Purrfect Litter - Automatic Cat Litter Box

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***Abstract* — A unique and practical electrical and computer engineering project, the Purrfect Cleaner is an efficient, low-cost design intended to bring high-end cat litter box functionalities to a budget price. The project incorporates many advanced cat litter box technologies: automatic cleaning, weight and motion detection, automatic disposal of waste. The Purrfect Cleaner provides smart cat technologies intended to protect the user while autonomously maintaining a fecal free environment. This paper focuses on the mechanisms contained within the Purrfect Cleaner and explains their functionality.**

I. Introduction

Inspired to give cat owners an efficient and economical automatic litter box, our group chose to design the Purrfect Cleaner. Commercial, automatic cat litter boxes range widely in terms of cost and functionality. Lower-end boxes generally fall within the price range of $75-150 and higher-end boxes within $250-350+. [1]. Boxes on the lower-end of the aforementioned cost range contain less functionality than their pricer counterparts. The Purrfect Cleaner is an automatic cat litter box design that bridges the gap between price and functionality within the current litter box commercial market. The Purrfect Cleaner design offers a range of functionalities, including smart-cat detection safety features, automatic cleaning, and automatic disposal of waste. Furthermore, the Purrfect Cleaner is a multifunctional litterbox design with a sum production cost less than $150. The safety mechanisms include motion and weight sensors designed to detect a cat or user's presence. The sensors relay signals back to the microcontroller, which will prevent the motor from running during a cleaning cycle. The automatic cleaning mechanism has been designed to allow for periodic cycles with a button for manual control. The cleaning mechanism itself consists of a DC motor with a chain belt and an attached sifting comb. Upon cycle activation either through manual button or periodic timer, the motor will activate and rotate the fixed comb through the litter. The comb will rotate until it reaches its initial position or is stopped by the sensors. If stopped by sensors, the motor will be placed on a brief timer until the sensors are unable to detect a presence. Finally, the automatic waste collection setup allows for easy-to-use disposal including a mini trash bag and tray.

II. Components of the System

The following section gives details on each and every component that makes up the Purrfect Litter system. The importance, functionality, and how each one interfaces with one another to ensure the finalization of the product.

A. Microcontroller

The microcontroller being used in the system is the ATMega328P-PU from Atmel. It features a high amount of Input/Output pins for use with multiple peripherals, 1KB of Read-Only Memory, 2KB of Random Access Memory, support for low-power modes, and operates in the 5V power range. Its low cost, while having the features listed above, made it a compelling option to use for the system.

B. Strain-Gauge Weight Sensor

The weight sensor used in the system is the S18X2+S19X2 Digital Load Cell from ShangHJ. It is able to measure up to a maximum of 20 Kilograms, operates in the 5V range, and is accurate to within a 1% difference. It is also made out of a robust Aluminum material to ensure it will sustain a high amount of trauma (pressure from weighting the object) without collapsing.

C. Infrared Photoelectric Sensor

The infrared photoelectric sensor used in the system is the E18-D80NK from HiLetgo. It is a versatile obstacle avoidance sensor featuring adjustable detection distances from 3 to 80 cm, powered by a 5V to 24V DC supply. The sensor provides a digital NPN output signal for easy interpretation to the ATMEGA328P. It delivers high sensitivity and stability with a fast response time of under 2 ms, making it suitable for the system. Its adjustable detection range and reliable performance make it an ideal choice for our application.

D. Slide Switch

The Slide switch used in the system is the OS102011MA1QN1. It is rated 12 Volts 100mA, although the system uses 5 V power supply the switch still operates at 5 volts. The switch is used to control the power supply of the system.

E. Push Buttons

The buttons used in the system are TS02-66-60-BK-260-LCR-D. It operates from 1 - 12 volts with current consumption of 0.01 to 50 mA. The function of the buttons is for setting the system to a different operation scheme.

F. Power Supply

The system has a 5 volts, 1.9 A max power consumption, which is when every component is operating at its maximum power. Since the system is designed to be stationary, the power is supplied from the wall outlet. Therefore, the power supply for the system is a 120 VAC to 5 VDC 2.4 A converter.

G. Worm Gear Motor

The motor used in the system is the NFP-5840-36ZY-1280. It is rated as a 12 Volt 0.6A reversible self locking DC worm gear motor. The worm gear motor is designed for high torque and low speed, which suits the project design parameters for the cleaning cycle. The self locking mechanism of the motor is crucial as the motor will not rotate unless power is supplied. For the Purrfect cleaner, this feature ensures the sifting comb will not be moved, which mitigates risk of damage or injury to the device or user. Although the system has only 5 volts, 6.5 when using the regulator, the worm gear motor operates at a reasonable speed and torque regardless of its 12 Volt rated voltage.

III. System functionality

The following section will go more in-depth on how the Purrfect Litter System is intended to function. We will look at the importance of each component, how each component interacts with one other, and the overall functionality that is met with the system. The easiest way to represent the function of the system is with a flowchart.

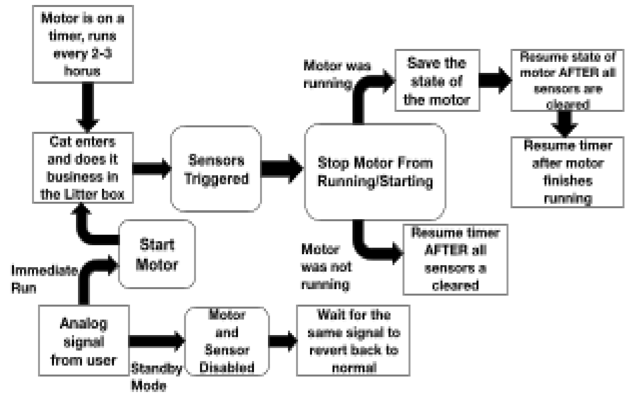

Fig. 1. Flowchart representation of system functionality that details what happens when a certain action occurs.

As shown in the flowchart, Fig. 1., it shows a linear progression in how it checks the sensors depending on the actions the cat takes. Starting on the top left, the motor in the system is being set on a timer that will run every 2-3 hours. It is set this way because a cat on average will poop around 1-2 times in the day, and this can occur at any time during the day. Having the motor set on a timer allows the motor to run 8-12 times in the day in order to ensure that all the feces made from the cat is collected into the bin. There are, however, some features built in that allow the user to control the behavior of the system.

Another starting point on the flowchart in Fig 1. is on the bottom left, the “Analog signal from user”, where there will be two tactile buttons that allows the owner of the system to be able to have some level of control. Each button does a certain action, the first being “immediate run”, and the second being “standby mode”. On the first action, when the user presses the first button, the motor will be set to run immediately and resetting the timer in the process. This is a simple function to allow the user to have some control. The second action, when the user presses the second button, the system will go into standby mode. In standby mode, the motor and all sensors are disabled, the state of the timer for the motor is saved, and only the button that initially pressed is active, waiting for it to be pressed again, and when pressed it will revert back to the original state. The standby mode is put in place to allow the user to do some standard maintenance without the risk of tripping the sensors or the motor starting while they work. Standard maintenance includes cleaning the litter box, removing something that is stuck in the litter box, and replacing the waste bin.

In the event that the motor begins running, whether activated by the user through the button, or the timer reaching the time required for the motor to run, a set of sensors is put in place in order to ensure a very important part of the system, safety of the feline. The motor that will drive the cleaning process of the litter poses a danger to the feline. If the motor runs while the feline is still present in the box, it can cause something negative to happen to the feline, an example such as pinching the cat's paws between the comb and the base of the litter. In any case, it is best to ensure the motor does not run when the cat is present in the litter box.

Both a motion sensor and weight sensor are put in place to ensure this does not happen. The motion sensor will detect motion within the boundaries of the litter box, should anything enter this boundary, the motion sensor will trip and prevent the motor from starting. The weight sensor is present for both preventing the motor from starting and stopping the motor if it is currently running. If the weight sensor is tripped while the motor is running, it will be stopped and the state of the motor will be saved to resume after the weight sensor has been cleared. Each and every component functions with one another to create the Purrfect Litter system.

IV. Standards & Constraints

We have abided by many different standards while designing and building our project. We understand the importance of these standards since they would provide guidelines and requirements to ensure the reliability and efficiency of the Purrfect Cleaner. It is also important that we discuss the constraints we have faced during the construction process in Senior Design 2.

A. USB-C Standards

The USB-C is one of the different types of USB ports that is considered more of a modern and versatile model for charging most electrical devices. One of its features include the reversible connection feature which makes it possible to plug in the connector both ways to eliminate the issue of plugging it into a device the wrong way. The USB-C also supports transfer speeds up to 40 Gbps with Thunderbolt 3 technology and has another feature called Power Delivery [6]. Power Delivery which enables higher power to be transferred to larger devices that need more power to be able to function.

B. American Power Standards

The American Power Standards are structured by a system that follows a 120 voltage and a frequency of 60 Hertz as a standard. The 120V/60Hz standard is used by the United States, Canada, and some parts of Central and South America [7]. The standard also comes with different configurations for outlets such as Type A and Type B which specifies the suitable voltage for powering electrical household appliances, personal devices, and industrial equipment.

C. Ingress Protection Classifications

The Ingress Protection (IP) is a standardized system that involves two digits. The first digit is responsible for indicating how well an enclosure can protect items contained in it from solid foreign objects. It ranges from 0 (no protection) to 6 (dust-tight) [5]. The second digit indicates how well an enclosure can protect against water and features more levels on the scale. It ranges from 0 (no protection) to 9 (protection against high-pressure, high-temperature water jets) [5]. In order to protect our PCB from damage we would have a 2 cm gap between the cover and the litter box that would fall in level 2 of the scale for protection against foreign objects. For the scale for protection against liquid objects we have the PCB covered at the top and bottom with plastic which would be classified at level 2. Thus would have our IP rating for the Purrfect Cleaner to be IP22.

D. Electrical Safety Constraints

Since our project does include electrical components such as the PCB, motor, weight sensor, and motion sensor, it would be important to consider potential heating issues. We wouldn't want any materials to be easily melted or catch on fire. That is why we decided to not use a plastic container for our litter box and considered a 3D-printed material. For the issue of having the possibility of any liquid or solid waste from the cat getting on any of the sensors and other electronics, we make sure to have them either covered completely or have proper protection.

E. Time Constraints

For our two semester long Senior Design project, there were some issues we had with time. We understand the importance of making sure that each task is finished in the proper time frame as we work on the project. However, there is always the possibility of something not going as planned which could cause changes to be made in the design or delays to occur when ordering parts, so that is why it would be important to discuss the time constraints we have faced during our time working on this project.

During Senior Design 1 in the spring semester, we had to write a 120-page paper in 14-weeks. The other 2 weeks were spent forming groups and brainstorming project ideas. We all had different class schedules as well so we had to establish proper weekly meeting times as well as dates to come into the lab to start testing on the motion and weight sensors. During these tests issues had occurred causing more discussion on how to fix or decide to replace parts for better alternatives.

In Senior Design 2, we also faced other time constraints as well. We faced more issues with testing with the sensors which caused us to make the decision to order a different motion sensor. We also had busy schedules since we all had classes and some of us had summer internships which caused us to miss some days to work in the lab. Lastly, we did have multiple iterations of our PCB that we had to wait to be delivered and tested so that did cause some delays. However despite these time constraints, we were able to continue to make progress with our project.

V. Engineering Specifications

For our engineering specifications, we have decided to showcase three demonstrable specifications for our live demo presentation. We feel that focusing on these three features would show the full capabilities of our automated litter box cleaner and why these features are beneficial for the user and their cat.

A. Motion Detection

The first demonstrable specification would be the accuracy of the motion sensor. The motion sensor's purpose would be to detect if the cat is near or inside the litter box within 3 meters so that the timer can be paused so that cleaning mode does not occur and the cat would not be harmed by the sweeping comb. So during our live demonstration our motion sensor would be able to detect motion with 90% accuracy if the cat is inside or near the box.

B. Weight Detection

The second demonstrable specification is the accuracy of the weight sensor. Its main purpose would be to detect the cat's weight at all times including when cleaning mode occurs.There could be a chance of the cat entering the box when during cleaning mode so it would act as a second precaution since the motion sensor would be deactivated since the comb would be moving across the box. To prevent injury to the cat, it would be able to detect the cat's weight with 90% accuracy to pause cleaning mode and the motor until the cat leaves.

C. Waste Removal

The final demonstrable specification would be showcasing how effective the motor and comb would remove the cat's waste from the container into a bag. It is extremely important to make sure that waste is properly removed since the cat would need a clean environment to relieve itself and for the owner to not have to use a shovel to dig out the waste. During the demo it should be able to clean 90% of waste from the litter box during cleaning mode.

VI. Hardware Design

In this section the hardware layout of the Purrfect Cleaner will be discussed in addition to the structure and design of the box. The hardware layout will include the components and show their interconnected layout in a block diagram. The structure and design of the box will be represented through 3-D software designs.

A. Hardware Block Diagram

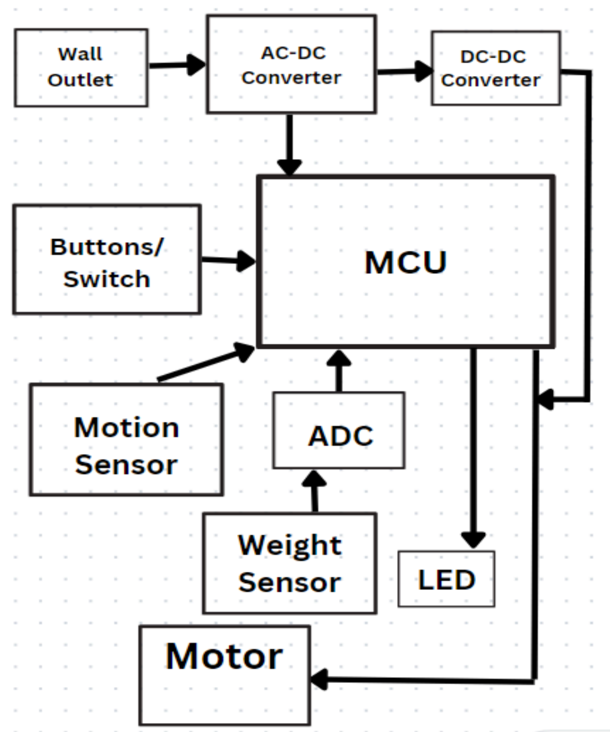

Fig. 2. Hardware Block Diagram for electronics

Fig. 2. above shows the hardware block diagram for all our electronic components used in the system. The motion sensor and the weight sensor are for safety measures. Since the weight sensor we chose outputs an analog signal but our microcontroller only takes in a digital signal. An analog to digital converter is needed. The motor only operates under certain inputs and sensor conditions. The LED is used as an indicator of which state the system is in

for the system. Refer to section IV. for how each component interacts.

B. Motor Control

The motor is used to control the comb, which pushes back and forth along the box. For our application, the speed of the comb isn't a requirement, therefore, precise motor control is not required. Instead, we used a NMOS and fly-back diode to switch the motor on and off. The state of the motor will be controlled by the voltage level at the gate pin. If the voltage exceeds a certain threshold, the motor turns on and vice versa.

C. Box Structure

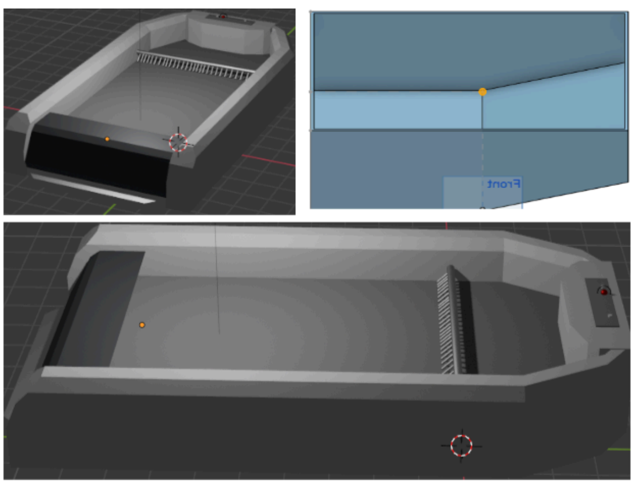

Fig. 3. Visual representation of the box using blender and onshape software applications.

Fig. 3. above gives a visual representation of how the final cat litter box will appear. The first two images in gray were created in the Blender 3D modeling software technology. These images were made to represent the design schematics for the box. The other image in blue specifically outlines the interior box from where the cleaning mechanism including the motor, chain belt, sprockets and sifting comb will be attached. The interior box will consist of a ¼' thick 20' x 7' x 12' BC plywood material in the shape of the blue image from Fig. 3. The motor will be attached to the board and have a circular cutout for the motor shaft. The shaft has a sprocket connected to it, held in place by interior tightening sprocket machine screws. Along the inside of the box, represented by Fig. 3. blue box, there are 3 sprockets from which a #25 stainless steel chains are tightly connected around the sprockets. The sifting comb is attached to the top of a chain in a fixed position. The outside of the box will contain a polypropylene exterior connected to the BC plywood interior. In addition to the box, there will be a detachable tray insert under the opening flag to the box. The tray will contain a box like structure meant to hold the cat excrement. The tray will allow for a mini plastic disposable bag to fit inside of the hole, which can be easily replaced. Note, the final model may vary slightly in terms of aesthetic from the software schematics

VII. Software Design

In this section, the structure of the code used to make the Purrfect cleaner function would be explained. This code was written in the C language and was run and tested on the Arduino IDE. This code consists of three main sections regarding the two button inputs of the litter box and also a running timer that activates the cleaning mode once 1 minute has passed for the sake of presenting for the live demo otherwise it would be after every 4 hours.

The two buttons are for standby mode which pauses the weight sensor, motion sensor, timer, and motor so that the owner can add or take out any litter from the box and the other button is to immediately activate cleaning mode rather than waiting for the designated time frame to pass. There are three if statements for three different scenarios where for scenario 1 if the standby mode button (button 1) is pressed, scenario 2 where standby mode is activated and button 1 is pressed again to deactivate standby mode, and the final scenario where the standby mode button was never pressed and includes a sub scenario where the cleaning mode button is pressed (button 2). This is shown below in figure 4.

```
If(button1== HIGH && standby == false){
    • motion senor off
    • weight sensor off
    • timer is paused}
if(button1 == HIGH && standby == true){
    • motion sensor activated
    • weight sensor activated
    • timer is resumed}
if(button1 != HIGH && standby == false){
    • motion sensor check
    • weight sensor check
    • if(button2 == HIGH || count == 60)}
```

Fig. 4. Simplified version of the software code.

To go more in depth, the first statement that represents scenario 1 does feature the standby mode button and a boolean variable that would hold the value of true or false if stand by mode is activated. Since scenario 1 is when stand by mode occurs, all the sensors would be off as the owner may be refilling the box as well as the timer since we wouldn't want cleaning mode to activate immediately once the user takes it out of standby mode. Also the boolean variable called standby is set to true.

For the second scenario, once button 1 is pressed again the litter box will be taken out of standby mode. The timer is then resumed as well all the motion sensors being turned on. The variable standby is lastly set to false to signify that standby mode is no longer in operation.

Lastly we have scenario three where the litter box has both of the sensors detecting any movement or additional weight in the litter box. If the motion sensor detects a moving object it would pause the timer until the moving object is out of view. For the weight sensor it would pause the timer as well if any significant weight is detected inside the box. By pausing the time in the case that both sensors detect anything it would delay when cleaning mode occurs which would prevent the likelihood of the cat being in the box when the motor is running. It also features a sub scenario where the cleaning mode occurs either when the timer reaches 60 seconds or if button 2 is pressed. The motor would run and start cleaning the litter and only stops if weight is heavy enough such as a cat's weight entering the box. The motion sensor would be deactivated during cleaning mode since the comb attached to the motor would move which would be a false reading since we want to only detect the cat's motion.

VIII. System Fabrications

This section details the design implemented for our PCB. It will show how each peripheral on our system is connected, how the board itself will be powered, and any regulators used for ensuring proper power delivery. The breakdown of the PCB can be split into three separate parts, "5V USB-C POWER", "PURRFECT LITTER SYSTEM", and "DC-DC CONVERTER".

A. 5V USB-C POWER

Fig. 5. details the layout of the 5V USB-C Power section, it is how the system will receive the power needed to operate.

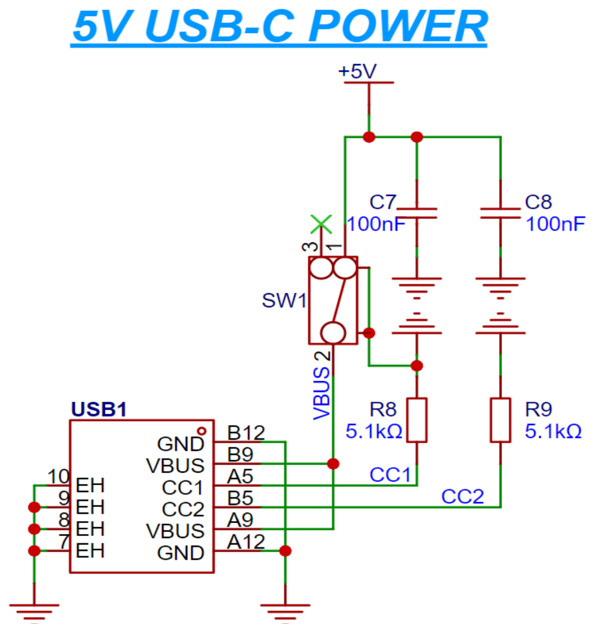

Fig. 5. 5V USB-C Power schematic layout, EasyEDA.

USB1 is the USB-C connector that will be used to power the board, the pins are connected in a way to deliver the 5V power needed to supply most of the components.

CC1 and CC2 are pins on USB1 that 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 VBUS 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 [2]. These CC pins are the output side of USB1, and The typical resistor values for the pulldown resistors are 5.1K Ohms, which are the values we are using for these pins.

The VBUS pins are the pins supplying the 5V power for the system, it is connected to a switch, SW1, for the user of the system to easily disconnect power when not needed. These pins are also connected to two capacitors that are meant for decoupling purposes.

B. PURRFECT LITTER SYSTEM

Fig. 6. details the layout of the Purrfect Litter system, it is the connections made between all the peripherals in the system: motor, weight sensor, motion sensor, LEDs, and button, and the main MCU that will be handling the communication signals sent by them.

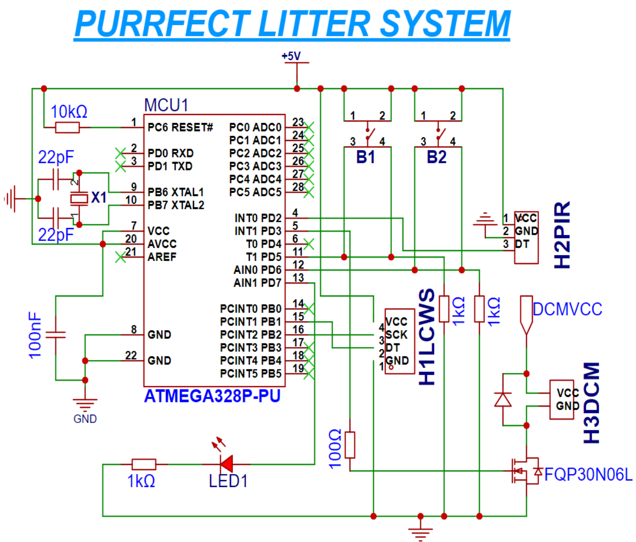

Fig. 6. Purrfect Litter System schematic layout, EasyEDA.

MCU1 is the ATMega328P-PU microcontroller that will be used in our system. Starting from the left, pin 1 (PC6/RESET) is connected to the 5V rail with a 10 kilo ohm resistor, this is present for setting up the MCU to be able to run the code that will be burned onto it. Pins 9 (PB6/XTAL1) and 10 (PB7/XTAL2) are connected to an external 16MHz oscillator, while the ATMega328P has its own internal 8MHz oscillator, using an external 16MHz improves accuracy and removes the hassle of needing to enable the internal oscillator. Pin 4 (PD2/INT0) is connected to the data pin of the header for the IR motion sensor (H2PIR) being used in the system for input on the state of the sensor. Pin 5 (PD3/INT1) is connected to the gate side of the FQP30N06L MOSFET to be used as a digital switch for activating and deactivating the motor. Pin 11 (PD5/T1) is connected to the first button of the system that will take an input signal when pressed and initiate the "immediate run" command. Pin 12 (PD6/AIN0) is connected to the second button of the system that will take an input signal when pressed and initiate the "standby mode" command. Pin 13 (PD7/AIN1) is connected to an LED light and 1 kilo ohm resistor, it will send an output signal to the LED to turn on and off to be used for knowing the system status. The final two pins, Pins 15 (PB1/PCINT1) and 16 (PB2/PCINT2), are connected to the header for the weight sensor (H1LCWS) that will be used in the system. Pin 15 is connected to the clock input (SCK) of the weight sensor and pin 16 is connected to the data signal pin (DT) of the weight sensor, where it will take input signals for measuring the weight of the litter box.

The remaining pins for each component in Fig. 4. are either power in pins, such as VCC or AVCC, ground pins such as GND, or additional I/O pins that will not be used that have a no connected flag (marked with a green X).

C. DC-DC Converter

Fig. 7. details the layout of the 6.5V DC-DC Converter. This is used to power the motor of our system, while the motor is able to receive 5V of power, the RPM produced was not sufficient enough for our specifications and therefore the 6.5V regulator was made for reaching it.

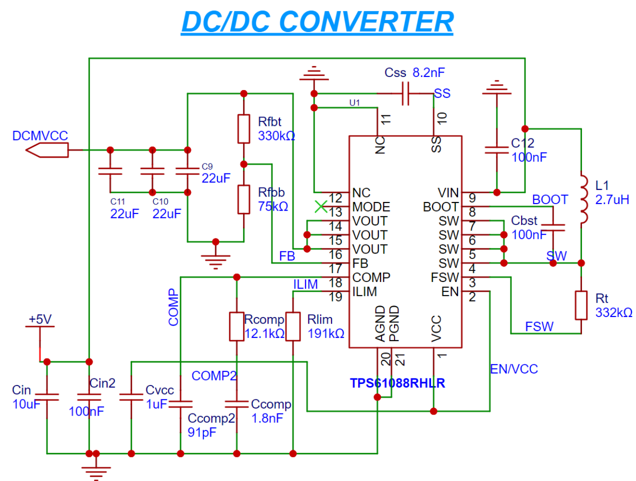

Fig. 7. DC-DC Converter schematic layout, EasyEDA.

The chip used to convert the 5V power to 6.5V power is the TPS61088RHLR from Texas Instruments. The circuit was first designed in the Texas Instruments WEBENCH Circuit designer tool, then moved into EasyEDA when finalized, and the values chosen for every capacitor, resistor, and inductor was based on the datasheet for the chip found in reference [3] to ensure the chip functioned as intended.

X. 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.

The Engineers

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