actuator for sealer section works after the linear actuators for filter section. The servo motor works at the beginning and the end of the procedure. (d) When the detection module detects the cat droppings, the data base could receive signals.	1. (a) Y (b) Y (c) Y (d) Y

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Table 2 – continued from previous page

Requirement	Verification	Verification status (Y or N)
3. Power Module Requirement (a) The adaptor could transform 110V AC power to 12V DC power. (b) The linear voltage regulator should be able to provide 3.3V and 5V ± 5% from a 12V source and could operate at currents within 0-50mA. (c) The power system should maintains thermal stability below 125°C.	3. Power Module Verification (a) The output of the adaptor is 12V DC voltage. (b) The linear voltage regulator can produce 3.3V DC voltage output and 5V DC voltage output. (c) Use thermometer to ensure the temperature stays in range.	1. (a) Y (b) Y (c) Y
4. Motor Module Requirement (a) 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% (b) The module must be able to carry the comb shaped filter cart to move along the track without any jam. The success rate should be at least 90 % (c) 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	4. Motor Module Verification (a) 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. (b) Run the linear actuators on the track 20 times and to count the times that more than one motor stopped following the track or lose synchronization. (c) 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.	1. (a) Y (b) Y (c) Y

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Table 2 – continued from previous page

Requirement	Verification	Verification status (Y or N)
5. User Interface Module Requirement (a) The user is able to send signals to litter box to initiate the machine remotely through the internet-connected device (b) The user is able to reset the weight data collecting criteria (c) The UI is able to register new users with their email address (d) The server will send reminders to the user when cleaning is needed	5. User Interface Verification (a) When the user pushes the start button on the remote app, the clean signal could be sent and recorded in an online database (b) When the user pushes the reset button on the remote app, the reset signal could be sent and recorded in an online database (c) 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 (d) The user could receive reminders by email when the cat droppings are detected and recorded in the database	1. (a) Y (b) Y (c) Y (d) Y