P.A.W.S.: **P**rotected **A**ccess for **W**hiskered **S**ubjects AI-Assisted Litter Box System

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***Abstract*—PAWS: Protected Access for Whiskered Subjects - AI-Assisted Litter Box System is designed to address the challenge of keeping dogs out of cat litter boxes in multi-pet households. This system takes advantage of a combination of optical sensors, machine learning algorithms, and custom circuitry to allow accurate detection and recognition of pets approaching the litter box. Using an infrared(IR) camera and strategically placed IR sensors, the system continuously monitors movement in the vicinity. A trained AI model processes visual data to distinguish between cats and dogs, ensuring that the motorized access door opens only for cats while remaining closed for other animals. This paper details the design methods, including sensor placement strategies, machine learning model development, and system integration. Emphasis is placed on the efficiency, reliability, and cost-effectiveness of the design, which allows for accurate recognition under varying lighting conditions while minimizing false triggers. Through this project, we present an innovative and practical solution contributing to a more harmonious coexistence between pets in shared living spaces.**

***Index Terms* — Cats, DC-DC power converters, imaging recognition, infrared detectors, machine learning algorithms, microcontrollers, motion sensors, motor**

I. Introduction

Households with cats and dogs often face the challenge of keeping dogs out of cat litter boxes. The strong odor of litter can attract dogs, leading to unwanted mess and potential health risks if the dog ingests litter materials. To address this issue, our senior design project introduces a smart AI-assisted litter box system that ensures only the cat can access the litter box. This system integrates artificial intelligence recognition technology, IR sensors, and a motorized door to create an automated access control mechanism. By utilizing detection methods, our design enhances both hygiene and convenience for pet owners in multi-pet households.

The core functionality of the system relies on an IR camera and strategically placed IR sensors. These sensors continuously monitor the area around the litter box, detecting any approaching animal. Once movement is detected, an AI-based object recognition algorithm determines whether the animal is a cat or a dog. If the system confirms that a cat is present, the motorized door is activated to grant access. In contrast, if a dog is detected, the door remains locked, preventing unwanted entry. This approach ensures that the litter box remains secure while providing a seamless user experience for the cat.

Our design prioritizes efficiency, reliability, and cost-effectiveness. The IR camera plays a crucial role in ensuring reliable animal classification, particularly in low-light environments where traditional vision-based systems may struggle. AI-powered object recognition further improves the system's accuracy, minimizing false triggers and unnecessary door activations. By combining these technologies, we have developed a solution that is both practical and adaptable to home environments with varying lighting conditions.

Beyond restricting dog access, our system also offers significant health benefits. By preventing dogs from consuming litter, it reduces the risk of exposure to harmful chemicals and potential digestive problems. In addition, it reinforces the primary function of a litter box: to provide cats with a private, secure, and stress-free environment. With its intelligent detection, precise access control, and user-friendly automation, our AI-assisted litter box system presents an effective and innovative solution to a common problem faced by pet owners.

II. Specifications

This section defines the key engineering specifications and design requirements established for PAWS. These specifications guided our decision-making process for both optical and electrical components, ensuring optimal performance. By prioritizing these criteria, we aim to achieve seamless operation, accurate pet recognition, and reliable access control within the automated litter box system.

Figure 1 shows the key product requirements and corresponding specifications for the PAWS. These specifications were established to guide the selection and performance benchmarks of the system's overall engineering specifications. Demonstrable parameters include a minimum cat identification accuracy of 75%, raspberry pi response of less than or equal to 3 seconds and a minimum door open/close timing of less than or equal to 8 seconds. Additional design considerations include object detection of approximately 10 inches from door, FOV for camera

Product Requirement	Requirement Specification
Object detection distance	~ 10 inches
Cat identification accuracy	≥ 75 %
FOV of IR imaging camera	≥ 75 °
Raspberry Pi response	≤ 3 seconds
Door open/close timing	≤ 8 seconds
Rail-system minimum linear velocity	≤ 1inch/second
Minimum weight detection for pressure pad	≥ 1 pound

Fig. 1. Overall System Engineering Specifications

	Component	Parameter	Specification
Electrical	Power Supply	Support Max Delivery	Up to 96W
	Regulators	Voltage Regulation	Provide stable 3.3V and 5.2V
	Motor	Reliability	Operate without fail **90%** of the time
	Motor Driver	Current Handling Capacity	Support up to 2.5A
	PCB	Power Draw	Less than 55W
	Image Processor	Response Time	Delivers verdict of identifying cat within **3 seconds** image capturing
Optical	Proximity Sensor Lens	FOV	**60°**
		Focal Length	15-25 mm
	Infrared LED	Output Power	150 mW
		Peak Wavelength	940 nm
	Photodiode	Receiving Angle	40°
		Range	7-8 m

Fig. 2. Engineering Specifications for Major Components

of at least 75º, a linear rail movement speed of at least 1 inch per second, and a minimum weight detection threshold of 1 pound for the pressure pad. Collectively, these specifications ensure the system operates reliably and maintains a high level of safety.

Figure 2 shows the component-level specifications for both the electrical and optical subsystems of the PAWS. On the electrical side, specifications include a power supply capable of delivering up to 96W and voltage regulators that ensure stable 3.3V and 5.2V outputs. The motor is expected to operate reliably at least 90% of the time, while the motor driver must handle currents up to 2.5A. The image processor is a critical component, required to deliver a classification verdict within 3 seconds of capturing an image, supporting real-time decision-making. The total power draw from the custom PCB must remain under 55W to maintain system efficiency. In the optical subsystem, the design focuses on ensuring accurate and efficient object detection. The IR system is designed with a minimum 60° FOV, and the proximity sensor lens is specified with a focal length between 15–25mm. The infrared LED operates at a peak wavelength of 940 nm with a max output power of 150 mW, making it suitable for indoor use and low-light environments. The paired photodiode features a 40° receiving angle and a detection range of 7 to 8 meters, supporting early and reliable object detection. These combined specifications ensure that the PAWS system can function accurately and consistently.

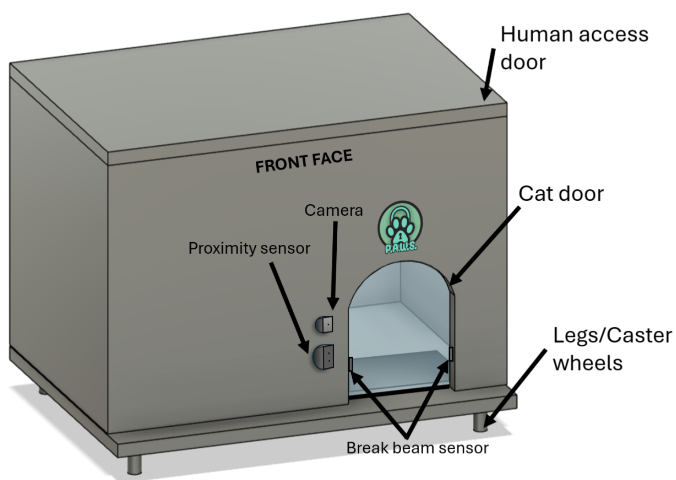

Fig. 3. Front Face of PAWS Enclosure

III. Overall Hardware Design

This section provides an overview of the hardware design and implementation of our system. The hardware that makes up the project can be divided into five subsystems: the main PCB, the Raspberry Pi, the optics, the linear rail and the power.

In addition to the five subsystems, the PAWS housing is a fully enclosed wooden structure featuring a guarded cat entrance and a top-hinged human-access door for easy litter cleaning and maintenance. All electrical hardware components are securely housed both inside and outside the enclosure with protective casings to conceal all circuitry.

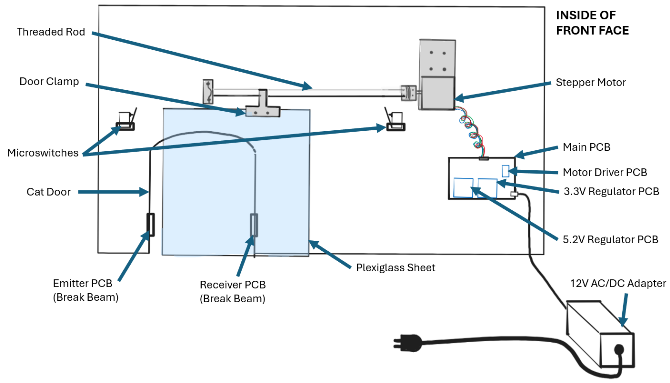

Fig. 4. Inside Front Face of PAWS Enclosure

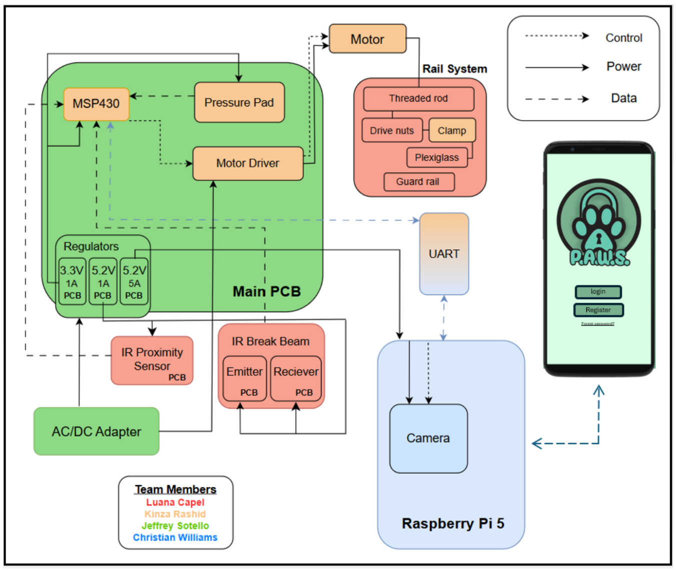

Fig. 5. Hardware Block Diagram for PAWS

A. Main PCB System

This system lies at the core of the project, with the central control hub being the MSP430 chip. It manages motor control, pressure and optical sensors, and communicates with the Raspberry Pi.

This system acts as a bridge connecting the other four major systems, with components from the other systems plugging directly into the Main PCB.

B. Raspberry Pi System

This subsystem is responsible for AI-based identification and management of user interaction through the mobile app. It includes a Raspberry Pi 5 and an IR Pi camera module. The Raspberry Pi processes data from the camera using a lightweight machine learning model (specifically, YOLO) to identify objects. In addition, its WiFi capability enables seamless data transmission to the mobile app. Communication with the main PCB system is handled through the UART interface.

C. Optics System

The optics is comprised of a proximity sensor and a break beam sensor that utilize IR emitters and photo receivers. A lens is used to converge the light into the proximity sensor's photo receiver and additional emitters are placed strategically around the enclosure to cover a larger area for detection. The break beam sensor does not require any lens design as the beam already spreads minimally as it propagates.

D. Linear Rail System

This system is responsible for allowing and blocking physical access into the PAWS enclosure through the cat door. The linear rail actuates the horizontal movement of the plexiglass door, operating using a lead screw mechanism with a drive nut. A door clamp attaches the plexiglass sheet to the drive nut so that when the motor turns, the entire door moves back and forth along the threaded rod with the drive nut. In addition, the door is guided by a guard rail that runs fully across the entrance of the cat door.

E. Power System

This system is responsible for delivering power to all the hardware components of PAWS. It is comprised of an AC/DC adapter and three regulator boards. All the regulators are step-down switching regulators.

IV. Optical Design

The optical design of PAWS plays an important role as the starting point for object detection. This section outlines the selection and placement of infrared sensors, as well as the reasoning behind these choices. Key considerations such as field of view, detection range, ambient light conditions, and integration with the AI recognition system are discussed to demonstrate how the optical components contribute to the system's overall effectiveness and reliability.

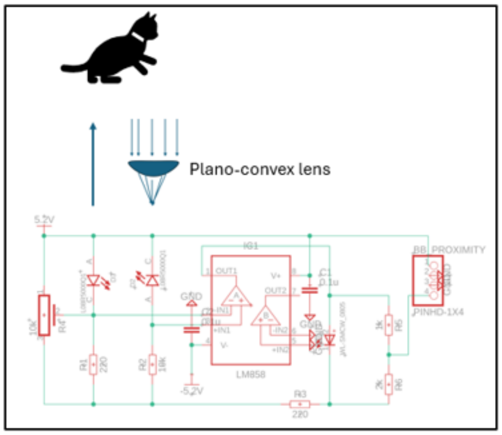

Fig. 6. Overall Schematic of Proximity Sensor Design

A. Proximity Sensor

The proximity sensor serves as the initial trigger in the detection process. Positioned near the entrance of the litter box, the sensor monitors for movement within a specific range and FOV, initiating the system's response once an object enters the detection zone. We selected an infrared-based proximity sensor for its reliability, cost-effectiveness, and ability to operate accurately in various lighting conditions. The sensor is configured with a FOV wide enough to cover the approach area and a detection range of approximately 10 inches, ensuring early and consistent recognition of an approaching pet. Once triggered, the system activates the IR camera and AI module to perform pet classification, distinguishing between a cat and a dog. This structured flow—starting with proximity detection and followed by visual classification—ensures that the system remains efficient, responsive, and accurate in controlling access to the litter box.

1) Lens Design: A lens is placed in front of the photodetector to improve the performance of the proximity sensor by collecting and focusing incoming infrared light onto the sensor's active area. This increases the intensity of the received signal, allowing for more accurate and consistent detection of objects within the target range. The choice of lens was made based on equation (1) such that we get our desired FOV, but keep the lens small so it can be seamlessly incorporated into our 3D printed housing for the optical PCB.

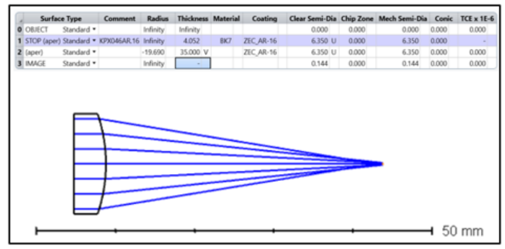

Fig. 7. Lens Design for Proximity Sensor on Zemax

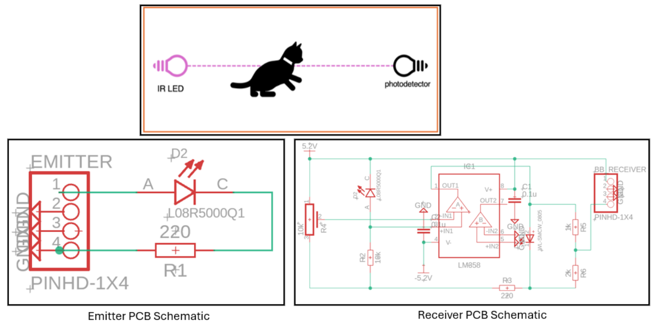

Fig. 8. Overall Schematic of Break-beam Sensor Design

$$EFL = \frac{D}{2\tan\left(\frac{FOV}{2}\right)} \tag{1}$$

B. Break-Beam Sensor

The break-beam sensor serves as a safety feature for PAWS, ensuring that the cat remains protected while entering the enclosure. Installed just at the entrance of the litter box, this sensor consists of an infrared emitter and receiver positioned across from each other to form an invisible beam. When the beam is broken—indicating that the cat has started to enter the litter box—the system registers the presence of the animal and keeps the door open. This prevents the motorized door from closing prematurely, eliminating the risk of injury or stress to the cat. We selected the break-beam sensor for its simplicity, low latency, and high reliability in detecting physical obstruction. Its placement on the threshold ensures that the door remains open until the cat has safely entered or left, making it a vital component in maintaining safe and pet-friendly operation.

V. Electrical Design

Here is an in-depth discussion on the electrical design of PAWS. The system relies on a series of

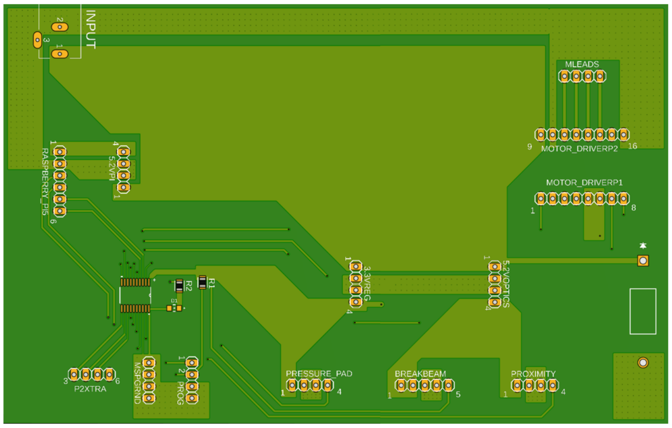

Fig. 9. Main PCB

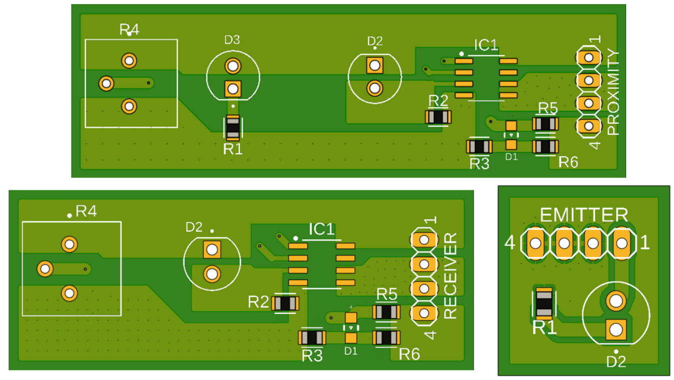

Fig. 10. Optics PCBs: Proximity PCB (top), Bream Beam Receiver PCB (bottom left), Bream Beam Emitter PCB (bottom right)

custom-designed PCBs to manage the various electrical subsystems, ensuring operation of the motorized cat door, sensors, and the animal identification system. The electrical design of the P.A.W.S. system consists of seven PCBs, each fulfilling a distinct role. The Main PCB acts as the core processing and control unit, handling communication between the Raspberry Pi, motor drivers, and sensors. The optics PCBs ensure accurate proximity and break-beam detection, while the voltage regulator boards provide stable power delivery. This modular and organized electrical architecture ensures reliable and efficient operation of the PAWS system, with easy debugging and future scalability in mind. The following sections describe the electrical subsystems and the integration of each PCB.

A. Main PCB

The first system of the electrical design is the Main PCB which serves as the central hub to connect and control the various electrical systems. It integrates the processing unit (such as the Raspberry Pi and MSP430), handles communication with motor drivers, and interfaces with the sensors responsible for detecting the cat and ensuring safe door operation. Each PCB is connected using pin headers for power and signal connections. In addition, jumper pins to isolate sections during testing or maintenance with any of the subsystems.

1) Microcontroller and Processing: The first subsystem is the MSP430 as the main processing unit which is mounted directly on the Main PCB. This system will handle the core logic for cat verification and door control. There will be a status indicator that the data is updating using a power LED for monitoring during testing. It receives data from the facial recognition system and proximity sensors, processes the information, and determines whether the door should open or remain closed. This part of the Main PCB includes: GPIO pins to connect to the Raspberry Pi enabling communication with the sensor and motor control circuits, motor control interface, and signal routing traces.

2) Optics PCBs: This system will use three different PCBs to handle optical sensor operations. The Proximity, Break-beam Emitter and Receiver PCBs will each have their own headers connected to the Main PCB for their power supply and communication to the MSP430.

3) Voltage Regulator PCBs: To power the PAWS system efficiently, we use one 3.3V and two separate 5V voltage regulator PCBs. These boards reduce the main power supply voltage from 12V to provide power to the necessary components separately. Here, there will be input and output filter capacitors to reduce noise and stabilize the output voltage. Also, thermal management components such as copper pours or heat sinks to dissipate heat during high current draws, for example, the 5V 5A Voltage Regulator. There will be pin connectors for easy integration with the Main PCB.

4) Motor Control and Door Actuation: The PAWS system utilizes stepper motors to control the motorized plexiglass doors. The Main PCB provides signals to the stepper motor drivers, which drive the necessary current and voltage to actuate the motors. Key features include motor driver connectors on the Main PCB for easy plug-and-play operation and motor-

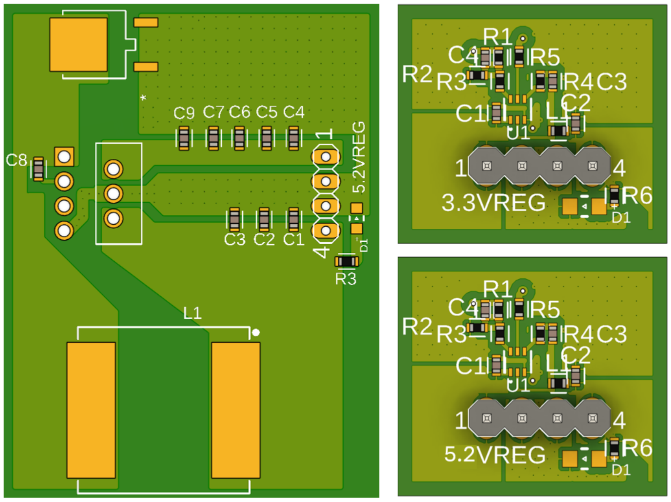

Fig. 11. Voltage Regulator PCBs: 5.2V 5A (left), 3.3V 1A (top right), 5.2V 1A (bottom right)

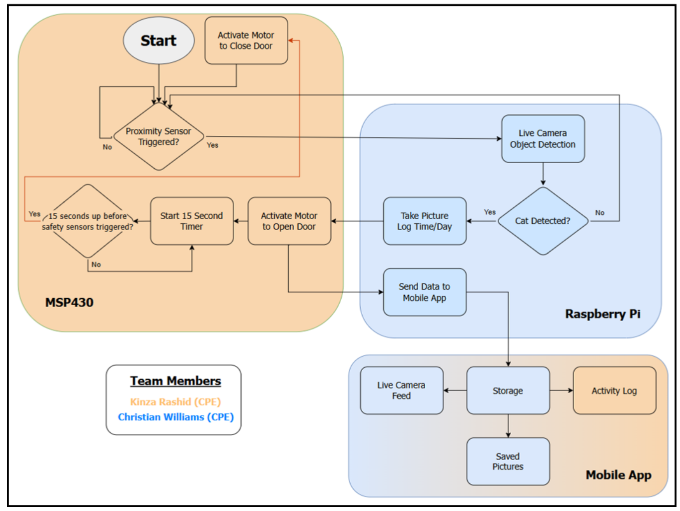

Fig. 12. Software Block Diagram for PAWS

specific power traces routed separately for accurate connection.

VI. Software Design

This section provides an overview of the software design and implementation of our system. The software that makes up the project can be divided into two subsystems: the embedded software and the application software.

The embedded software is responsible for controlling and collecting data from all peripherals of PAWS like the sensors and motor. Embedded programming languages like C/C++ are used to program the TI MSP430 chip and the Raspberry Pi. The two computers send messages back and forth to each other to start important PAWS actions.

The application software allows the user to interact with PAWS. It's a cross-platform mobile app that tracks pets' litter-box visits.

A. Embedded

The embedded software is divided across two major components, the MSP430G2553 and the Raspberry Pi 5. In this section we'll further explore the embedded software design of each.

1) MSP430G2553: The MSP430 chip is a G2553 model coded in Code Composer Studio using embedded C programming language. The software is comprised of ADC conversions for both optical sensors and the pressure pad, motor control via the DRV8825 motor driver pins, a 10-second timer

Input	Transition	Output
S0 (Door Closed)	A: Proximity sensor triggered and cat identified	S1
S1 (Door Opening)	B: OPEN_DOOR microswitch pressed	S2
S2 (Door Opened)	C: 10-second timer up	S3
S3 (Door Closing)	D: CLOSE_DOOR microswitch pressed	S0
	E: Break beam or pressure pad triggered	S1

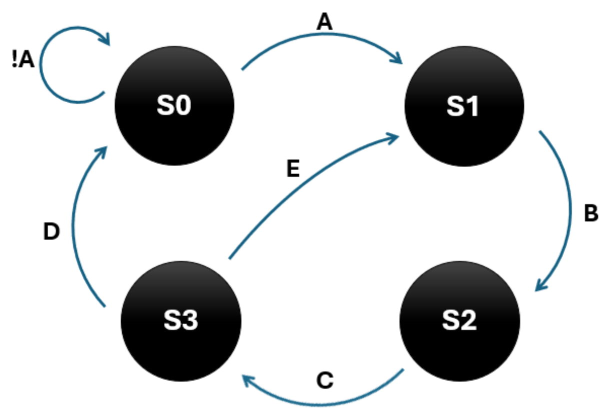

Fig. 13. State Transition Table and Moore Machine State Diagram of MSP430 Software

to aid in the door-closing sequence, microswitch coding for signaling the full close and open door states, and the UART. The software categorizes different parts of PAWS functionalities into different states dependent on the cat door (refer to Figure 13).

The chip receives data from both optical sensors and the pressure pad via 3 distinct ADC pins. All ADC math and conversions occur in the software as no ADC module interfaces between the sensors and the chip. The chip also interfaces with a DRV8825 motor driver via various other GPIO pins to control the stepper motor that actuates the linear rail. This is also handled within the software to control the closing and opening of the door. Additionally, the chip communicates with the Raspberry Pi via the transmitting and receiving pins and two other GPIO pins for handshaking to establish a UART embedded communication protocol. The chip is configured via software and handles transmission rate calculations to create a baud rate of 9400 out of a 2MHz internal clock signal.

2) Raspberry Pi 5: The Raspberry Pi 5 is a single-board computer coded in the pre-packaged Thonny editor that uses the Python programming language. The software utilizes the YOLO11 model for object detection and classification. This model is trained on the COCO image dataset, allowing for accurate object predictions.

The connected Raspberry Pi Camera Module 3 takes constant video surveillance of the area in front of the PAWS enclosure. Each frame is passed through the YOLO network at a resolution of 160x160 pixels. A class ID filter is applied to all prediction attempts to ensure that the only objects returned by the model are from the cat or dog classes. Through testing, the medium YOLO11 weight file was chosen as a middle ground between fast real-time detection and accurate classification. Testing cats in a variety of lighting and setting scenarios (see Figure 14) resulted in an average cat identification rate of 86.8 percent, with each frame prediction response taking an average of 100.61ms to complete.

As mentioned in the MSP430G2553 section, the Raspberry Pi 5 communicates with the MSP430 chip through the transmitting and receiving pins, as well as with two other GPIO pins for a hand-shaking protocol. Whenever an animal, cat or dog, is detected and classified by the Pi, it will send a short signal to the MSP430. The chip does not need to send any information back to the Pi, as any enclosure states and actions are handled in the MSP430 itself. The Raspberry Pi also supports Wi-Fi, allowing direct communication between the Pi and Firebase. This includes sending image frames to Firebase Storage and an text-based activity log to Firebase Firestore, both of which are used for key mobile application functions.

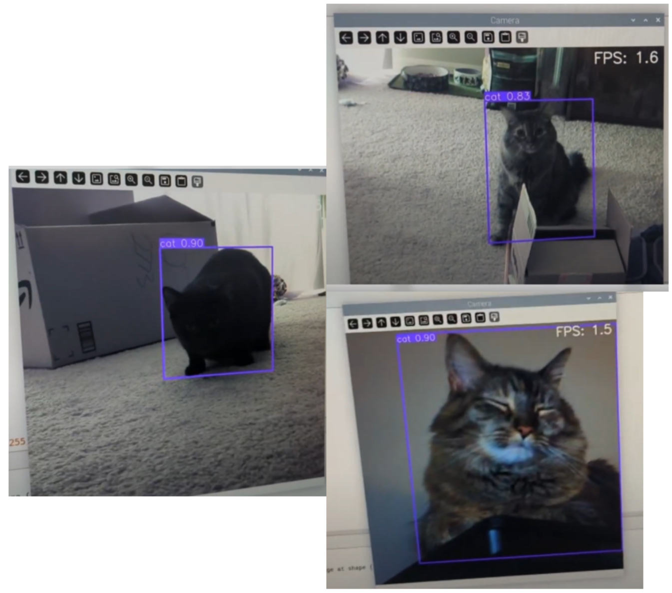

Fig. 14. YOLO11 Model for Animal

B. Application

The application software is the cross-platform compatible mobile app component of PAWS.

1) Flutter: The mobile application's front-end UI is built with the Flutter framework, which uses the Dart programming language. Flutter has cross-platform support, allowing the application to be deployed on both the Android and iOS platforms with a single codebase. The framework also includes hot reloading and color swatch theming for easier and faster development.

2) Firebase: The mobile application's back-end services are handled with a variety of Firebase services. Firebase Authentication is a highly customizable method of handling user credentials authentication, allowing control over specific parameters such as password requirements, email verification, sign-ups, and logins. Firebase Storage is the database that stores image frames sent from the Raspberry Pi. These images are then displayed in the application's Gallery page. In the application's Activity Log page, Firebase Firestore is used as the database for storing raw text files. These include timestamps of animal detection, enclosure access granted/denied notifications, and image favorites status.

VII. Conclusion

In conclusion, the PAWS AI-Assisted Litter Box System provides an effective solution to a persistent challenge in multi-pet households by preventing canine access to feline waste facilities. Through the integration of optical sensors, machine learning algorithms, and custom circuitry, the system successfully differentiates between cats and dogs, ensuring species-specific access control. This work addresses fundamental limitations of conventional mechanical barriers by implementing an infrared camera and a network of sensors for real-time detection, identification, and pet safety. The trained AI model significantly improves system reliability by reducing false positives and maintaining consistent performance across different lighting conditions. Our development methodology prioritized system efficiency, operational reliability, and implementation feasibility. The resultant architecture demonstrates that complex pet management challenges can be addressed through thoughtful hardware-software integration, yielding a solution compatible with existing pet care practices. The interdisciplinary nature of this project—combining elements from Optical Engineering, Machine Learning, and Embedded Systems—illustrates the potential for cross-domain collaboration in solving everyday problems. As future work, we plan to explore miniaturization of the sensing apparatus, a better solution for detecting the close/open status of the cat door, and potential advancement of the mobile application beyond litter box access control. The PAWS system not only contributes to improved quality of life in multi-pet households but also serves as a framework for future innovations in smart home pet management technologies.

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