March 17, 2019

Dr. Craig Scratchley

School of Engineering Science

Simon Fraser University

Burnaby, BC, V5A 1S6

Re: ENSC 405W/440 Design Specification for a Cat Health Monitor

Dear Dr. Scratchley,

The attached document is the specification of the design for the successful implementation of our product, a smart cat litter box, as outlined in our Requirements Specification. Our goal is to produce a litter box that is capable of reporting on various metrics of a cat's health to the owner and their veterinarian. The information will help the owner know when their cat isn't feeling well, even though there may not be any obvious signs. To complete this product, we are required to design a hardware and software system and integrate them effectively.

This design specification documents all the designs for our product; we will outline the designs for our hardware and software systems independently, and then show how we plan to integrate them. The document will also serve as a reference throughout the design process that may be fine-tuned or adjusted later.

We appreciate you taking the time to review the specifications for Cat Health Monitor. If you have any questions, please do not hesitate to contact Gary Atwal, our Chief Communications Officer, by email (gatwal@sfu.ca) or by phone (604-908-1456).

Sincerely,

Hakeem Wewala

Chief Information Officer

9 Lives

Enclosed: Design Specification for a Cat Health Monitor

Design Specification – Cat Health Monitor

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Abstract

The Cat Health Monitor is a surface that can be placed underneath a cat litter box and provides the user with the capability to monitor their cat's health remotely through data that is collected and analyzed via sensors placed within the surface. The duration and frequency of the cat's use of the litter box, the weight of the cat and the pH of the cat's waste is measured and trended over time. The information is provided in a user-friendly manner to the owner and/or veterinarian. In this document, the design specifications are defined for the Cat Health Monitor product created by 9 Lives. Attached in the Appendix, is the Supporting Test-Plan and User Interface and Appearance documentation.

Revision Record

Revision #	Description	Revised By	Date
1.0	Initial Release	Gary Atwal, Harinderpal Khakh, Brandon Shen, Gabe Teeger, Hakeem Wewala and Timothy Yu	March 17, 2019

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Glossary

Term	Definition
ADC	Analog to Digital Converter
BOM	Bill of Materials
C	Proof-of-Concept
Des	Design Specification
F	Final Product
HI	Health Index
HX711	Amplifier and ADC
IP67	The unit can be dropped into a body of water up to a meter deep for half an hour and is resistant to dust.
P	Prototype
PC	Personal Computer
PCB	Printed Circuit Board
Req	Requirement Specification
UI	User Interface

1.0 Introduction

Diagnosing illnesses in animals is a core part of Veterinary Sciences. Unlike animals, humans can convey symptoms precisely to doctors. Pet owners will usually only seek care for their pets once their symptoms are clearly presented through their appearance and behavior. Unfortunately, pets are often brought to veterinarians after their illnesses has progressed further than necessary, making it harder to treat them and at a greater cost to the owner and to the animal's health.

Pre-emptively avoiding certain serious health problems in animals would be greatly beneficial to owners, veterinarians, and pets. Many aspects of any animal's health, particularly their digestive health, can be measured by their bathroom habits. Our goal is to design a device that will provide consistent and reliable information to the owner about a cat's health by capturing the cat's duration and frequency of use of the litter box, the cat's weight and pH of the cat's waste over time. This data can be examined for any early indicators of illness and pre-emptively warn users. For example, frequent attempts at urination may be linked to kidney stones or blockage and if there is blood in the urine it may be linked to a more life-threatening condition, feline interstitial cystitis [1]. However, the device would be able measure how frequent the cat uses the litter box and potentially sense that there is blood in the urine using a pH sensor.

Although this technology would be beneficial to all animals, our product is specifically designed for pet cats. Because cats are independent and do not require much supervision, their symptoms of illness may go unnoticed. Many owners are left with an unexpected death to their cats that may have been preventable through simple monitoring of the cat's health. According to a study by Olsen and Allen [2] on 1000 cats over 10 years, 79 cats died suddenly and unexpectedly [2].

The Cat Health Monitor is a surface with built-in sensors that can be placed underneath an owner's current litter box as opposed to the product being a whole new litter box, resulting in a more economical and user-friendly product. We aim to provide accurate real time alternatives to obtaining important parameters regarding a cat's behaviour. This will allow the owners of cats and veterinarians to monitor a cat's health in a quick easy way so they can provide better care for the cats and save money on otherwise expensive medical bills.

This document outlines the design specifications for the Cat Health Monitor throughout the three stages of the design process: Proof-of-Concept (C), Prototype (P) and Final Product (F). An Acceptance Test Plan and a summary of the user interface (UI) and appearance design requirement specification is provided in the Appendix. Engineering standards, environmental impact and safety concerns are also considered. The design requirement specifications are broken down into six categories:

1. High Level Requirements
2. Overall Performance Requirements
3. General Physical Requirements
4. General Hardware Requirements
5. General Software Requirements
6. User Interface Functionality Requirements

2.0 Overview

The cat health monitor focuses on three main aspects, the weight of the cat, duration in the litter box, and the frequency of usage. To achieve this, a load sensor will be an important component. A strain-gauge will be used and it will provide weight measurements and detect whether the cat has entered or left the litter box. An Arduino will be used to process the signal and present the data to the user in an easy-to-understand way.

Sometimes the force exerted on the strain gauge can be very miniscule and the change in output voltage can be very small even after amplification. The Arduino does not have an ADC with high enough resolution to generate a digital signal from small voltage changes. Thus, a HX711 24-bit ADC and an integrated amplifier will be used. It will amplify and create a readable digital signal from small voltages.

The output of the HX711 ADC/amplifier circuit will be connected to the Arduino. On the other end, the Arduino supplies a 5V rail voltage and a ground for the load sensors and HX711 circuits. In addition, it will do the calculations for the weight, duration, and frequency. The values will then be displayed in the serial monitor on the connected computer or sent through email to the owner.

3.0 Design Requirements

3.1 High-Level Requirements

The Cat Health Monitor aims to provide owners with pre-emptive warning of behaviours that indicate illness in addition to providing veterinarians with longevity to accurate data to assist in their diagnosis. Our project will tackle this problem with a smart litter box that activates and acquires measurements upon the detection of a cat. Indicators of illness and important parameters will need to be identified through research and discussions with professional veterinarians in the field. The product will be required to identify and indicate problems and document data for veterinarians. Table 1 contains the general high level design requirements that will be broken done further in the following sections.

Table 1: High Level Requirements

Des 3.1.1 – P	Integrate designs specified in latter sections to measure, record and analyze parameters within a tolerance specified in the overall performance design requirements. *Reliably measure, record, and analyze parameters from cats to identify and notify users of potential problems.*
Des 3.1.2 – P	Store the data on the PC to ensure longevity of the data and allow users to submit to professionals for further analysis. *Provide longevity to data for users to submit to professionals for further analysis.*
Des 3.1.3 – P	Product to be a built-in physical platform for existing litter systems to be placed on. *Be an add-on to existing litter systems*

Des 3.1.4 – F	Be a product with a non-slide platform and enclose all electronics to allow for easy cleaning. *Be a complete product prioritizing safe integration and ease of cleaning.*
Des 3.1.5 – F	The task of identifying a cat could prove to be troublesome, as the product will have a tolerance for weight due to food and water intake. To be specified later. *Identify and create profiles for different cats; providing users with graphical representation of health and trends.*

In *italics* is the corresponding requirement specification Req 3.1.x for the design specification Des 3.1.x

3.2 Overall Performance Requirements

Table 2 specifies the overall performance design requirements for the Cat Health Monitor.

Table 2: Overall Performance Requirements

Des 3.2.1 – C	A microswitch, by creating a voltage potential, will notify the Arduino upon detection large weight changes. Detection of movement or weight being removed would indicate a cat. Constant weight could represent an object (e.g. litter), in which the new tare value will be set, and the Arduino will deactivate. A false positive will be detected by fluctuations of weights within 1 second. *Activate upon the detection of a cat and distinguish between false positives.*
Des 3.2.2 – C	Measurements must be within 10g. This averaged measurement data will be transmitted through a wire to a computer for storage. *Accurately measure and store weight data of the cat.*
Des 3.2.3 – C	Integrate the analysis of data and the UI display system to provide analytics. *Provide analytics on weight data obtained*.
Des 3.2.4 – P	Outsource Arduino plug-and-use hardware for urinary parameters and store the data using the same pipeline as the weight measurements. *Measure and store data using sensors to record pH in urine and provide alerts if something is not normal.*
Des 3.2.5 – P	Utilize the same pipeline as the weight measurements to provide analytics regarding urinary parameters. *Provide analytics on urinary parameters along with weight.*

Des 3.2.6 – P	Using conditional statements, detect trends that indicate potential problems and alert users through the UI display. *Detect and alert the user of problems from trends of parameters through the expertise of veterinarians.*
Des 3.2.7 – P	To be specified later. *Based on previous data, distinguish between different cats.*
Des 3.2.8 – F	Execute reliability tests to ensure durability and enclose the electrical components in a durable casing. *Be durable, sturdy and non-slip.*
Des 3.2.9 – F	The enclosure containing the electrical components will be IP67 rated to prevent urine and other liquids from affecting the components, allowing easy cleaning. *Be easy to clean.*
Des 3.2.10 – F	Utilize an Arduino dongle to communicate with an application; this will be further discussed in the software section. *Have wireless capabilities/either connect to a phone application or personal computer.*
Des 3.2.11 – F	Send an email with easy to analyze raw data and basic graphical representation to the user and any emails recorded in their profile. *Provide printable files with graphical representation of selected parameters.*

In *italics* is the corresponding requirement specification Req 3.2.x for the design specification Des 3.2.x

3.3 Physical Requirements

Cat Health Monitor needs to be easily compatible with most cat litter boxes. The product shouldn't require any relocation of litter boxes, if they are within range of an electrical outlet. Table 3 outlines the physical design requirements to ensure that the Cat Health Monitor can be integrated into a home with ease.

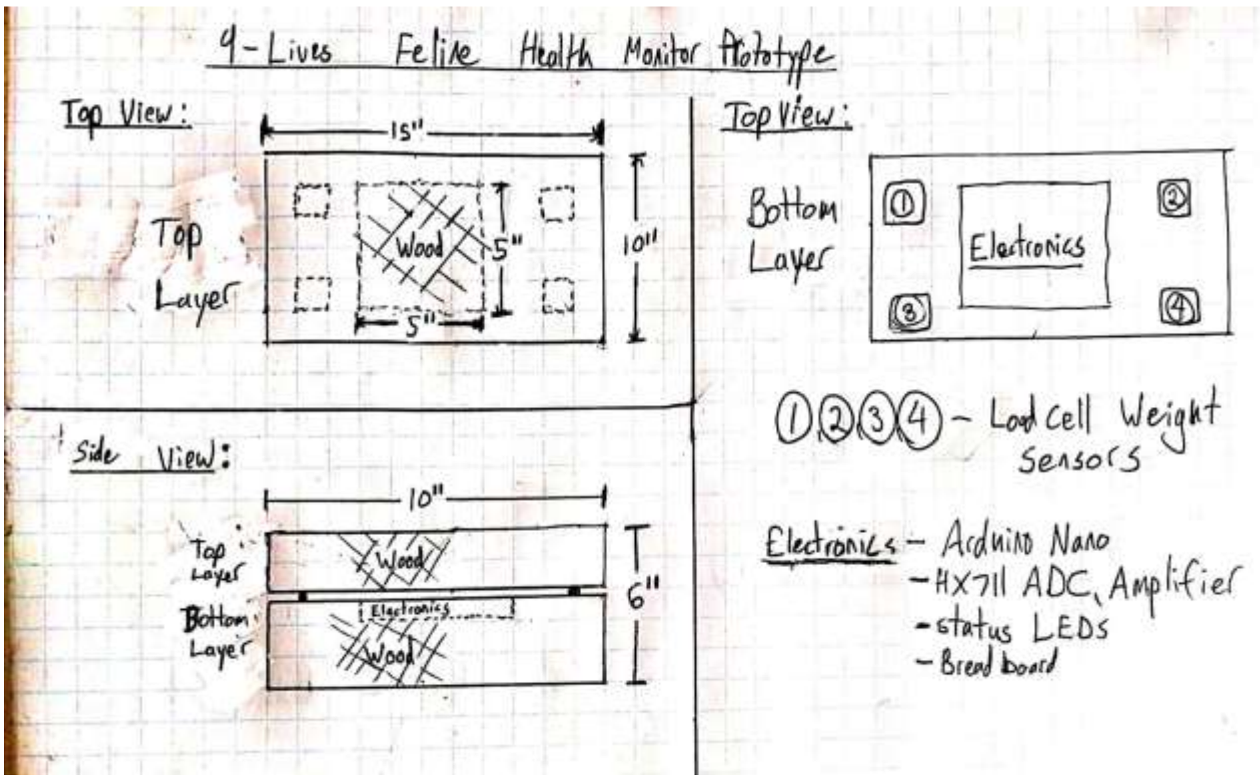
Table 3: General Physical Requirements

Des 3.3.1 – C	The surface will be made from wood as it is cheap and accessible. See Figure 1 for more details. *The surface can be made from wood or plastic*
Des 3.3.2 – P	To be specified later. *The surface material must be able to prevent the litter box from slipping due to excessive force.*

Des 3.3.3 – F	To be specified later. *The surface area of the surface should not be much greater than the surface area of a generic litter box*
Des 3.3.4 – F	To be specified later. *The size of the PCB should not exceed the size of the surface.*
Des 3.3.5 – F	To be specified later. *The circuitry should be protected by the surface without interfering with the sensors*
Des 3.3.6 – F	To be specified later. *The surface should be able to withstand the combined weight of a cat and its litter box*
Des 3.3.7 – F	To be specified later. *The surface should not change the height of the litter box by too much when placed underneath*
Des 3.3.8 – F	To be specified later. *Circuitry should not be exposed anywhere*
Des 3.3.9 – F	To be specified later. *The surface should be sealed such that nothing leaks into it and damages the sensors or circuitry*
Des 3.3.10 – F	To be specified later. *Company logo must be visible on the product*

In *italics* is the corresponding requirement specification Req 3.3.x for the design specification Des 3.3.x

Figure 1: Physical Layout of the Health Monitor (C)



Sketch of the physical layout of the Proof-of-Concept (C) version of the Cat Health Monitor.

3.4 Hardware Requirements

The Cat Health Monitor will require the integration of different systems to capture, parse and record weight sensor measurements. This system will ultimately be put on a fully-fabricated printed circuit board (PCB), requiring the design of a schematic and its corresponding layout. Table 4 lists the design requirements of the hardware system.

Table 4: General Hardware Requirements

Des 3.4.1 – C	See Section 3.4.3 for more details. *Employ a hardware system that can deliver interrupts to underlying software.*
Des 3.4.2 – C	See Section 3.4.1 for more details. *Capture information from weight sensors when necessary.*

Des 3.4.3 – C	See Section 3.4.2 for more details. *An amplifier is needed to capture small changes in output from weight sensors.*
Des 3.4.4 – C	See Section 3.4.2 for more details. *An ADC is needed to capture analog measurements taken from the weight sensors and to convert them into digital signals.*
Des 3.4.5 – C	See Section 3.4.2 for more details. *The ADC should have a high resolution, preferably 24-bits.*
Des 3.4.6 – C	See Section 3.4.3 and 3.5 for more details. *An Arduino to capture and manage the data from the weight sensors.*
Des 3.4.7 – C	See Section 3.4.1 for more details. *A schematic of the overall layout of the circuit.*
Des 3.4.8 – C	Use a laptop with a cable. *Have a computer to connect to via serial port.*
Des 3.4.8 – P	See Section 3.4.1 for more details. *Weight must be measured precisely with an accuracy of approximately 1 gram.*
Des 3.4.9 – P	See Section 3.4.3 for more details. *Use LEDs to convey information about the status of the device to the user.*
Des 3.4.10 – P	To be specified later. *Perform analysis to find trends and potential health indicators.*
Des 3.4.11 – P	To be specified later. *A bill of material (BOM) containing all of the components needed, their prices and reference to their datasheet.*
Des 3.4.12 – P	To be specified later. *A PCB layout with footprints corresponding to each component.*
Des 3.4.13 – P	See Section 3.4.1 for more details on design satisfying this requirement. *A prototype circuit constructed on a breadboard with through-hole components.*
Des 3.4.14 – P	To be specified later. *Gerber files generated from the PCB layout that are to be submitted to a third-party company for fabrication.*
Des 3.4.15 – P	See Section 3.4.3 for more details on design satisfying this requirement. *5V input is needed for the weight sensors and Arduino.*

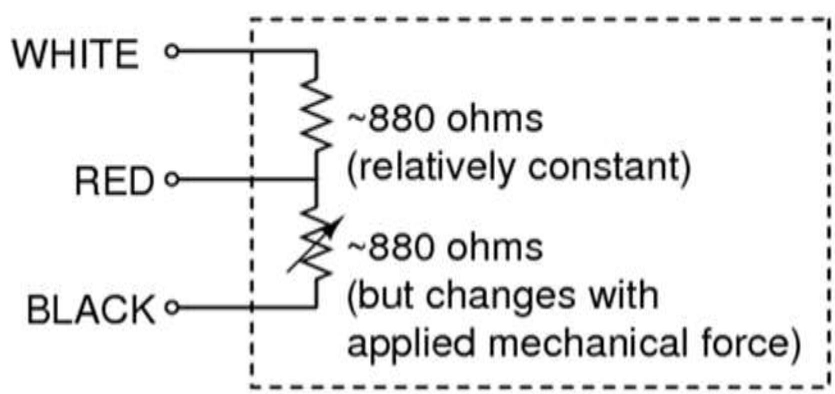
Des 3.4.16 – F	To be specified later. *Addition of pH sensor and necessary hardware.*
Des 3.4.17 – F	To be specified later. *Power adapter for the PCB so it can be plugged into an outlet.*

In *italics* is the corresponding requirement specification Req 3.4.x for the design specification Des 3.4.x

3.4.1 Weight Sensing Circuit

The load sensors weight measuring and detecting abilities come from the strain gauge inside it. The circuit schematic inside a load sensor that we will be using in the cat health monitor is shown in Figure 2 below.

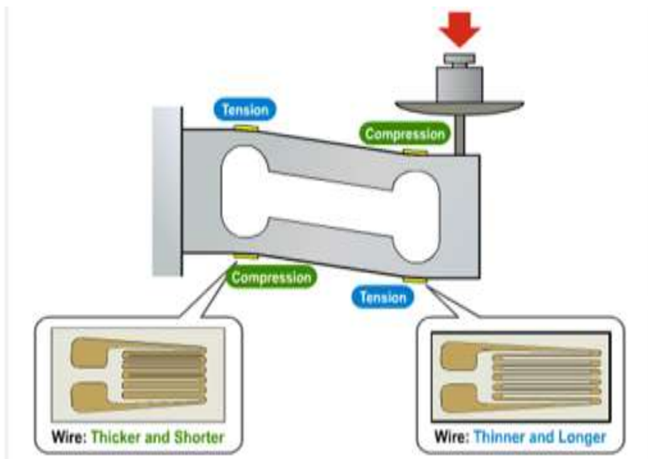
Figure 2: The Load Sensor



The components inside of a 50 kg flat load sensor [3].

The variable resistor in Figure 2 is a strain gauge. The strain gauge resistance value changes based on the force exerted on it (change in strain) because of the thin conductive wire inside that changes shape. Tension is when the strain gauge and the wire inside is stretched and the resistance goes up. Compression is when the wire inside is pressed closer together and the resistance goes down [4]. This process is demonstrated in the Figure 3.

Figure 3: The Strain-Gauge



An illustration of a strain gauge in compression and tension [4]

So, with a voltage divider created from a resistor and strain gauge, the change in output voltage can be measured and calculated as weight. This will be proportional to the change in resistance that is proportional to the force from the weight applied. To compensate for the temperature sensitivity of the strain gauge and to increase the sensitivity of the strain gauges, we will be connecting four of the load sensors that are shown in Figure 2 in a Wheatstone bridge structure which is shown in Figure 4 [5].

The variables R_1, R_2, R_3 and R_4 are all strain gauges with variable resistance. R_2 and R_3 are in tension (positive change in resistance), while R_1 and R_4 are in compression (negative change in resistance). We will apply an input voltage V_s of 5V to node A and ground node B to produce an excitation voltage of 5V to the circuit. The output voltage will be taken between node C and D.

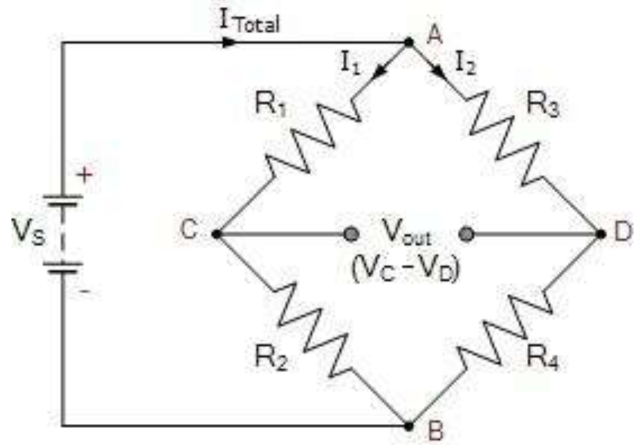
For the configuration of our Wheatstone bridge, the equation below is the relation between the output voltage and the change in resistance when the bridge is balanced, meaning the ratio of the resistors in the voltage dividers are the same, $R_1/R_2 = R_1/R_4$ [6].

$$\frac{V_0}{V_{ref}} = \frac{R_2 + \Delta R_2}{R_1 + \Delta R_1 + R_2 + \Delta R_2} - \frac{R_4 + \Delta R_4}{R_3 + \Delta R_3 + R_4 + \Delta R_4} \quad (1)$$

If all the elements are all active with the compression and tension setup as described for Figure 3, then our transfer function for the output voltage becomes equation (2) [6].

$$\frac{V_0}{V_{ref}} = \frac{1}{4}\left(\frac{\Delta R_2}{R_2} - \frac{\Delta R_1}{R_1} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) \quad (2)$$

Figure 4: Full Wheatstone Bridge



A typical full Wheatstone bridge setup.

The relation between the change in resistance and the strain is shown by Equation (3) [6,7].

$$G = \frac{\Delta R \Delta L}{RL}, \frac{\Delta L}{L} = \epsilon \to \frac{\Delta R}{R} = G \cdot \epsilon \tag{3}$$

where R is the resting resistance of the strain gauges under no strain, G is the gauge factor defined by the strain gauge datasheet and ϵ is the strain, which is the change in length over the original length. Combining Equation (2) and (3) together gives Equation (4), which relates the output voltage to the strain felt by the strain gauge.

$$\frac{V_0}{V_{ref}} = \frac{G}{4}(\epsilon_2 - \epsilon_1 + \epsilon_3 - \epsilon_4) \tag{4}$$

To get the individual strains of the strain gauges, an assumption will be made that the strain will be spread evenly among them because they are identical. The weight can be calculated from strain by using the strain gauge's elasticity E to calculate the stress felt by it. The relation between strain and force is shown in Equation (5) [6,7].

$$E = \frac{\sigma}{\epsilon} = \frac{F}{A\epsilon} \quad \Longrightarrow \quad F = EA\epsilon \tag{5}$$

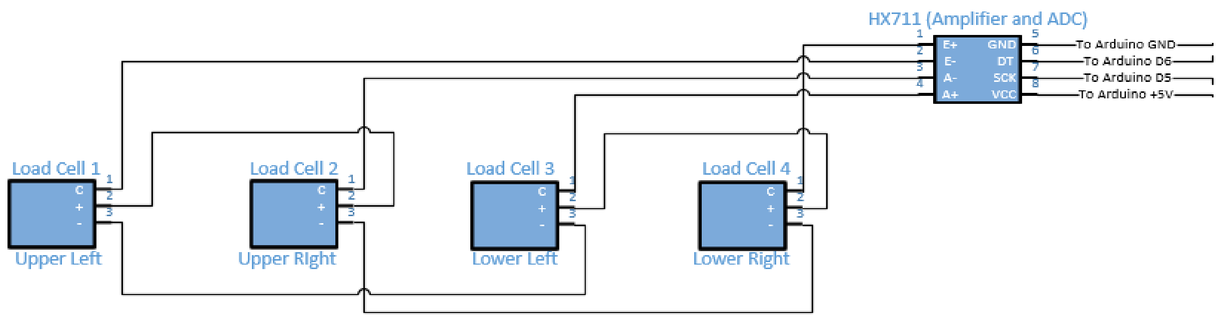
The definition of stress σ is the force F over the area A it's applied on. To determine the mass, use Newton's second law $F = ma$ where m is the mass and a is the acceleration due to gravity. To get the subject's mass, it should be four times the mass calculated from one strain gauge.

3.4.2 HX711 ADC/Amplifier

The ATmega328P microcontroller within the Arduino only has a 10-bit ADC [8]. This means that the digital signal will only have a resolution of 210 = 1024 steps. With a maximum input voltage of 5V for the Arduino, the smallest change in voltage that can be read in is 5V1024 = 4.9mV [8]. As stated above, the HX711 has a 24-bit ADC, meaning the resolution of the digital signal will be 224 = 16777216 steps [9]. The Arduino will now read in this digital signal and the smallest change in voltage that can be measured will now be 5V16777216 = 0.298µV.

The HX711 provides a great advantage for the cat health monitor in allowing it to measure small weights like solid and liquid waste products. However, there is a drawback with having such high resolution and that is the cat health monitor will be more affected by small noise. To mitigate environmental noise, the product will have a rigid casing and a voltage change tolerance will be set in the Arduino code. The final weight sensing circuit with the output terminals connected to the HX711 Amplifier and ADC are shown in Figure 5.

Figure 5: Weight Sensing Circuit



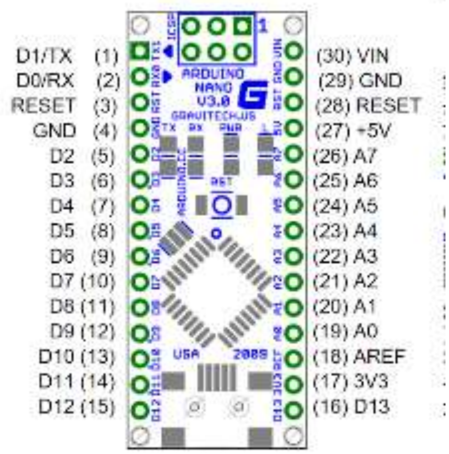
Circuit setup showing the I/O connection between the load cells, HX711 and Arduino.

3.4.3 Arduino

The Arduino is the controller and processor of Cat Health Monitor. It will control when the system is on by providing the input and excitation voltage to the HX711 and load sensor circuits. It also provides a clock input for the ADC in the HX711. It will process the signal coming from the amplifier to calculate the weight, duration and frequency. Then, this data will be displayed on the computer connected to the Arduino or through email to the owner.

Figure 6 below contains the pin assignments of the Arduino Nano used inside the cat health monitor [10,11].

Figure 6: Arduino Nano Board



The pinout of an Arduino Nano Board.

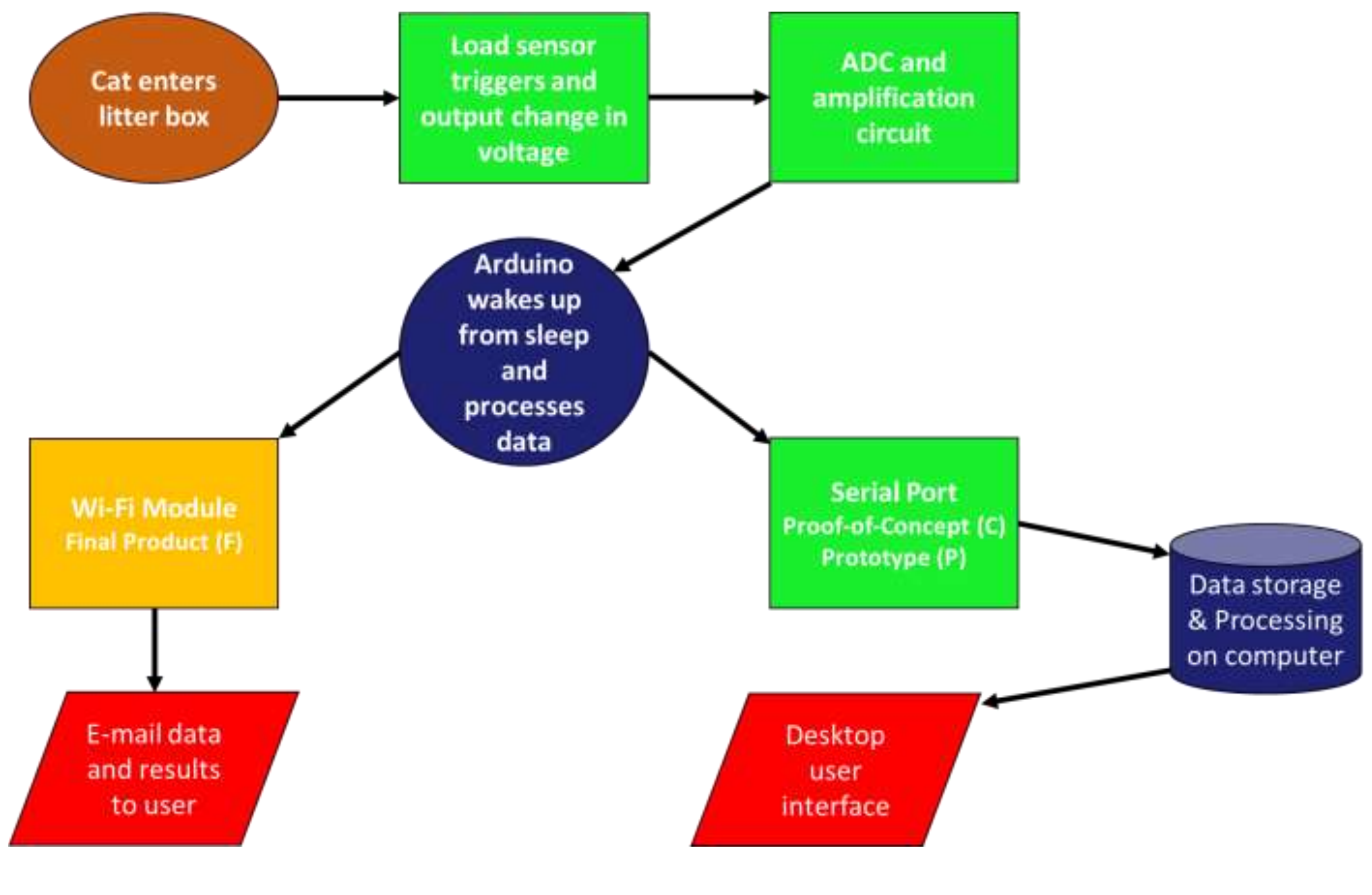
The 5V (27) pin will supply the excitation and input voltage for the load sensors Wheatstone bridge and HX711 ADC/amplifier circuit. The GND (4) pin on the Arduino Micro will be used to ground the circuits as well. The output signal from our HX711 will be connected to D6 (9) pin. The ADC in the HX711 will be outputted by D5 (8) pin. For further stages in our project development, we will connect two LEDs to some of the digital pins on the Arduino for status indicators as described in Appendix B: User Interface and Appearance.

3.5 Software Requirements

The Cat Health Monitor will require an embedded system to integrate with the weight-sensing circuitry. Analytics on the data shall be performed on the same device for compactness and efficiency. The collected data will be converted into useful charts to allow the user to easily keep track of their cat companion's litter habits. This will be done by programming an Arduino Nano using the Arduino Software (IDE) that is provided with the board.

Figure 7 shows a high-level system overview diagram of the Cat Health Monitor. When the cat enters the litter box, it is detected by a button/switch which triggers the system to begin collecting data via the load-sensors. In the Proof-of-Concept (C) and Prototype (P) version of the product, the data will be communicated from the Arduino to the computer through a serial port. Whereas in the Final Product (F), the data will be communicated wirelessly to the user.

Figure 7: System Overview



High-level system overview of the Cat Health Monitor.

The software design requirements are listed in Table 5.

Table 5: General Software Requirements

Des 3.5.1 – C	A button/switch that is trigger when a cat enters the litter box will turn on the Arduino Nano and it will start collecting data from the load sensors. *Employ an interrupt-driven system to wake from a low-power state to measure weight.*

Des 3.5.2 – C	Using a known weight, the software program will calibrate the conversion between voltage and mass. *Convert readings from scale to weight values.*
Des 3.5.3 – C	The Arduino will be connected to the computer via USB to mini-USB cable. *Communicate data to a connected computer using a physical port.*
Des 3.5.4 – C	Measure the time-averaged weight of the cat each time it enters the litter box and store the time it entered the litter box in csv file that is to be saved on the computer. This file will be updated each time the cat enters the litter box and thus measuring the weight trend over time. *Measure weight trends over time.*
Des 3.5.5 – C	In addition to measuring the cat's average weight each time it enters the litter box, the program will also record the time it spends in the litter box in the csv file in a third separate column. To obtain the frequency of visits per day or over a time period of interest, count the number of rows in the csv file corresponding to date(s) of interest. These functions will be implemented using the Arduino programming language and IDE that is provided. *Extract additional data from weight sensor such as amount of time spent in litter box and the frequency of the visits.*
Des 3.5.6 – P	To be specified later. *Perform analysis to find trends and potential health indicators.*
Des 3.5.7 – P	To be specified later. *Handle data collection and analysis for multiple cats.*
Des 3.5.8 – P	To be specified later. *Issue alerts for urgent situations (too few visits, too many visits, excessive visit duration, drastic changes in weight, etc.).*
Des 3.5.9 – F	To be specified later. *Record urine pH level.*
Des 3.5.10 – F	To be specified later. *Communicate data to user wirelessly.*
Des 3.5.11 – F	To be specified later. *Provide printable document with analytics data.*

In *italics* is the corresponding requirement specification Req 3.5.x for the design specification Des 3.5.x

3.6 User Interface Functionality Requirements

A key component of the Cat Health Monitor system will be a clear and concise representation of collected data and performed analytics to the user. This will be initially displayed using a wired connection to a computer and eventually communicated wirelessly for the final product. The user interface design and appearance specification are defined in Appendix B: User Interface and Appearance.

4.0 Conclusion

The Cat Health Monitor is an add-on to existing litter boxes marketed towards all the 7.9 million cat owners and 3,224 veterinary clinics in Canada alone. Our product will be an easy to use device that allows users to acquire data about their cat's health. It will be able to extract basic urinary parameters specifically for veterinarians due to the required expertise. We aim to provide accurate real time alternatives to obtaining important parameters regarding a cat's behaviour

5.0 References

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6.0 Appendix A: Test Plan

Currently, 9 Lives' cat health monitor test plan contains testing at the proof-of-concept and engineering prototype stages. The test plan verifies that all basic functionalities implemented for the users at each stage works correctly and presents any potential problems that need to be fixed. For the proof-of-concept stage, the tests are in depth and separated into software and hardware functionalities. The engineering prototype software and hardware are still being planned, so this stage's tests will be for high level user features that will be implemented.

Proof-of-concept stage

Software tests

Arduino prints data on connected computer's serial monitor	
Test method: 1. Open a serial monitor program, i.e. Arduino IDE Serial Monitor 2. Place weight in cat health monitor 3. Confirm there is data displayed on the serial monitor screen	
Comments:	☐Pass ☐Fail

Entering and leaving of cat health monitor is registered	
Test method: 1. Open a serial monitor program, i.e. Arduino IDE Serial Monitor 2. Place weight in cat health monitor 3. Confirm "Cat has entered the litter box" shows up in the serial monitor 4. Remove weight from cat health monitor 5. Confirm "Cat has left the litter box" shows up in the serial monitor	
Comments:	☐Pass ☐Fail

Correct weight is calculated and displayed	
Test method: 1. Open a serial monitor program, i.e. Arduino IDE Serial Monitor 2. Place 3 kg weight in cat health monitor 3. Confirm 3 kg weight is displayed in the serial monitor	
Comments:	☐Pass ☐Fail

Correct duration is calculated and displayed	
Test method: 1. Open a serial monitor program, i.e. Arduino IDE Serial Monitor 2. Place weight in cat health monitor 3. Leave weight resting for 30 seconds 4. Remove weight from cat health monitor 5. Confirm 30 seconds duration is displayed in the serial monitor	
Comments:	☐Pass ☐Fail

Weight remaining in cat health monitor is calculated correctly and displayed	
Test method: 1. Open a serial monitor program, i.e. Arduino IDE Serial Monitor 2. Place sperate 3 kg and 1 kg weights in cat health monitor 3. Remove only 3 kg weight from cat health monitor 4. Confirm 1 kg remaining is displayed in the serial monitor	
Comments:	☐Pass ☐Fail

Hardware tests

Cat health monitor surface and load sensors can withstand and measure a maximum weight of 6 kg	
Test method: 1. Open a serial monitor program, i.e. Arduino IDE Serial Monitor 2. Place 6 kg weight in cat health monitor 3. Check for any deformities, cracks, broken wires, etc. 4. Confirm that 6 kg weight is displayed on the serial monitor	
Comments:	☐Pass ☐Fail

Each load sensor is working correctly and produces a change in output voltage when a force is applied to it	
Test method: 1. Remove the surface cover for the load sensors and underlying circuit 2. Connect voltmeter to output of load sensors circuit and ground 3. Supply an excitation voltage of 5V to the input of the load sensors circuit 4. Apply force to each load sensor individually 5. Observe a change in output voltage on the voltmeter	
Comments:	☐Pass ☐Fail

A minimum of 100g can be detected by the load sensor and amplifier circuits
Test method: 1. Remove the surface cover for the load sensors and underlying circuit 2. Connect voltmeter to output of amplifier and ground 3. Supply an excitation voltage of 5V to the input of the load sensor circuit 4. Place surface cover back on 5. Place 100g weight on cat health monitor 6. Observe a change in output voltage on the voltmeter

Comments:	☐Pass ☐Fail

Engineering prototype stage

High level usability tests

On/Off switch turns on and off the cat health monitor system	
Test method: 1. Switch on the cat health monitor 2. Observe ON LED lights up 3. Place weight in cat health monitor and see data is displayed on connected computer's serial monitor 4. Switch off the cat health monitor 5. Observe ON LED is not lit up and serial monitor is not displaying any more data	
Comments:	☐Pass ☐Fail
Red LED lights up when the cat health monitor detects a potential problem	
Test method: 1. Make sure the cat monitor is turned on 2. Create a problem scenario, for example entering and exiting the litter box multiple times in quick succession 3. Observe that the Red LED lights up and blinks	
Comments:	☐Pass ☐Fail

Data collected by the Arduino in one session is stored correctly on the computer

Test method: 1. A session starts when a cat enters the litter box and ends when the cat leaves 2. Make sure the cat monitor is turned on 3. Place a weight in the cat health monitor 4. Remove the weight from cat health monitor 5. Look in the Arduino program folder for the text file in which the data are stored 6. Confirm the data stored matched the session	
Comments:	☐Pass ☐Fail

Email can be sent to users and contains the correct information	
Test method: 1. Initiate an email to be sent by the Arduino in the desktop app 2. Check that an email is received 3. Confirm the email contains average daily cat's weight, waste weight, duration, and frequency in the last 30 days	
Comments:	☐Pass ☐Fail

7.0 Appendix B: User Interface and Appearance

7.1 Introduction

The Cat Health Monitor by 9 Lives is designed for two environments; clinical setting and residential use. Due to space constraints of kennels in veterinary clinics, we designed a thin platform to place under a litter box. 9 Lives strives to create a product that is unnoticeable for residential use, and this aligns with the goal of an inconspicuous residential product. The design of the monitoring device in both environments' targets simplicity and functional non-invasiveness. Functional non-invasiveness stipulates that this should not affect the daily routine of how a user and their cat's function in the use of a litter box (e.g. the cleaning of a litter box will not be drastically affected). For the user requested data, an email should be sent with a focus on easy to understand graphical and numerical representation of clean data.

7.2 Purpose

The purpose of this document is to present the hardware UI of the Cat Health Monitor and the UI of the email sent upon user request. The designs will take the ideas of simplicity and size mentioned above into consideration.

7.3 Scope

This document will discuss 5 main topics:

1. User Analysis
2. Technical Analysis
3. Engineering Standards
4. Usability Testing
5. Summary

7.4 User Analysis

The target market of the Cat Health Monitor encompasses both veterinary clinics and owners of cats who are interested in recording data of important cat health parameters. The product is easy to use and is designed to simply be an add-on to existing litter systems.

For veterinarians, we provide the option to add urinary sensors which will give longevity to urinary parameters. Litter boxes require constant maintenance and need to be emptied frequently. Therefore, all components will either be waterproof, or will be inside a waterproof enclosure to allow for ease of cleaning.

The mode of providing data to the user is through an email, and this is because emails are simple to setup and is the most common online activity [12]. This aligns with the focus of our product being easy to use. Emails also allow near instant information sent to multiple people (veterinarians, or owners across the world). Raw data, summarized data, and any graphical representation will be sent through an email to addresses that have been entered into the database upon registration. All registration will be done online to initialize the product and configure all required information into a profile for the user and their cats.

7.5 Graphical Presentation

Figure 8 below shows the proposed physical design. Figure 9 below shows the email that will be sent to all emails affiliated with the cat profile. Figure 10 attached below shows the graphical summary of cat health with respect to each parameter to provide easier to understand representation of the data. Figure 11 represents raw data with timestamp provided through a text file in the email which may also be sent to and analyzed by professionals.

Figure 8: Proposed Physical UI Design

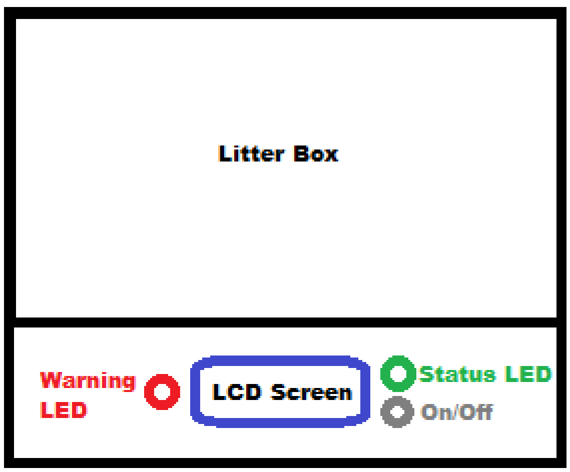


Figure 9: Example Email Sent to Addresses Affiliated with the Profile

Dear John Doe,

We at 9 Lives have been notified that it has been requested that information regarding cats/a cat under your care be sent to you! Please see our health index calculated from weight and urinary parameters along with figures briefly identifying the health of the cat with regards to each parameter. Our HI is only for reference and may not accurately depict the health of the cat. Please find the text file storing the cats' raw data attached to this email.

Regarding: Oliver, 5 y/o (Male Maine Coon)

Health Index (HI):
70

Last five HI:
60 65 62 72 70

Best Regards,

Figure 10: Cat Health Represented in the Health Index (HI) Metric

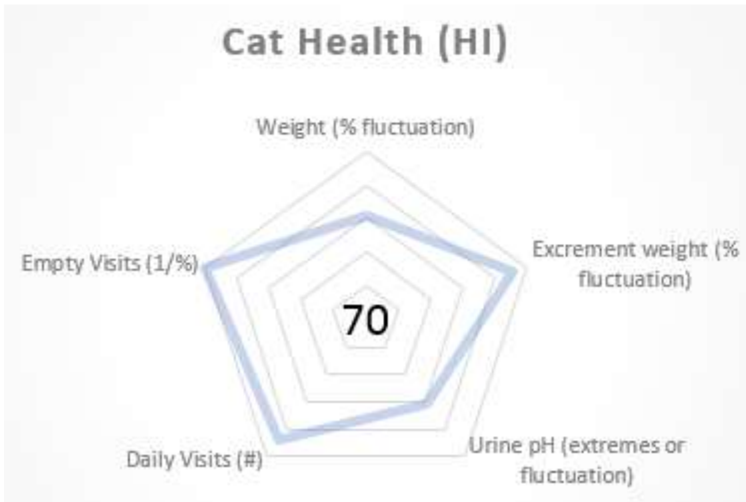


Figure 11: Example of Raw Data Attached to Sent Email

Regarding: Oliver, 5 y/o (Male Maine Coon)
Data requested: 14:12:59 (13/03/2019)

TIME	DATE	WEIGHT (KG)	EXCREMENT WEIGHT (KG)	URINE PH	DAILY FREQUENCY	DAILY OCCURANCES OF NO EXCEMENT	RED FLAGS
05:06:15	01/03/2019	2.1022	0.0083	6.21			
10:06:12	01/03/2019	2.1050	0.0025	6.82			
18:06:15	01/03/2019	2.1355	0.0050	N/A			
23:06:15	01/03/2019	2.2120	0.0042	6.21			
					4	0	
02:06:15	02/03/2019	2.1983	0.0098	6.41			
08:06:15	02/03/2019	2.1125	0.0066	6.00			
13:06:15	02/03/2019	2.1675	0.0071	6.01			
19:06:15	02/03/2019	2.1031	0.0073	6.67			High pH
22:06:15	02/03/2019	2.1120	0.0001	6.90			High pH & no excrement
					5	1	
01:06:15	03/03/2019	2.1125	0.0012	6.89			High pH
06:06:15	03/03/2019	2.1308	0.0020	7.3			High pH

7.6 Technical Analysis

As outlined in Don Norman's book "The Design of Everyday Things", there are 7 main elements of UI interaction: Discoverability, feedback, conceptual models, affordances, signifiers, mappings, and constraints [13]. This section will show how the Cat Health Monitor device considers the 7 elements in both hardware interfaces and software interfaces.

Discoverability

A good design should make it easy for users to discover what the product can do. A balance between efficiency for experienced users and ease of use for new users must be found. We analyzed both software and hardware discoverability and all interactions between user and the product.

1. Hardware
    a. The hardware is limited to only one button to reset the system, one to request that the email regarding cat health data be sent, and a power switch. A bright LED is used to indicate problems with the cat and a RGB LED with drastically lower lumens is used to inform the user of device status.
    b. There are limited interactions the users can have with the product, increasing hardware discoverability.
2. Software
    a. As discussed in previous sections, the software is simplified for the user. The registration requires entering information online and easy initialization of entering the model number of the product to initialize it to the database.
    b. The software interaction between user and product is through email. As stated in Section 7.4, email is widely used in North America and the learning curve is low and many users would have had previous experience.
    c. The email provides easy graphical representation and a numerical representation, the HI metric, of the health of the cat.
    d. For more skilled and experienced users, mainly the veterinarians in this case, a text file is provided with data to allow further analysis.

Feedback

Feedback provides the user with information about what has been completed or any issues with the system. For the prototype model, the Cat Health Monitor device will include a bright red LED that indicates any problems with the cat through trends in the measured parameters. An LCD will be attached to the device in the final product while the prototype feedback is through the computer. The screen will print a word providing feedback to the user to identify that their command is being executed.

1. Hardware
    a. Device failure - Red "FAILURE" printed on LCD or computer screen
    b. Device sending data - "Sending" printed on LCD or computer screen
    c. Device activated by weight detected - "Measuring" printed on LCD or computer screen
2. Software
    a. Email sent after device initialization

Conceptual Models

Conceptual model is the mental model that people have of how something should be done. The Cat Health Monitor should imitate a platform that the litter box goes on and be similar to a scale. The product, at its core, is a scale along with an optional pH sensor; which will be added on during the prototype phase. This is intuitive and will look like a flat scale that the litter box goes on. The simple registration website will be similar to other registration forms found online. Additionally, the concept of an email is widely used, and even if a user does not have experience with email, it imitates mail and has a lower learning curve than most other online communication means.

Affordance

Affordances are clues about how an object should be used. Much like the conceptual model of the device being like a scale, the product will allow the user to perceive it as a “smart scale”. We will have labels beside the three buttons and one LED. The red LED, widely used for representing error, represents a potential problem. To minimize confusion, the LCD screen, as mentioned under “Feedback”, outputs a word which describes the current task providing clarity.

Signifiers

Signifiers make affordances clearer. Signifiers make it clearer for the perceived affordances of the user. The signifiers are delivered by the LCD screen, allowing easy understanding of the status of the device. In addition, the email will show an updating weight, and potential urinary updates focusing on the deviation from normal and trends of the parameters.

Mapping

Mapping is important and to keep it aligned with the conceptual model of the product feeling like a scale, there will be a small LCD screen and dashboard protruding from under the litter box. The placements of the buttons will mimic scales. The LCD screen will be in the center of the dashboard with an on/off push button switch on the right of the LCD screen, and an RGB LED above the button switch. The RGB LED is close to the LCD screen since the RGB LED identifies device status and it is intuitive to have the closest LED represent the status of the device (controlled by the push button switch). There will be a red LED to the left of the LCD screen to indicate problems with the cat.

Constraints

Design constraints are limitations on a design. This device is heavily reliant on user input and when the user requires the data be sent to the emails specified on their profile. The user will have to remember to request the data prior to a visit to the veterinary clinic. The Cat Health Monitor requires that the user has means of connecting to the internet to initialize a profile, access data through email, and update data. The user will also need to change the batteries of the device frequently if they are not plugging it into a power outlet. The user will need to recognize the use of switches and the patterns of LEDs and any problems they represent. The data is summarized into an HI and the user needs to recognize that it is not a professional diagnosis, but rather a simple metric to track general health trends. The user must understand that raw data is attached to the email as a text file, which should be further analyzed by a professional.

7.7 Engineering Standards

9 Lives and its cat health monitor will conform to proper Canadian and international standards to create a maintainable, marketable, and safe product. 9 Lives will follow the standards outlined by the CSA and the ISO. In addition, 9 Lives will reference the FDA guidelines on Animal Medical Devices for important animal safety and responsibilities.

The following table will show the standard and responsibility requirements that the Cat Health Monitor Standard will keep with the code on the left column and a brief description on the right.

CSA 22.1-18 [14]	The AC power adapter and electrical connections to the cat health monitor will comply with the CSA Safety Standards for Electrical Installations.
ISO 10377:2013 [15]	The electronic components and system will follow the safety guidelines for consumers and users.
ISO 14040:2006 [16]	The cat health monitor will have an environmentally sensitive product life cycle.
Animal Products FDA Regulations [17]	The cat health monitor's safety and responsibility for animals will reference FDA regulations on Animal Medical Devices.
IEEE 2700-2017 [18]	Standard for Sensor Performance Parameter.
IEC 62133:2012 [19]	Standard for the safe operation of portable sealed secondary cells and batteries (other than button) containing alkaline or other non-acid electrolyte, under intended use and reasonably foreseeable misuse.
IEC 60950-1:2001 [20]	Standard for rated voltage not exceeding 600V

7.8 Analytical Usability Testing

Analytical usability testing will have users be the designers of the product. The team at 9 lives will create a profile for multiple cats and use different weighted items to test the weight. The weight parameters will be measured and algorithms for HI will be tested. The parameters will be sent to database; shortly after, the testing member will request the data be sent through email to addresses specified in the profile initialization. The Proof of Concept stage will display data through the Arduino Serial Monitor. Therefore, tests during the Proof of Concept stage will be testing the profile creation and hardware tasks such as cleaning.

Designer testing

The following tasks will be executed for analytical usability testing at the Proof of Concept stage:

1. Connect the device to a USB port on a computer.
2. Run program to display readings out of the Arduino.
3. Place item 1 on the device.
4. Wait for the device to tare.
5. Remove item 1 and place item 2 (of different weight than item 1).
6. Remove item 2 from the device.
7. Wait for the device to tare.
8. Place both items 1 and 2 on the device.
9. Remove item 1 from the device.
10. Verify that each the device activated upon weight each time.
11. Place an item with less weight than the activation threshold weight and verify that the device does not activate.
12. Select the button that transmits the data onto the Arduino Serial Monitor and verify that the values are identical to values seen in steps above.

Steps 3 to 7 evaluate the accuracy of weight measurements of the device while step 8 to 10 evaluate the capabilities to detect weight shifts and calculating a new tare value.

The following statements must be evaluated against the device.

For the Proof of Concept stage:

1. Weight sensors measure correct weight within specified tolerances when an object is placed on the device. The weights must be accurate regardless of the position of the object and if the object is moving.
2. Frequency of visits along with weight of the cat and its excrements are measured and calculated.
3. The detection of excrements and calculating a new tare upon the tests in steps 8 to 10 above.
4. Parameters are displayed on the Arduino serial monitor upon request.
5. Upon drastic weight change, or repetitive lack of excrements, the user is notified through the blinking of a red LED.

For the Prototype stage:

1. Weight parameters are tested along with urinary parameters.
2. The Cat Health Monitor device is in a thin and waterproof enclosure.
3. The device does not affect users' or their cats' living conditions and habits.
4. Graphical representation of the data shown to the user upon request.

7.9 Empirical Usability Testing

Empirical usability testing will be split into two sections; product usability testing and functional usability testing. Product usability testing will be executed to simulate how a user may interact with the product. Functional usability testing will test the interaction between the device and users and cats. This split allows for early UI testing and a larger sample market for testing. Product usability does not require the user to be a cat owner, and they may treat the device as a scale. Whereas, the functional usability testing will require the tester to be a cat owner and involve their cats in the study. Our empirical usability testing will survey participants on electronic evaluation of our device. This allows for easier distribution of surveys, participant engagement, digital copy of data, and easy data analysis.

The Cat Health Monitor device will be tested in both environments specified above: clinical and residential. Friends and family members, regardless of whether they own cats, will be asked to assist with testing the usability of the product. Background information will be asked on the electronic survey to separate the tester into the categories of either clinical, developer, or residential, whether a cat was in the test and how much experience they have with cats. The team will seek participants will limited to no knowledge regarding the product to avoid prior knowledge affecting the opinion of usability of each participant. The testing will be executed in three ways:

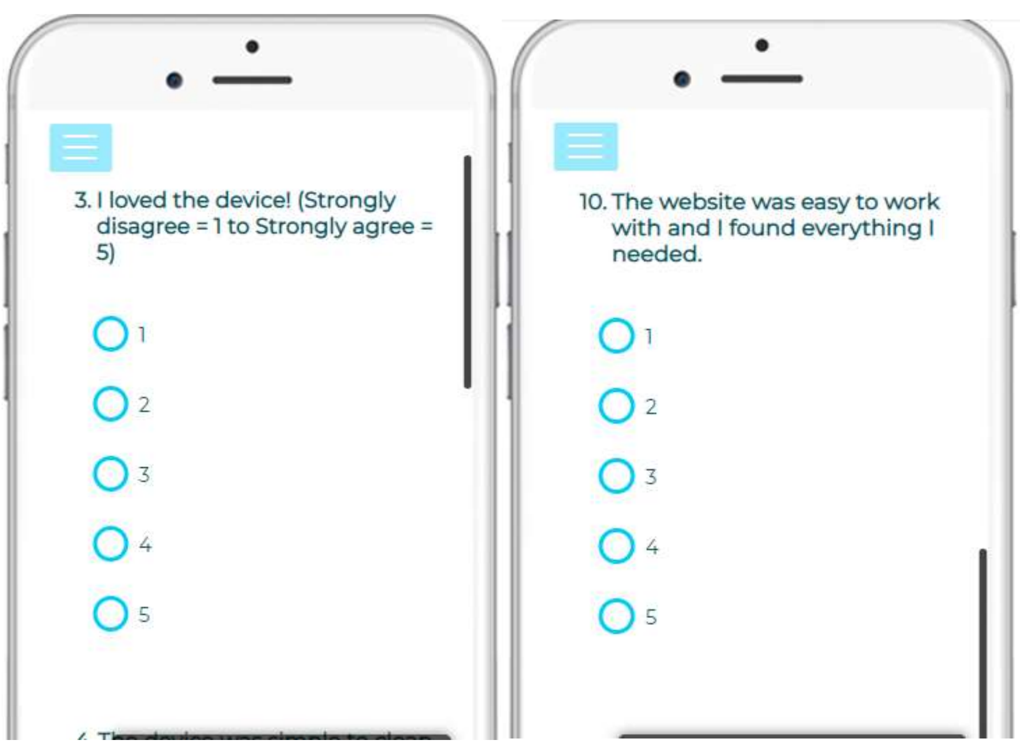
7.9.1 Residential

Product usability: Users assisting with residential product usability testing will be tasked with three tasks:

1. Cleaning
2. Registering a profile
3. Weighing an item

The user will be tasked the three tasks listed above to test the ease of cleaning, intuitive registration, and intuitive hardware and software design. These users will be surveyed with the following statements with a scale from 1 (strongly disagree) to 5 (strongly agree) indicating their opinion of the device with regards to the statement. The survey can be easily filled on a cellular device as shown in the **Figure 12** attached below.

Figure 12: Survey Sent to User to Collect Usability Testing Results



The following statements will be presented to the users after the background information probing questions:

1. I loved the device!
2. The device was not in the way.
3. The device was simple to clean.
4. I was worried about getting the device wet.
5. I believe I cleaned the device well.
6. The profile was easy to create.
7. The profile was short and did not ask too much.
8. The buttons were easy to understand/I was able to turn on the device easily and understood what each button meant.
9. The device is just like a scale!
10. I would recommend this to my friends and family that own cats.
11. The website was easy to work with and I found everything I needed.

Functional Usability: This test targets cat owners and analyzes the cat's behaviour around the product. The testing procedure will be the same and the same survey used in the product usability testing will be provided to the tester along with the following questions added on.

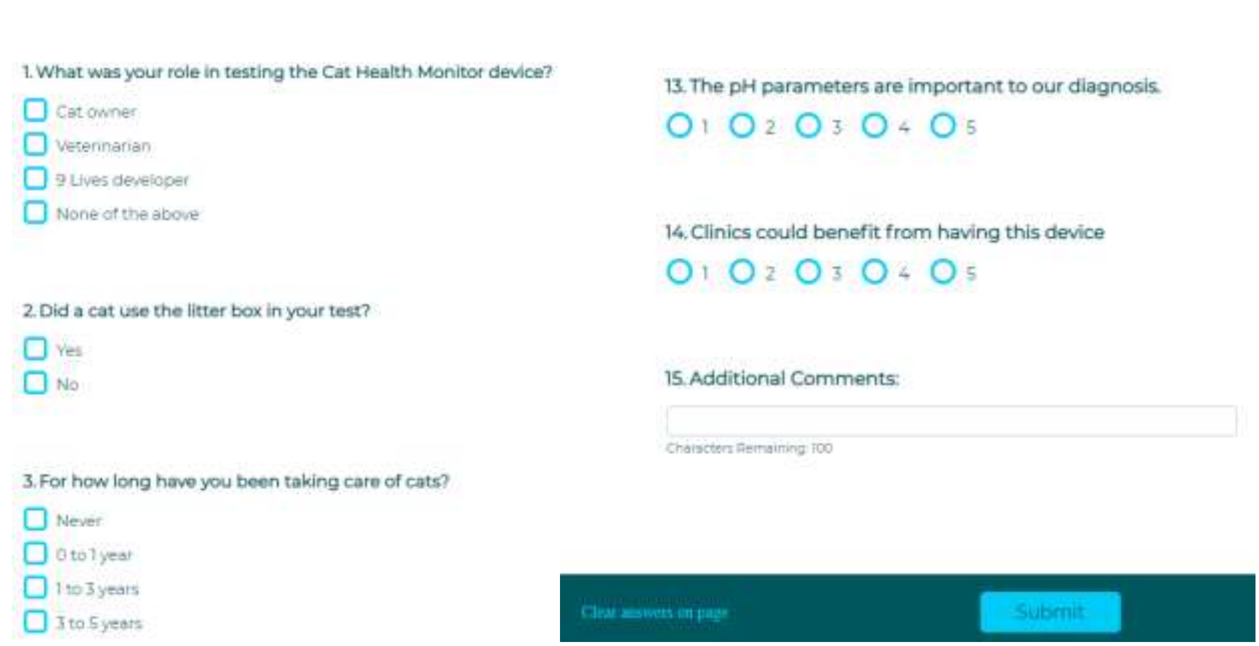
1. My cat did not notice the device.
2. My cat used the litter box as usual.
3. I was able to record accurate measurements of their weight.
4. This device could help me understand the health of my cat.

7.9.2 Clinical

The team at 9 lives have connections with veterinarians at clinics. Instead of asking veterinarian clinics to perform tasks specified in Section 7.9.1 geared towards residential users, veterinarians will implement the device and perform their duties as if the device was not there. Along with the weight sensors, the veterinarians will place the device along with optional pH sensors and answer the following questions in the same surveying method specified above after the background information probing questions.

1. The cats were comfortable with the device.
2. The device was simple to clean.
3. The device did not affect other tasks.
4. The device assisted in our measurements and provided valuable information.
5. The weight parameters are important to our diagnosis.
6. The pH parameters are important to our diagnosis.
7. Clinics could benefit from having this device.

Figure 13: Background Information (Left) and Typical Clinical Study Questions (Right)



7.10 Conclusion

User Interface (UI) design is essential to creating a user-friendly product. It is malleable to the needs and preferences of the target market and each part of the device needs to consider the effect on user experience. The UI appendix is created to determine methods of testing the target market preferences, align our product with the 7 main elements of UI interaction, and present graphics on the layout of both software and hardware components and how our product strives to improve user experience. Through aligning our specifications with the ideas listed above, 9 Lives aims to create a user friendly and intuitive product that considers clinical professionals and residential cat owners that may use this device. For the proof of concept design, the UI focuses mainly on the hardware functionality and all software UI will be through an Arduino Serial Monitor. The prototype version of the Cat Health Monitor device will strive to align with the 7 elements of UI interaction and provide a detailed, yet, easy to understand email for the user and their veterinarian. 9 Lives will create the Cat Health Monitor with the user and their cats' experience spearheading the design process.