P.A.W.S.

Protected **A**ccess for **W**hiskered **S**ubjects: AI-Assisted Litter Box System

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Chapter 2 - Project Description

2.1 Project Background and Motivation

Allowing dogs constant access to a litter box can be the origin of some serious health risks, both for the dog and for humans within the same household. Litter boxes are designed for cats, and their waste should be handled in a particular way. When dogs have free roam to a litter box, they might engage in a behavior called coprophagia, which is when they ingest feces. According to PetMD, this is a very common practice among canines. However, this behavior can lead to exposure to a great deal of harmful bacteria and parasites. This will lead to many gastrointestinal issues, and in severe cases it can lead to deadly infections.

Toxoplasma gondii is a parasite commonly found in cats, and is transmitted through their feces, however it can be found in most warm-blooded animals. This parasite causes an infection called toxoplasmosis. Although it is not deadly to an average adult, it can be very dangerous to pregnant women and immunocompromised people. Toxoplasmosis can even lead to birth defects and even miscarriage.

When dogs continuously engage in this behavior, not only is it dangerous for the humans in the same household, but it can also be dangerous to their health. Most types of litter are designed to clump when in contact with the cat's urine and feces, for the ease of clean up, this clumping factor can cause gastrointestinal blockages on the dog if they carry on eating litter. This will lead to severe stomach issues causing constant veterinary visits. Another issue that can affect dogs is the dust from the litter, which may affect their respiratory system. Furthermore, dog's hygiene habits vastly differ from cats, it's not part of their behavior to clean themselves thoroughly like cats. Their lack of hygiene will increase the spread of litter and fecal matter throughout a household.

2.2 Goals

2.2.1 Basic Goals

Our basic goals are what we expect to achieve throughout the development of P.A.W.S. Initially, the design involves creating a litter box housed by a wooden enclosure that can seamlessly blend into everyday furniture. There will be infrared proximity sensors that will initially detect when the cat is within a foot of the enclosure. There will be a cat recognition verification system implemented to allow exclusive access for the cat, which will trigger the motorized plexiglass door that will provide entry and exit for the cat only, along with infrared safety sensors to prevent the door from closing while the cat is in the doorway, preventing possible injury.

Other features will include a top-mounted hinged door, allowing easy access for placing, removing, or cleaning the litter box. Also, for added security, a manual override switch will allow the owner to open the door in case of power or mechanical failure.

2.2.2 Advance Goals

The advance goals are some of the core elements that will set P.A.W.S apart from other ordinary litter boxes. The design features AI-powered object detection through real-time image processing, allowing the system to identify whether a cat, dog, or neither is in front of the enclosure. This is the type of verification system mentioned from the basic goals we will implement and focus on because we do not want to have any false positive access to the litter box.

Also, we want to include a mounted LCD screen on top of the enclosure that will display an emoting character, with expressions that change based on movement detection and pet identification.

Ideally, we will integrate a mobile app that will let users monitor a live camera feed, track door opening times, and view image snapshots of when a pet triggers the door. The system will notify the owner of litter box activity via a notification. This cross-platform app will also enable the user to adjust settings for the enclosure, LCD screen, and motorized door. This type of customization will allow the cat owner to manage their household with ease.

2.2.3 Stretch Goals

Furthermore, we have stretch goals we want to include that aren't required for the main functionality of our system but will be additional benefits to the user if they can be added. This includes allowing the owner to save snapshots from the live camera feed locally. If they have multiple cats, it would be useful to allow them to categorize images by pet.

Other stretch goals include a cat paw-pad scanner that will identify and note multiple pets' litter box usage. We may also want to integrate data collection such as weight tracking to better determine pet health over a long period of time, which can help the owner avoid costly medical bills for their pet.

Lastly, we would add an improvement with a liquid crystal sheet (turns opaque when voltage applied) attached to the plexiglass door to provide privacy to the cat once it enters the enclosure.

2.3 Objectives

The primary objectives of the P.A.W.S. smart litter box system is to create a protected and private space for the bathroom needs of felines, keep canines from rooting in the cat litter, and to overall promote a clean home environment. By preventing unauthorized access-- particularly from canines who regularly engage in ingesting feces-- the system aims to minimize the spread of harmful bacteria while safeguarding them from ingesting potentially hazardous substances. Additionally, the system is designed to monitor and track cats' bathroom patterns, enabling early detection of potential health issues (e.g., by identifying sudden changes such as increased frequency of visits or extended duration per use). Ultimately, this comprehensive solution seeks to enhance a sanitary living environment for all household members: cats, dogs, and humans alike.

2.3.1 Basic Objectives:

The basic objectives of the system will feature a durable wooden enclosure that integrates seamlessly into household furniture. It will include infrared proximity sensors calibrated to detect the cat's presence within a set distance, even in varying lighting conditions. A motorized plexiglass door with stepping motors and safety sensors will ensure safe entry and exit, only closing when the cat has fully exited. For added convenience, the system will have a top-mounted hinged door with hydraulic hinges for easy access, along with a manual override switch connected to the Raspberry Pi for security in case of system failure.

2.3.2 Advance Objectives:

The advanced objectives include developing and implementing AI-powered object detection that ensures exclusive access for the recognized cat by minimizing false positives and preventing unauthorized entry by other pets. Additionally, the system will feature a mounted LCD screen that displays an animated character with five dynamic expressions that respond to motion and pet identification within 1 second. A cross-platform mobile app will be developed, offering a live camera feed, door activity tracking, and push notifications, along with customizable settings for key features.

2.3.2 Stretch Objectives:

Furthermore, if we accomplish the previous objectives, we will add to the system several innovative features to enhance user experience and pet monitoring. The mobile app will be developed to allow users to save high-resolution snapshots from the live camera feed to their local devices, with seamless download capability and the ability to organize images by pet. Additionally, a cat paw-pad scanner will be integrated into the enclosure to accurately recognize individual pets and link to the data collection module, enabling users to log and review litter box usage in the app. The system will also incorporate a weight tracking feature within the litter box, displaying weight trends and providing alerts for significant changes, with comprehensive testing. Finally, we'll implement a liquid crystal sheet mounted on the plexiglass door that turns opaque for cat privacy using a relay switching mechanism.

2.4 Existing Products

2.4.1 Market Analysis

Two prominent players in the smart pet-care field are SureFeed and Meowspace, each providing unique solutions to common multi-pet household challenges. SureFeed specializes in Microchip Feeders, which grant food access only to pets with correct identification microchips or SureFlap RFID collar tags. This technology proves particularly useful in scenarios where a pet requires prescription food, there are greedy pets present that will attempt to steal their companions' meals, and where a pet's weight needs careful management. Meowspace, on the other hand, offers a selective-access pet enclosure that doubles as both a food and litter-box protection system. It features a locking pet door that can be unlocked via magnetic collars, RFID-tag embedded collars, or embedded microchips.

Figure (2.1) - MeowSpace Regular Sized Microchip System.

Figure (2.2) - SureFeed Microchip Small Dog & Cat Feeder.

While these systems offer innovative solutions, they share a common limitation: reliance on external hardware attached to the animal. This dependency, whether through embedded microchips or collars, presents several potential issues, such as damage risk during rough play or outdoor adventures, discomfort for cats unaccustomed to wearing collars, potential hazards unless quick-release functions are incorporated, expense of multiple collars for multi-cat households, and inconvenience for cat-fostering homes or frequent pet-sitters who would need to regularly update device information.

Despite these advanced options, the market still lacks a fully cohesive, dog-excluding cat litter protection system. The P.A.W.S. provides a more comprehensive solution, featuring universal cat recognition with an IR imaging software without relying on collars or microchips and making it unaffected by light conditions. It also enables effective dog exclusion, and the app control allows for monitoring pet usage and aiding maintenance. P.A.W.S. provides a more accessible, hardware-hassle free, and user-friendly solution for all types of cat owners, from single-cat households to fostering environments, to felines with and without microchips and special collars.

2.5 Engineering Requirements and Specifications

2.5.1 Specifications

Product Requirement	Requirement Specification	Units

The system shall use a proximity sensor to detect objects within a certain distance of the enclosure	≤ 1.5	feet
The system shall use an IR imaging camera with at least 90% identification accuracy	≥ 90	%
The system shall have a field of view for the IR imaging camera of at least 75°.	≥ 75	°
The system shall have a response time from the Raspberry Pi of 5 seconds or less.	≤ 5	seconds
The motorized rail-system shall move at a speed of at least 1 cm/sec.	≥ 1	cm/sec
The system's fully enclosed structure shall have minimum dimensions of 3’ x 2’ x 2’.	≥ 3' x 2' x 2'	feet
The system's plexiglass door shall have a maximum dimension of 16” x 16”.	≤ 16" x 16"	inches
The system shall use a battery with a minimum lifespan of 2 weeks.	≥ 2	weeks
The LCD display shall have brightness between 300 and 600 nits.	300-600	nits
The IR flood light shall have an angle range of 90°-100°.	90-100	°

The IR flood light wavelength shall be approximately 700 nm.	~700	nm
The photosensors shall consume no more than 70 mW of power.	≤ 70	mW
The Velostat shall detect a minimum pressure of 1 lb.	≥ 1	lbs

Table (2.1) - Engineering requirements specifications for the performance and physical features of the envisioned system.

Component(s)	Parameters	Specification
IR Imaging camera	Identification Accuracy	≥ 90%
	Field of view	≥ 75 degrees
Raspberry Pi	Response Time	Within 5 seconds
Motorized rail-system	Speed	Minimum 1cm/sec
Fully-enclosed rectangular structure	Dimensions	Minimum 3' x 2' x 2'
Plexiglass door	Dimensions	Maximum 16" x 16"
Battery	Minimum lifespan	2 weeks
LCD display	Brightness	Ranging from 300-600 nits
IR flood light	Angle	90-100°
	Wavelength	~700 nm
Photosensor (2)	Power consumption	70mW
Velostat	Pressure	1lb minimum

Table (2.2) - Engineering specifications; demonstrable specs highlighted.

2.6 Prototype Illustrations

2.6.1 P.A.W.S. Enclosure Design

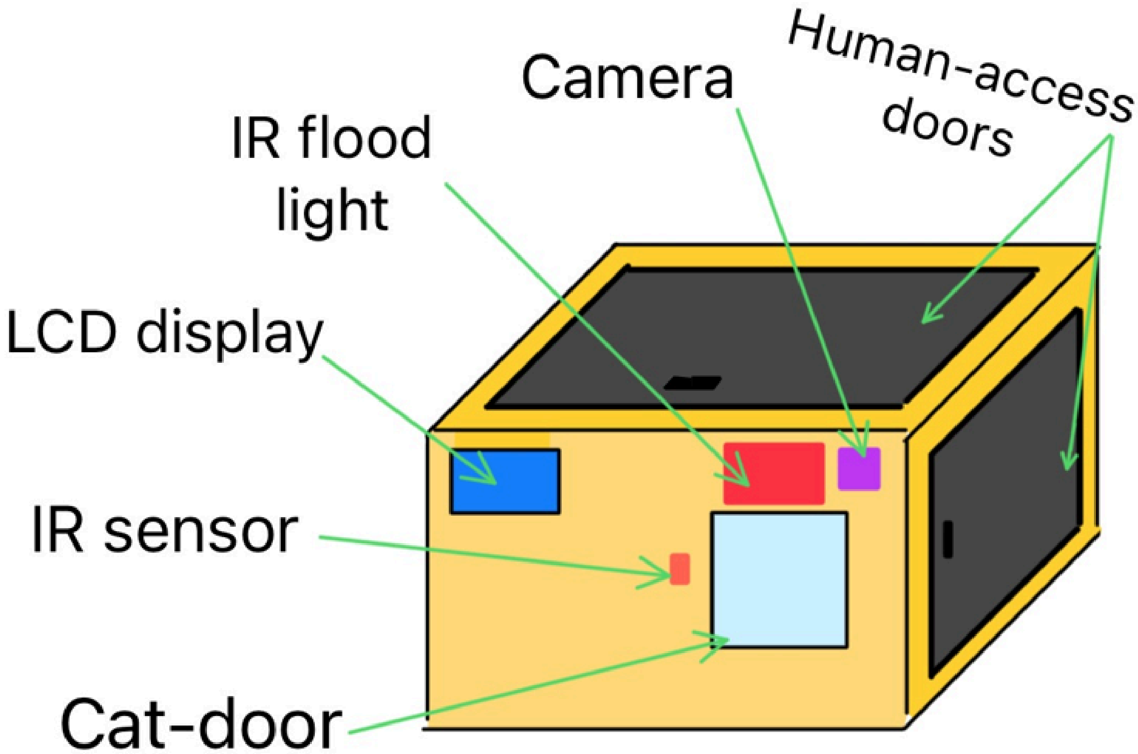

Figure (2.3) - Design concept for the physical P.A.W.S. litter box structure.

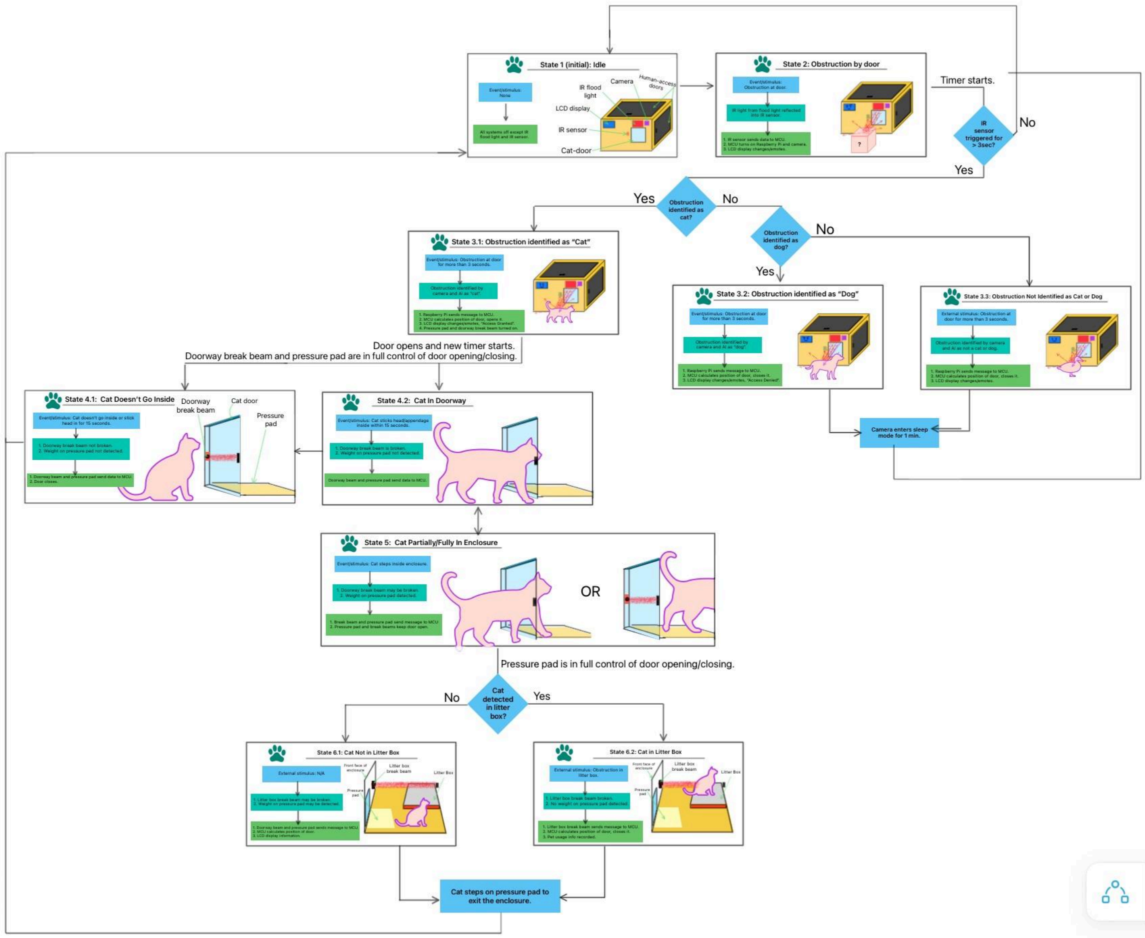

Figure (2.4) - Sequence of P.A.W.S. states.

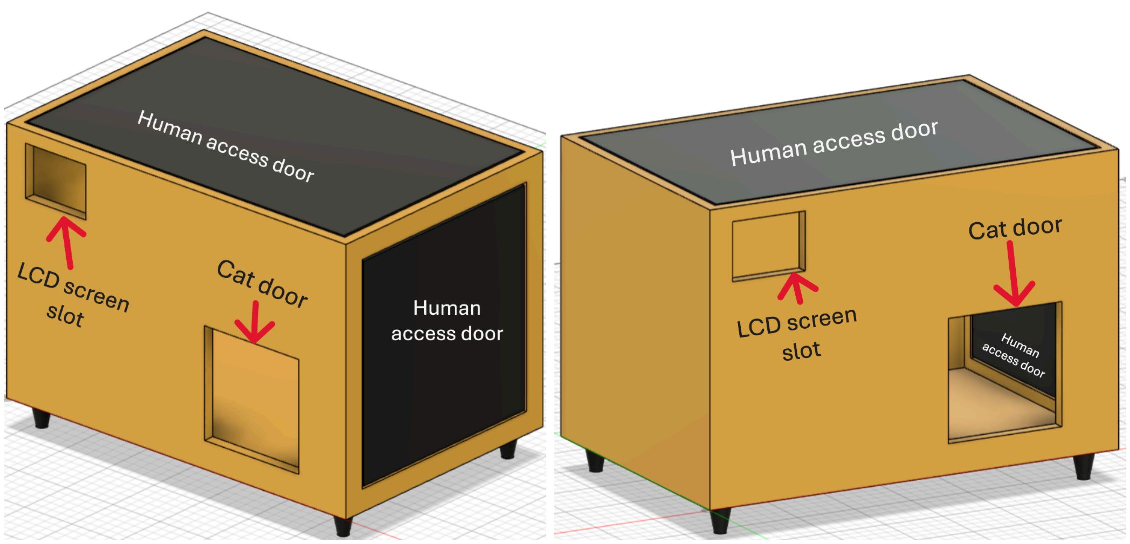

Figure (2.5) - 3D prototype concept for the physical P.A.W.S. litter box enclosure.

2.6.2 Mobile Application Design

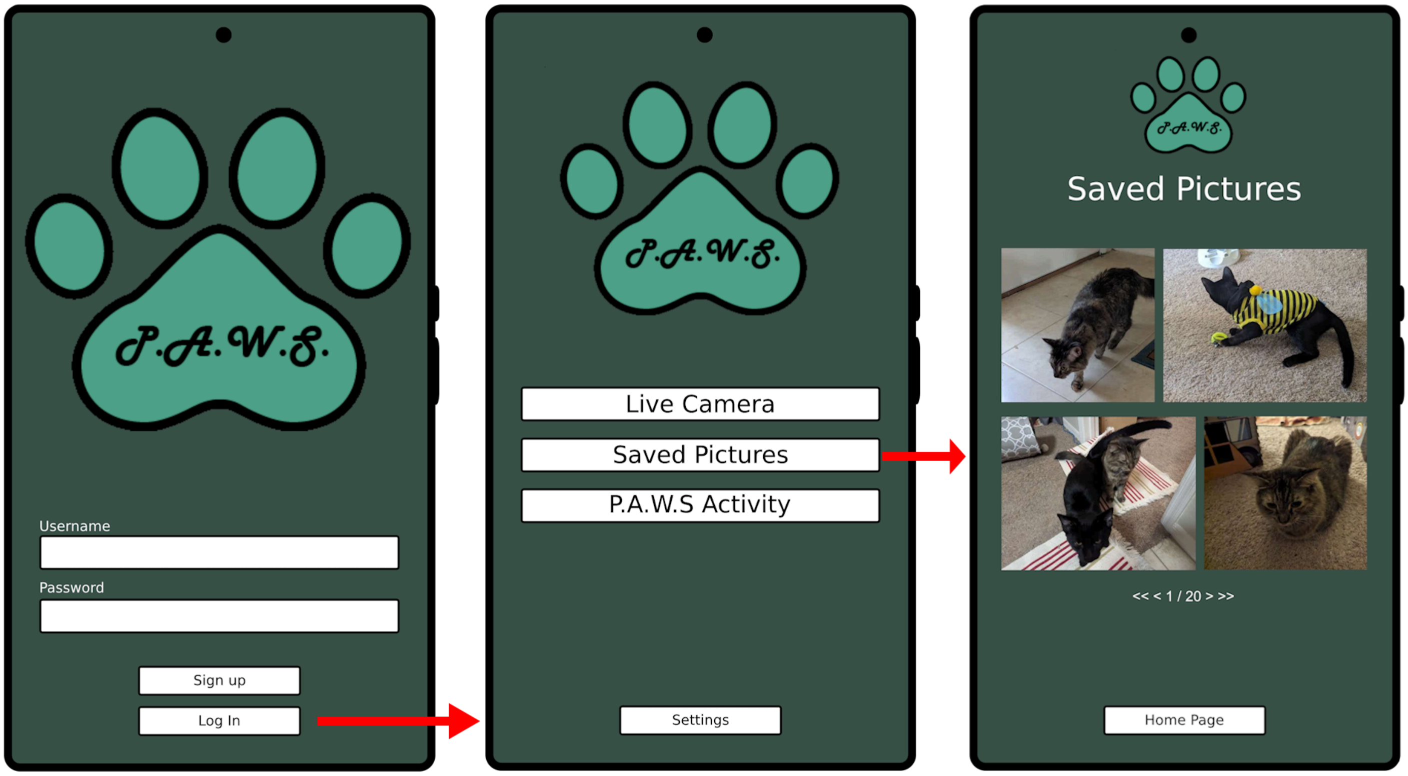

Figure (2.6) - Design mockup of the integrated mobile app. Examples include the sign-up/sign-in page, the home screen, and the “Saved Pictures” tab.

2.7 Functionality of Design

2.7.1 P.A.W.S. Enclosure Functionality

The enclosure will have a fully-enclosed, hollow rectangular form factor made from wood (refer to Figures 2.3-2.5). Its dimensions will be 3 feet in length by 2 feet in width by 2 feet in height. There will be a human-access door on the top face of the structure to allow for easy cleaning and maintenance. This access door will feature hydraulic hinges to stay in place when the user opens it. A motorized rail system will be attached to the front face of the structure and will serve as the actuator for sliding the plexiglass door, effectively opening and closing the 16-by-16 inch opening in the lower right corner of the front face of the structure). An LCD screen will be secured into the structure at the top left corner of the front face. Four 2.5-inch long tapered legs are attached to the underside of the enclosure. The structure will be fully painted with the P.A.W.S. logo featured on the top face of the structure, and the authors plan to color-match the final logo design as well.

2.7.2 Mobile Application Functionality

The P.A.W.S. project will have an integrated mobile application. Upon first-time startup, a user is prompted to either log in with a previously created account, or sign up to create a new account. A P.A.W.S. enclosure can be connected to the account, and all corresponding functions will be available to the owner. These functions currently include:

- Receiving notifications when there is important activity detected by the sensors and/or the camera.
- Accessing a live video feed from the front-facing camera.
- Saving and viewing snapshots taken by the camera when a pet is detected nearby the P.A.W.S. enclosure.
- Viewing historical data of when the door is triggered to open. This data is especially useful for monitoring pet health over a long period of time.
- Access/modify enclosure's settings, LCD screen, and motorized door.

The mobile app will communicate with the P.A.W.S. enclosure through the Raspberry Pi's integrated WIFI capability. If not currently being interacted with, the Pi should stay in low-power mode in order to maximize the overall battery life. Saved pictures and activity logs are stored locally on the user's phone, and the live video is streamed directly from the Raspberry Pi only when being actively viewed. Additionally, the user will be able to directly activate the motor regardless of current detection status. Allowing manual control is a highly important safety feature should any electrical or mechanical failure take place.

2.8 Hardware Block Diagram

The MCU (MSP430) controls and coordinates the peripherals in the system, such as the LCD screen, IR sensor, stepper motor, and the Raspberry Pi 4 board via UART communication. It features LCD control, timers, and UART, all necessary for the project implementation. The LCD display will interface with the MSP430 chip to present information to the user, timers will be used for the motor control, and the UART communication system will be used to exchange important data between the Raspberry Pi SBC and the MCU. The regulators regulate the power supply going to different parts of the system, ensuring the appropriate voltages for the MSP430 MCU, the Raspberry PI SBC, LCD Screen, stepper motor, flood light, and sensors.

The PCB houses the MCU, LCD Screen, and regulators. The AC power supply converter transformer provides power to the entire system. The infrared flood light is powered directly by the AC supply. A signal is added to the flood light and modulated to be sensed by the IR sensor. The camera module is a wide-lens IR camera used for animal identification. The photosensor will be used as a break-beam sensor to add an extra layer of safety to detect obstructing objects in the door's path. The pressure sensitive conductive sheet is used to detect weight on the inside of the door, forcing the door open until the weight is removed. The tasks of animal identification and processing sensors' data are delegated to the Raspberry Pi, while the MCU on the PCB will configure and coordinate motor control, the LCD control, and the IR sensor data. So when the correct conditions arise (determined after processing the camera and sensor data), the Raspberry Pi will send a message to the MCU via UART, which will then activate the motor for the door opening/closing.

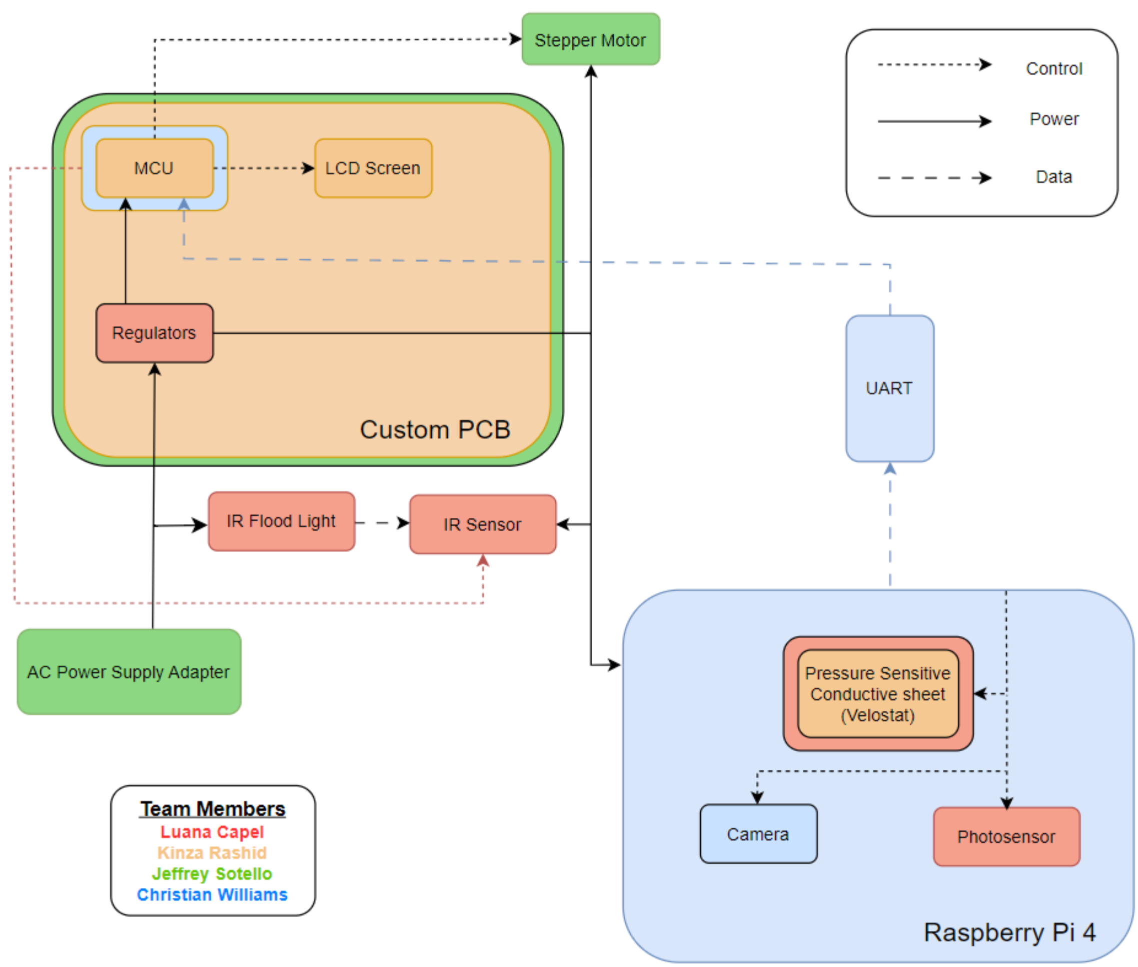

Figure (2.7) - Hardware Block Diagram.

2.9 Software Block Diagram

The P.A.W.S. enclosure is equipped with an infrared flood light that is constantly on (AC-powered). There is a signal added to the flood light, so when the flood light's radiation is reflected into the IR sensor (which means there's been movement close enough that enabled this light to be reflected), the IR sensor sends a message to the MCU, which uses UART communication to trigger the camera to begin sending a live video feed to a connected Raspberry Pi for real-time image processing. This enables the Raspberry Pi to remain in a low-power draw or off state in order to save battery life. During image processing, an AI object detection model will be able to determine if the movement in front of the enclosure is a cat, dog, or neither. The "neither" option includes any human or animal that isn't explicitly annotated in the training set as either a cat or a dog. If this "neither" option is detected, then the system will simply do nothing and idle. If a dog is detected, the Raspberry Pi will communicate with the MCU to check if the door is open. If so, then the MCU will control the motor and close the door. Similarly, if a cat is detected and the door is currently closed, then the door will be opened. Additionally, the camera will take a picture and log the current time and date. This data is saved locally to be viewed within the integrated mobile app; the app's functions are described above in section 2.9.2 and an early design mockup is shown in figure 2.4.

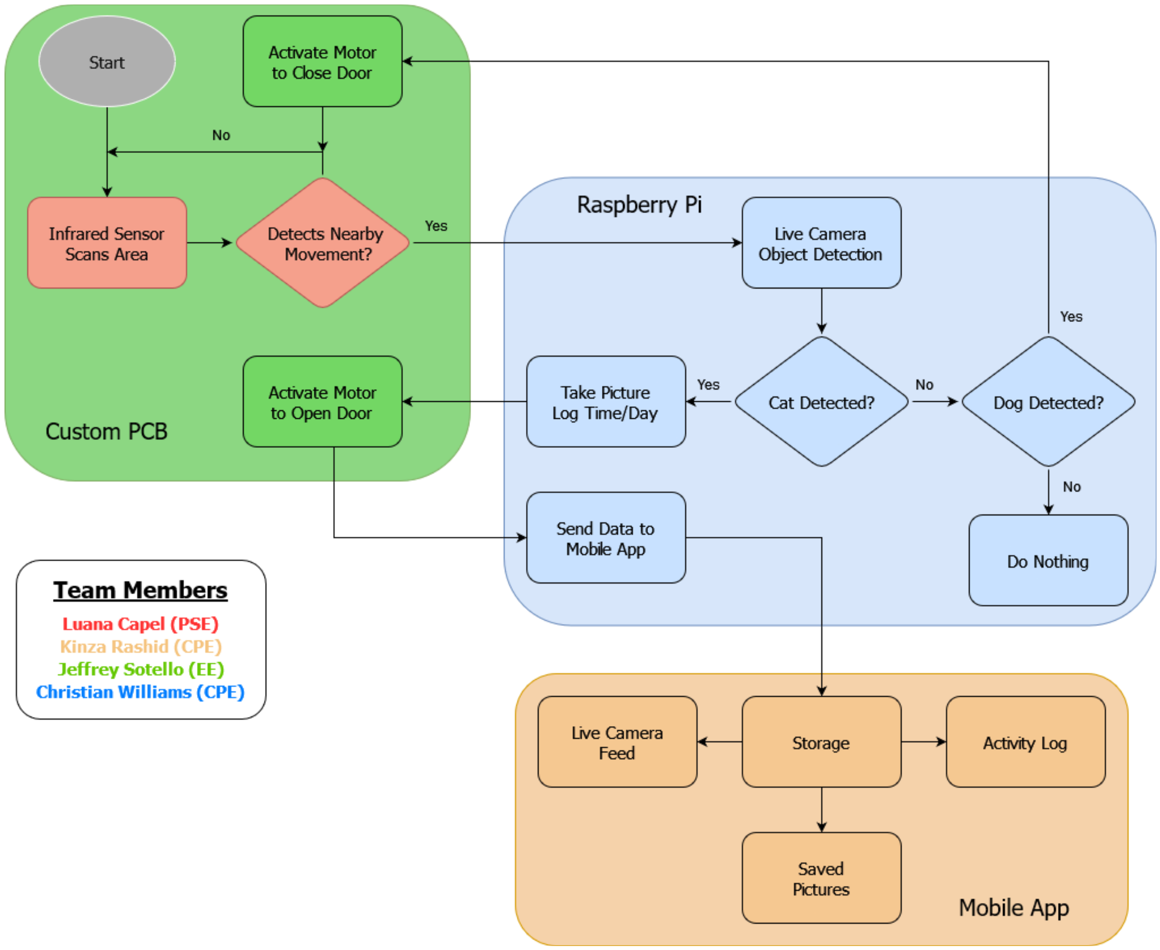

Figure (2.8) - Software Block Diagram.

Chapter 10 - Administrative Content

10.1 Marketing

10.1.1 Budget and Financing

Component(s)	Unit Cost	Total
Fully-enclosed rectangular structure	$74.99	$74.99 (1)
IR Imaging camera	$19.99	$19.99 (1)
Plexiglass door	$19.99	$19.99 (1)
Motorized rail-system	$39.99	$39.99 (1)
Battery	$9.99	$9.99 (1)

LCD display	$14.99	$14.99 (1)
IR flood light	$19.99	$19.99 (1)
Photosensor	$4.99	$9.98 (2)
Velostat pressure sensitive sheet	$4.99	$4.99 (1)
Misc. Hardware (screws, wiring, etc.)	$14.99	$14.99 (1)
Single-Board Computer (Raspberry Pi)	$44.99	$44.99 (1)
Microcontroller	$9.99	$9.99 (1)
Custom PCB	$9.99	$9.99 (1)
Overall Total		$299.85

Table (10.1) - Budget breakdown and financing details. Does not factor in delivery costs and taxes.

10.1.2 House of Quality

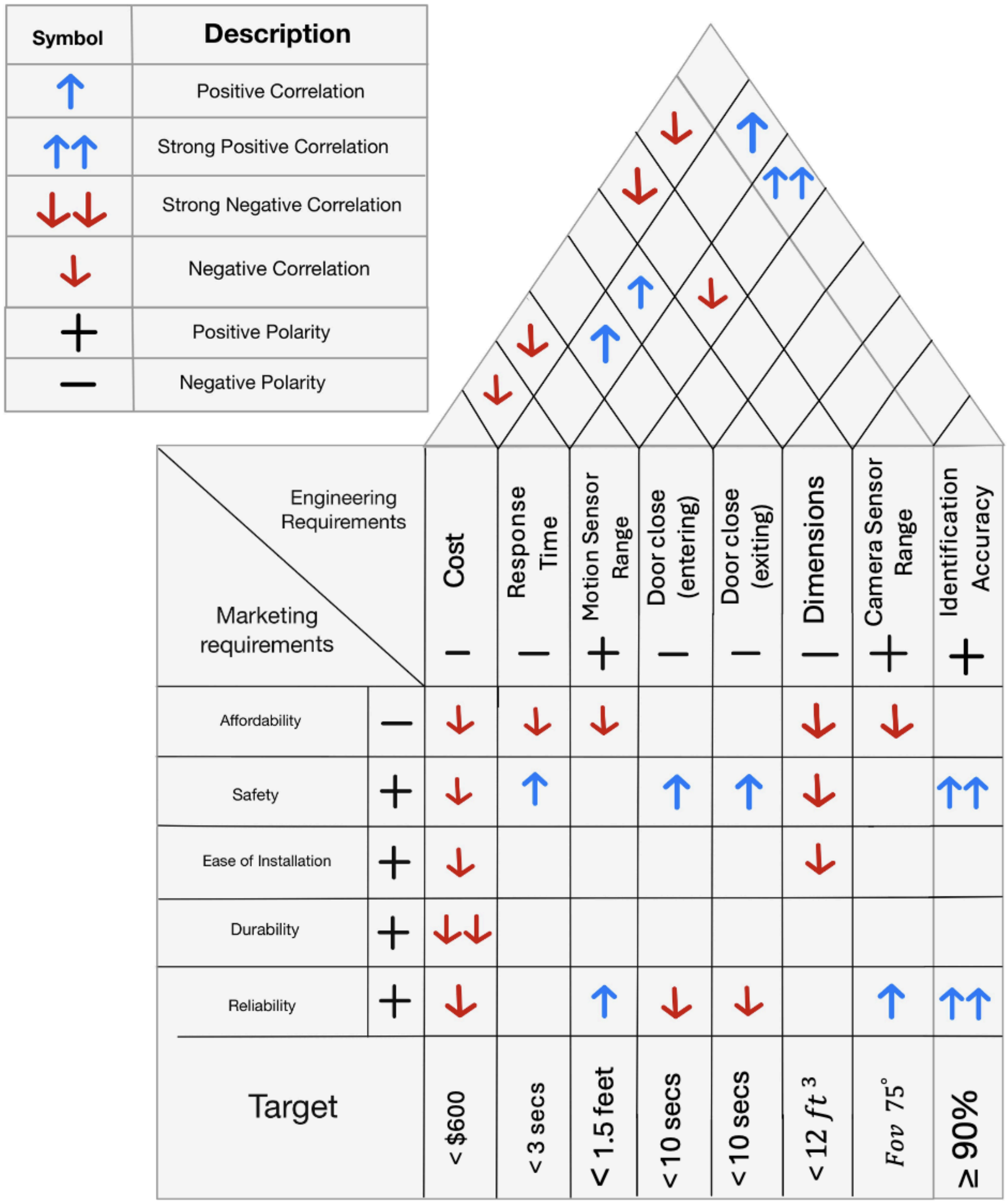

Figure (10.1) - House of Quality Diagram

10.2 Work Distribution

Photonics Engineering	Responsibilities

Luana Capel Secondary: Christian Williams	Laser Implementation
	Sensor Design and Implementation
	Enclosure Design
	Administrative Documentation
	Project Manager
Computer Engineering	Responsibilities
Kinza Rashid Secondary: Luana Capel	Mobile App Design
	Enclosure 3D Modeling and Development
	PCB Fabrication
	App Data Management
Electrical Engineering	Responsibilities
Jeffrey Sotello Secondary: Kinza Rashid	PCB Design
	PCB Fabrication
	Power Supply Research and Implementation
	Motor Configuration
Computer Engineering	Responsibilities
Christian Williams Secondary: Jeffrey Sotello	Embedded Software Design
	Software Management
	Camera Implementation
	UART Configuration

Table (10.2) - Team member work distribution and responsibilities.

10.3 Project Milestones

SD1 Milestones - Project Definition, Research, and Design

Start Date	Due Date	Target Slack Time (days)	Task	Description
8/20/2024	8/22/2024	0	Group-forming	Members assembled as Group 9: Luana Capel (PSE), Kinza Rashid (CPE), Jeffrey Sotello (EE), Christian Williams (CpE)
8/23/2024	9/1/2024	0	Project discussion and brainstorming	Several virtual and in-person meetings to discuss project details and ideas.
8/25/2024	9/6/2024	2	D&C document, draft	Several virtual and in-person meetings to work on drafting Chapters 2 and 10 of Final Report.
9/1/2024	9/25/2024	1	Selection of components (proposed)	Several virtual meetings and check-ins to pick components and start drafting the Bill of Materials.
9/11/2024	9/27/2024	1	D&C document,	Several virtual and in-person

			revised	meetings to work on finalizing Chapters 2 and 10 of Final Report. Possible addition of Chapter 3.
9/26/2024	10/10/2024	1	Selection of components (finalized)	Meeting(s) w/ Dr. Weeks to verify selected project components.
10/11/2024	10/17/2024	0	Order prototype components	Order and collect all components necessary for the prototype.
9/28/2024	10/25/2024	3	60-Page Report, draft	Several virtual and in-person meetings to work on drafting the 60-Page Report.
10/11/2024	10/17/2024	0	Order prototype components	Order and collect all components necessary for building the prototype.
10/30/2024	11/8/2024	1	60-Page Report, revised	Several virtual and in-person meetings to work on finalizing the

				60-page Report.
10/31/2024	11/26/2024	2	Build prototype	Start building on breadboard(s), testing each component before integrating together for the final prototype.
11/9/2024	11/26/2024	3	Final report	Several virtual and in-person meetings to complete the 120-page Final Report.

Table (10.3) - Senior Design 1 project milestones.

Appendix A - References

[1] Boze, B.G. (2008). A Comparison of Common Treatments for Coprophagy in Canis familiaris.

[2] Dubey JP. Toxoplasma Gondii. In: Baron S, editor. Medical Microbiology. 4th edition. Galveston (TX): University of Texas Medical Branch at Galveston; 1996. Chapter 84.

[3] Hart, B.L., Hart (Geyer), L.A., Thigpen, A.P., Tran, A., & Bain, M.J. (2018). The paradox of canine conspecific coprophagy. *Veterinary Medicine and Science, 4*, 106 - 114.

[4] Why do dogs eat poop?. PetMD. (n.d.). https://www.petmd.com/dog/behavior/why-do-dogs-eat-poop

Image resources:

- P.A.W.S. logo by Patrick King (Software used: Photoshop)
- P.A.W.S. design concept and state sequence diagram by Kinza Rashid (Software used: Freeform)
- Mobile Application Design by Christian Williams (Software used: Photopea)
    - “Saved Pictures” cat images taken by Christian Williams
- 3D P.A.W.S. prototype concept by Kinza Rashid (Software used: Fusion 360)
- Hardware Block Diagram by Kinza Rashid (Software used: draw.io)
- Software Block Diagram by Christian Williams (Software used: draw.io)

Product Links:
https://meowspace.biz/shop/
https://www.chewy.com/surefeed-microchip-small-dog-cat/dp/157144

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