INTI International University

FINAL YEAR PROJECT REPORT

PROJECT TITLE:
SMART CAT LITTER BOX IN MONITORING FAECES FOR EARLY HEALTH DETECTION USING MACHINE LEARNING ALGORITHM

"A dissertation submitted in partial fulfillment of the requirement of an Honours Degree in Computer Science at INTI International University under the management and supervision of Faculty of Information Technology."

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by

Student Name	:	Chin Wei Zhen
Student ID	:	I22021653
IC No / Passport No	:	010101-10-1396
Project ID	:	FDSIT-INTI-IU-BCSI-JUN-2024-0003

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I also extend my heartfelt thanks to INTI International University for providing the necessary resources and knowledge that have been crucial for this project.

A special thank you to Dr. Joanne, a veterinarian, who graciously allowed me to interview her and provided essential domain knowledge in pet health. Her assistance in categorizing stool images was particularly helpful.

I am also grateful to Zi Wei and Wei Min for allowing me to observe their cats' activities with the litter box. This observation provided me with valuable insights into the existing problems and helped ensure that the project is well-suited to real-world scenarios.

Finally, I would like to thank my family members and friends for their support throughout this journey. Their encouragement and belief in me have been a constant source of motivation.

About the Author

The author, Chin Wei Zhen is a Software Engineer from Malaysia. Currently pursuing a Bachelor of Computer Science with a major in Software Engineering at INTI International University.

During the time at INTI International University, the author gains knowledge and hands-on experience in various programming languages, including Python, Java, C++, ASP.NET, and SQL. The academic journey has equipped her with the skills necessary to tackle complex software engineering challenges and develop innovative solutions.

Project Proposal

Title: Smart Cat Litter Box In Monitoring Faeces For Early Health Detection Using Machine Learning Algorithm

Abstract:

Cats are not always forthcoming when unwell, and often, by the time symptoms manifest, they may be in advanced stages of illness, treatment cost can be higher at this stage. Hence, early detection is crucial, and one method is through the analysis of cats' faeces. However, smart litter boxes currently available on the market lack features that directly observe cat faeces. The challenge arises when manual observation is and has poses a drawback against the use of smart litter boxes that primarily provide self-cleaning features. Furthermore, there is a lack of research utilizing machine learning techniques to observe pet faeces.

This project introduces a Cat Faeces Monitoring System employing machine learning. A motion camera in the litter box captures cat activities, and the images are processed using a trained model to analyse faeces shape and colour. A user-friendly mobile app is included to offer visualizations of cat's waste analysis.

This system primarily targets cat owners including owners with multiple cats, addressing challenges in monitoring cat faeces. The system provides a solution to enhance remote health monitoring without constant manual inspection. This also beneficial for cat cafe owners managing numerous cats. The system aims to provide early health insights, alerting owners to potential issues and enhancing overall feline well-being.

Project Description:

There are two methods for analysing faeces: one involves the subjective observation of stool characteristics such as shape, consistency, and colour, while the other utilizes microscopic detection and chemical analysis for objective assessment. However, it is challenging to perform microscopic and chemical testing as part of routine daily life, as highlighted in reference. (Zhang et al., 2022). Thus, subjective observation is important and has become the primary approach to identifying early health problems.

Various diseases of cat can be identified through subjective observation of stool analysis, including dietary changes, food intolerance or allergies, ingestion of inappropriate substances, parasites, bacterial or viral infections, inflammatory bowel disease (IBD), pancreatitis, medications, and stress or anxiety. Study mention that Feline Coronavirus (FCov) infection, a disease common in crowed environments such as catteries, shelters, and homes with multiple cats, is associated with diarrhoea (Felten et al., 2022). Other than shapeless, mushy, or watery stool that indicate diarrhoea, other health problem such as sign of parasite for stool with white flecks, black coloured stool that relate to blood from stomach, and red coloured stool that indicate of internal bleeding. These are considered abnormal stools, which needed a veterinary diagnosis to identify the underlying disease.

Upon seeking veterinary assistance when cat is unhealthy, additional information such as stool shape, colour, and smell may be necessary for accurate diagnosis. Some veterinarians may request picture of the cat's faeces or inquire about recent behaviour and excretion activity, a challenging task that most cat owners have jobs and are unable to watch at their pets every minute, making observation difficult. Moreover, for multi-cats' household, it is challenging to identify the cat that is experiencing diarrhoea or abnormal faeces. This is where the smart cat litter box becomes a valuable tool to assist owners in record and providing the necessary information to veterinarians.

Literature Review

Various studies on "Smart Litter Boxes" have primarily concentrated on features such as defecation detection, self-cleaning mechanisms, and alerts related to sand level using Internet of Things (IoT). There are vary IoT components used for different reason and solution. One study that focus is on self-cleaning, and alerts related to cat litter depletion using pressure sensors to detect cat movement for automatic self-cleaning, while ultrasonic sensors monitor the cat litter level and trigger auto-refilling (Wang, 2021). Another proposed Smart Pet Litter Box that also specializes in excrement removal, utilizing a Passive Infrared motion sensor (PIR) to detect pet presence in litter box transmitting data to an Arduino PIC micro-controller for processing, determine if is needed and is able to perform cleaning. (Binti sazali, binti vera nu @ Veera nu and binti Moktar, n.d.)

For research that focus on health of pets, a study has emphasized analyte detection through biosensors for urinalysis. This involves using a sodium activation solution to identify sodium levels and employing enzyme and cross-linker solutions to detect glucose levels in feline urine testing. The collected data is stored in big data, and owners and veterinarians receive alerts through a web app in case of abnormal salt levels (Sun and Vega, 2023). Another approach integrates intelligent computing technology, including face recognition through a convolutional neural network (CNN) that support multi-cat and health status assessment via big data

analysis. The health data that collect from the litter box include temperature and weight, through the incorporate thermometer and weight sensor. Additionally, the record includes the cat's daily activities, weight changes, and health status, which is then transmitted to the mobile app for the cat owner's reference. The mobile app provides historical statistical information and trends, allowing cat owners to monitor their cat's health and well-being. (Cai and Li, 2021)

It is a trend to used machine learning to identify images and forecast health issue in medical sector, including research that focus on analysing and classifying stool to identify human health, which combine with Internet of Things (IoT) to monitor the frequency, volume and duration of excretion and urinary. As outlined in reference, one approach involves the analysis of human stool shape and form using the Bristol Stool Form Scale (BSFS), which categorizes stool into constipation, normal, and diarrhoea. The study utilized a deep Convolutional Neural Network (CNN) trained on clinically scored image by healthcare professionals. This technology specifically emphasizes the measurement of both the form and frequency of stool (Wang and Camilleri, 2020).

Another study introduces an end-to-end convolutional neural (CNN) framework named StoolNet based on ResNet18, which enable two output branches for colour and shape recognition in stool analysis. Additionally, it incorporates a dual attention mechanism to enhance feature extraction during the analysis. The result show that this end-to-end framework based on ResNet18 have better category discrimination capability on real datasets. (Zhang et al., 2022).

For observation on feline faeces, a study mentions a grading system Cats Protection Faecal Scoring System, it categorized cat stool based on its consistency, ranging from 1 (watery) to 6 (hard, dry). This faecal consistency scoring system evaluating the health conditions of cat such as diarrhoea and constipation. Diarrhoea is characterized by a faecal score of 3 or less, with severe diarrhoea indicated by a faecal score of 2 or less. On the other hand, constipation is associated with a faecal score of 6 (German, Cunliffe and Morgan, 2016).

Problem Statement

Veterinarians may request pictures of problematic faeces for further diagnosis, but manual inspection is sometimes challenging since observations need to be made immediately when the cat is using the litter box, and most owners are unable to monitor their cats throughout the day due to work commitments. Additionally, cats may cover their faeces after using the litter box due to their natural behaviour, making inspection difficult.

There are many smart cat litter boxes in the market that focus on detect of defecation, self-cleaning, alert on litter volume. Some smart litter box that adds AI features to weight cat and cat stool or urine, the time cat takes, number of times a

day defecation to analyse if the cat needs more water or food, or if they are healthy. Analyse whether the cat is suffering from chronic kidney disease, urinary tract stones, cystitis, etc. through urine and weight data by using big data. However, there is a lack of features that directly observe faeces using machine learning techniques. While there is much research focusing on human faeces, implemented in smart toilets to monitor human excretion conditions based on colour and shape, there is a lack in research utilizing machine learning techniques to analyse the health of cats based on their faeces.

The most common of classification of stool in cat is based on consistency and form, to determine if cat is having diarrhoea. Besides, the observation of stool include colour to help in indication of other health problem. However, there is a lack in classify stool colour in recent study. This is crucial, as observing cat faeces colour providing other valuable information on abnormalities, such as the presence of worms or bloody faeces, which may indicate more serious health problems.

The current practice of requiring owners to manually open waste boxes for inspection after cleaning introduces a counterproductive element to the purpose of smart litter boxes designed with self-cleaning capabilities, which aim to keep owners from direct contact with pet faeces. This manual inspection process poses a potential health risk to both humans and animals, particularly in the context of zoonotic diseases—disease that can be transmitted between animals and humans (Overgaauw et al., 2020b), opposes the principles of both One Health and SDG Goal 3, which seeks to ensure healthy lives and promote well-being for all at all ages.

Project Objectives

1. Smart Cat Litter Box

One key objective is to develop a smart litter box that integrates a range of sensors to capture comprehensive health data for cats. This innovative system will include a camera for image capture of both the cat and its faeces, a weight sensor to accurately record the cat's weight, a thermometer to monitor the cat's temperature, and an infrared sensor to detect the cat's presence within the litter box.

2. Developing a Pet Health Monitoring System with ML-powered Cat Recognition and Faeces Analysis

The aim of this project is to create a machine learning model capable of recognizing cat and understanding activities of cat, either excreting or urinating. Additionally, the system will feature the ability to capture and analyse faecal

samples. The captured objects will be examined, and their characteristics such as shape, colour, length, and overall condition will be classified.

3. A Mobile App for Pet Wellness Tracking

As an integral part of pet health monitoring system, a user-friendly mobile app will be developed. This app is designed to visualize the data collected from the pet's waste analysis, providing owners with insights into their pet's excrete and urinary status. The visualizations will include detailed information about faeces shape, colour, and the time taken for elimination. Furthermore, the application will notify the owner in the event of any irregularities in the cat's waste status.

Project Scope

Initially, the system's camera detects movement as a cat enters the litter box, initiating video recording until the cat leaves. The recorded videos undergo pre-processing such as extract image cat, faeces, then perform analysis to identify cat activities, distinguishing between excretion and urinary events. Additionally, the system employs face recognition for cat identification and determines the health status of faeces based on shape, colour, and form. The collected data is stored in a database accessible to owners via a mobile app. If unhealthy faeces are detected, the system sends alerts through the mobile app.

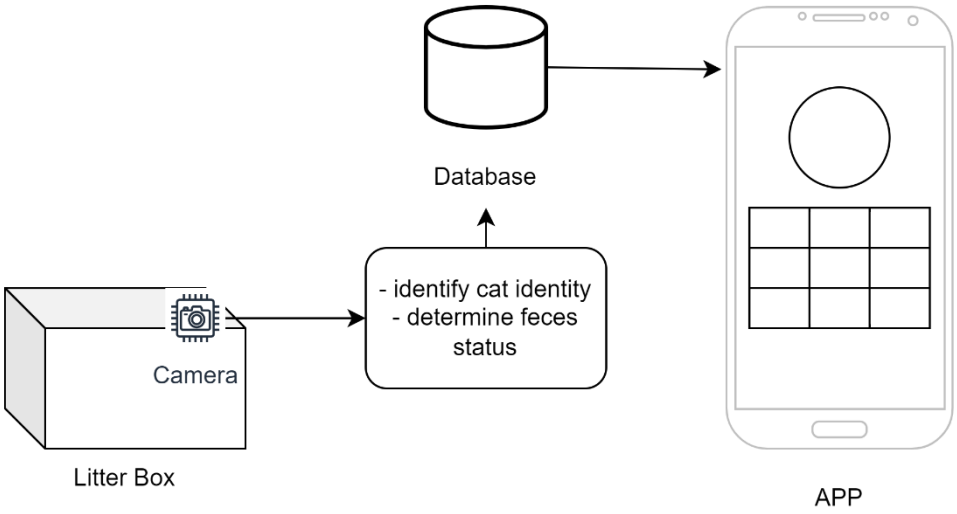

Diagram 1. Abstract Of Faeces Monitoring System

The project encompasses five main components: hardware, face recognition, cat faeces analysis model, mobile application, and database integration.

The hardware aspect involves installing a motion camera in a standard litter box, capturing images and recording cat activities for subsequent storage and analysis.

To accommodate multiple cats sharing a litter box, the system incorporates a face recognition feature, distinguishing which cat has utilized the litter box. The primary feature involves training a faeces analysis model using labelled faeces images. During analysis, data such as shape and colour is categorized, yielding a healthy or unhealthy classification. The results, along with extracted data, are stored in a database, including associated images.

The mobile application serves as the user interface, enabling owners to visualize results for each cat in the household. Owners receive notifications when abnormal faeces are detected, pinpointing the cat with potential health issues. The mobile app facilitates access to original faeces images, allowing owners to share them with veterinarians for further diagnosis.

The tools and languages that will be use in this system including:

- Python and associated library for model development.
- Java Programming Language using Android Studio IDE to create mobile application.
- Draw IO in drawing diagrams such as Unified Modelling Language (UML) diagrams for design of system flow, Entity Relationship Diagram (ERD) for database design and the design of mobile interface.
- Monday.com to track progress and task of the project.
- Google Drive in saving a duplicated project for backup.

Hardware resource that will needed to contain in developing the system:

- IoT devices: motion sensor, camera with wireless connection.
- Graphic Processing Unit (GPU) for mode training.

Project Limitation

While the proposed project aims to offer insights into feline health through a smart cat litter box and mobile application, there are several limitations:

(1) Exclusion of Urine Analysis

The system focuses exclusively on the analysis of cat faeces and does not extend its capabilities to determine urine characteristics. This limitation arises from the absorption of urine by cat sand, presenting challenges in analysis.

(2) Language Support Restriction

The mobile application will only be configured to support only the English language. While efforts have been made to ensure a user-friendly experience in English, additional language support is not included in the current scope.

(3) Camera Blockage Issue

The mobile application may encounter limitations in capturing images if a feline obstructs the camera. This potential obstruction could affect the system's ability to utilize visual data for analysis.

Research Methodology

The proposed cat faeces monitoring system encompasses a dual-component framework comprising a model and a mobile application. The primary objective of the model is to recognise identity of incoming cat and predict the health status of cat faeces, classifying them as either healthy or unhealthy based on identified features. Concurrently, the mobile application serves as a user interface, providing visualization of the faeces evaluation results and issuing alerts in instances of abnormal stool characteristics.

1. Requirement Analysis

Fact finding techniques including interview and questionnaire will be utilised to gather information. For interview, two veterinaries will be interviewed to have more understanding on the domain of cat faeces, the consistency and colour in related disease, and on how to determine healthy and abnormal cat faeces. For questionnaire, feedback from 50 pet owners especially cat owner about the thought on the proposed system and problem of manual observations of pet stool will be gathered. Besides, secondary research will be performed to have more understanding in machine learning algorithms. These gathered data are then derived into requirement specification of the system.

2. Cat Faeces Monitoring System: Model Development

Phase 1: Dataset Acquisition

The requisite dataset comprises images of cat faeces sourced from open databases such as GitHub, Kaggle, etc. Additionally, primary data will be collected from a household with nine cats ensures a comprehensive dataset containing both healthy and unhealthy stool images. The size of the dataset is primarily set to 500, including image of health stool and abnormal stool.

Phase 2: Data Pre-processing

This stage involves image processing operations such as de-drying, smoothing, and transforming from the stool samples. Key features encompass colour, shape, consistency, texture, and length will be extract and select to perform pattern recognition (Deshmukh, 2023). Subsequently, the dataset will be labelled, designating each stool sample as either healthy or unhealthy. To ensure accuracy, expert consultation from two veterinary professionals will be sought.

Phase 3: Model Training and Testing

Convolutional Neural Network is employed for categorization and classification. The model undergoes training using the dataset, facilitating the acquisition of patterns and relationships between features and the classification of stool as either healthy or unhealthy. The prepared dataset will divide into two, 60 percent for training and 40 percent for testing.

3. Mobile Application Development

Phase 1: Design and Build

The initial of mobile application development is design the app's user flow and interface, alongside the creation of a database structure. The build of mobile application integrating features that allow for the seamless viewing of data collected from the smart cat litter box. This phase lays the foundation for a well-structured and visually appealing application.

Phase 2: Integrate Testing and system testing

Following the design and build phase, the developed mobile application is integrated with the trained model. Integration testing is conducted to evaluate the smooth functioning of the entire system, emphasizing the interaction between the mobile app and the cat litter box. System testing ensures that all components collaborate seamlessly, verifying the accuracy and reliability of data flow and communication between the application and the integrated model.

4. User Acceptance Testing

To proof the practicality and effectiveness of the developed Cat Faeces Monitoring System, user acceptance testing is carried out. This involves the implementation of the system in two households, allowing for a real-world evaluation of the system's performance. The period of user acceptance testing will be one week, users interact with the application by installing the camera in their litter box, providing valuable feedback on usability, functionality, and overall user experience. This testing will be iterative for refining the application, ensuring that it aligns with user expectations and effectively addresses their needs.

Target Audience:

The primary audience for this system is for individuals who are cat owners, with a particular focus on those managing multiple feline companions. The challenges faced by cat owners in monitoring their cats' faeces, especially when leading busy lives or when the faeces are concealed by litter sand. Especially for owners with multiple cats sharing a litter box, as it becomes challenging to attribute specific faeces to individual cats. By implementing this system, cat owners gain the advantage of remotely checking on their cats' health status without the need for constant manual inspection. It enhances the overall experience for cat owners, particularly those in multi-cat households, by providing a more accessible and efficient means of monitoring their feline companions' litter box activities.

Additionally, cat cafe owners who manage establishments with numerous cats can benefit from this research. The research focuses on developing a system that allows owners to monitor and track essential information such as the number of cats, their activities, and the time they use the litter box each day. Simultaneously, the development of the smart litter box seeks to uphold a health-conscious environment suitable for households with multiple cats while also catering to customers visiting cat cafes and engaging in cat interactions.

This information can be valuable for cat owners and cat cafe managers in maintaining the well-being and health of the cats, as well as improving the overall management of the feline environment. This can also maintain the well-being and the health of human in preventing the risk of zoonotic through early health insight and less close contact to pet faeces, contribute to One Health Approach and indirectly contribute to Goal 3: Good Health and Well-being in Sustainable Development Goal (SDG). Furthermore, healthy pets can impact the mental and emotional health of their owners, which also align with Goal 3 in improving the happiness of owner.

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CHAPTER 1: INTRODUCTION

1.0 Overview

This project introduces a Cat Faeces Monitoring System employing machine learning. A motion camera in the litter box captures cat activities, and the images are processed using a trained model to analyse faeces shape and colour. A user-friendly mobile app is included enables real-time monitoring of cat faeces colour, shape, and consistency, providing valuable insights into potential health issues. The project addresses the challenges faced by cat owners in manually inspecting faeces, especially in multi-cat households, by offering a user-friendly mobile application interface for data visualization and notifications. Through a comprehensive methodology encompassing requirement analysis, dataset acquisition, model development, and mobile application integration, the system aims to enhance the well-being of both cats and their owners by promoting early detection of health issues and preventing zoonotic diseases. With its focus on leveraging technology to improve pet health and well-being, the Cat Faeces Monitoring System aligns with the principles of the One Health Approach and contributes to Goal 3: Good Health and Well-being of the Sustainable Development Goals (SDGs).

1.1 Problem Statements

Veterinarians may request pictures of problematic faeces for further diagnosis, but manual inspection is sometimes challenging since observations need to be made immediately when the cat is using the litter box, and most owners are unable to monitor their cats throughout the day due to work commitments. Additionally, cats may cover their faeces after using the litter box due to their natural behaviour, making inspection difficult.

There are many smart cat litter boxes in the market that focus on detect of defecation, self-cleaning, alert on litter volume. Some smart litter box that adds AI features to weight cat and cat stool or urine, the time cat takes, number of times a day defecation to analyse if the cat needs more water or food, or if they are healthy. Analyse whether the cat is suffering from chronic kidney disease, urinary tract stones, cystitis, etc. through urine and weight data by using big data.

However, there is a lack of features that directly observe faeces using machine learning techniques. While there is much research focusing on human faeces, implemented in smart toilets to monitor human excretion conditions based on colour and shape, there is a lack in research utilizing machine learning techniques to analyse the health of cats based on their faeces.

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The current practice of requiring owners to manually open waste boxes for inspection after cleaning introduces a counterproductive element to the purpose of smart litter boxes designed with self-cleaning capabilities, which aim to keep owners from direct contact with pet faeces. This manual inspection process poses a potential health risk to both humans and animals, particularly in the context of zoonotic diseases—disease that can be transmitted between animals and humans (Overgaauw et al., 2020b), opposes the principles of both One Health and SDG Goal 3, which to make sure healthy lives and promote well-being for all.

1.2 Project Objectives

1.2.1 Smart Cat Litter Box

One key objective is to develop a smart litter box that integrates a range of sensors to capture comprehensive health data for cats. This innovative system will include a camera for image capture of both the cat and its faeces, a weight sensor to accurately record the cat's weight, a thermometer to monitor the cat's temperature, and an infrared sensor to detect the cat's presence within the litter box.

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The aim of this project is to create a machine learning model capable of recognizing cat and understanding activities of cat, either excreting or urinating. Additionally, the system will feature the ability to capture and analyse faecal samples. The captured objects will be examined, and their characteristics such as shape, colour, length, and overall condition will be classified.

1.2.3 A Mobile App for Pet Wellness Tracking

As an integral part of pet health monitoring system, a user-friendly mobile app will be developed. This app is designed to visualize the data collected from the pet's waste analysis, providing owners with insights into their pet's excrete and urinary status. The visualizations will include detailed information about faeces shape, colour, and the time taken for elimination. Furthermore, the application will notify the owner in the event of any irregularities in the cat's waste status.

1.3 Project Scope

Initially, the system's camera detects movement as a cat enters the litter box, initiating video recording until the cat leaves. The recorded videos undergo pre-processing such as extract image cat, faeces, then perform analysis to identify cat activities, distinguishing between excretion and urinary events. Additionally, the system employs face recognition for cat identification and determines the health status of faeces based on shape, colour, and form, categorized into constipation, normal, and diarrheic. The collected data is stored in a database accessible to owners via a mobile app. If unhealthy faeces are detected, the system sends alerts through the mobile app.

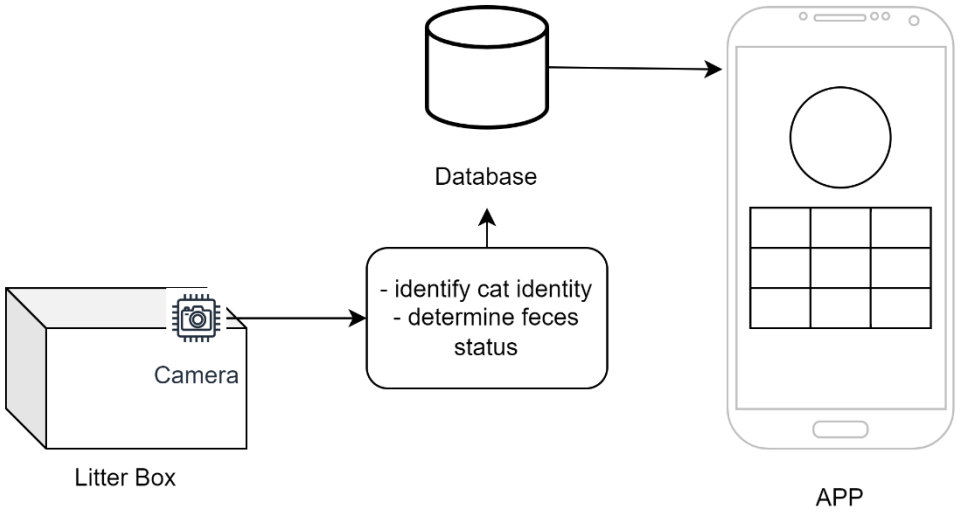

Figure 1.1 Abstract of Faeces Monitoring System

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To accommodate multiple cats sharing a litter box, the system incorporates a face recognition feature, distinguishing which cat has utilized the litter box. The primary feature involves training a faeces analysis model using labelled faeces images. During analysis, data such as shape and colour is categorized, classifying into constipation, normal or diarrheic. The results, along with extracted data, are stored in a database, including associated images.

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1.3.1 Tools and Language

The tools and languages that will be use in this system including:

- Python and associated library for model development.
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1.3.2 Hardware Resource

Hardware resource that will needed to contain in developing the system:

- IoT devices: motion sensor, camera with wireless connection.
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1.4 Methodology

The proposed cat faeces monitoring system encompasses a dual-component framework comprising a model and a mobile application. The primary objective of the model is to recognise identity of incoming cat and predict the health status of cat faeces, classifying them as either healthy or unhealthy based on identified features. Concurrently, the mobile application serves as a user interface, providing visualization of the faeces evaluation results and issuing alerts in instances of abnormal stool characteristics.

1.4.1 Requirement Analysis

Fact finding techniques including interview and questionnaire will be utilised to gather information. For interview, two veterinaries will be interviewed to have more understanding on the domain of cat faeces, the consistency and colour in related disease, and on how to determine healthy and abnormal cat faeces. For questionnaire, feedback from 50 pet owners especially cat owner about the thought on the proposed system and problem of manual observations of pet stool will be gathered. Besides, secondary research will be performed to have more

understanding in machine learning algorithms. These gathered data are then derived into requirement specification of the system.

1.4.2 Cat Faeces Monitoring System: Model Development

1.4.2.1 Phase 1: Dataset Acquisition

The requisite dataset comprises images of cat faeces sourced from open databases such as GitHub, Kaggle, etc. Additionally, primary data will be collected from a household with nine cats ensures a comprehensive dataset containing both healthy and unhealthy stool images. The size of the dataset is primarily set to 500, including image of health stool and abnormal stool.

1.4.2.2 Phase 2: Data Pre-processing

This stage involves image processing operations such as de-drying, smoothing, and transforming from the stool samples. Key features encompass colour, shape, consistency, texture, and length will be extract and select to perform pattern recognition (Deshmukh, 2023). Subsequently, the dataset will be labelled, designating each stool sample as either constipation, normal, or diahrrea. To ensure accuracy, expert consultation from two veterinary professionals will be sought.

1.4.2.3 Phase 4: Fine-tuning

Convolutional Neural Network is employed for categorization and classification. The model undergoes training using the dataset, facilitating the acquisition of patterns and relationships between features and the classification of stool as either healthy or unhealthy. The prepared dataset will divide into two,75 percent for training and 25 percent for testing.

1.4.3 Mobile Application Development

1.4.3.1 Phase 1: Design and Build

The initial of mobile application development is design the app's user flow and interface, alongside the creation of a database structure. The build of mobile application integrating features that allow for the seamless viewing of data collected from the smart cat litter box. This phase lays the foundation for a well-structured and visually appealing application.

1.4.3.2 Phase 2: Integrate Testing and system testing

Following the design and build phase, the developed mobile application is integrated with the trained model. Integration testing is conducted to evaluate the

smooth functioning of the entire system, emphasizing the interaction between the mobile app and the cat litter box. System testing ensures that all components collaborate seamlessly, verifying the accuracy and reliability of data flow and communication between the application and the integrated model.

1.4.4 User Acceptance Testing

To proof the practicality and effectiveness of the developed Cat Faeces Monitoring System, user acceptance testing is carried out. This involves the implementation of the system in two households, allowing for a real-world evaluation of the system's performance. The period of user acceptance testing will be one week, users interact with the application by installing the camera in their litter box, providing valuable feedback on usability, functionality, and overall user experience. This testing will be iterative for refining the application, ensuring that it aligns with user expectations and effectively addresses their needs.

1.5 Target Audience

The primary audience for this system is for individuals who are cat owners, with a particular focus on those managing multiple feline companions. The challenges faced by cat owners in monitoring their cats' faeces, especially when leading busy lives or when the faeces are concealed by litter sand. Especially for owners with multiple cats sharing a litter box, as it becomes challenging to attribute specific faeces to individual cats. By implementing this system, cat owners gain the advantage of remotely checking on their cats' health status without the need for constant manual inspection. It enhances the overall experience for cat owners, particularly those in multi-cat households, by providing a more accessible and efficient means of monitoring their feline companions' litter box activities.

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emotional health of their owners, which also align with Goal 3 in improving the happiness of owner.

1.6 Summary

The project aims to address challenges in monitoring cat health through real-time observation of their faeces. Current methods of manual inspection are impractical due to owners' busy schedules and cats' natural behaviours. Existing smart litter boxes lack comprehensive features for health analysis, particularly in utilizing machine learning for faecal examination. Key objectives include developing a smart litter box equipped with sensors and a camera, creating a machine learning model to analyse cat faeces, and designing a mobile app for pet wellness tracking. The methodology involves dataset acquisition, data pre-processing, model training, mobile app development, integration testing, and user acceptance testing. The target audience includes cat owners and cat cafe managers, aiming to improve the monitoring of cat health and well-being while reducing the risk of zoonotic diseases and promoting the One Health approach.

CHAPTER 2: LITERATURE REVIEW

2.0 Overview

An in-depth study on performed in this chapter to elaborate chapter 1. This chapter would cover the important of faecal inspection in cat and the challenged cat owner met in monitoring. In addition, some of the similar studies and technologies that have been done to address the challenge and the remains gaps and limitation in faecal analysis and health monitoring.

Furthermore, machine learning, particularly convolutional neural networks (CNNs), shows promise in faecal classification, but research in this area, especially concerning pets like cats, is limited. The classification of cat faeces includes shape and colour considerations, which are crucial for detecting health issues would also be mentioned throughout this chapter.

2.1 Faecal Analysis in Health Monitoring

There are two methods for analysing faeces: one involves the subjective observation of stool characteristics such as shape, consistency, and colour, while the other utilizes microscopic detection and chemical analysis for objective assessment. However, it is challenging to perform microscopic and chemical testing as part of routine daily life, as highlighted in reference. (Zhang et al., 2022). Thus, subjective observation is important and has become the primary approach to identifying early health problems for human and animals.

2.1.1 Important of Faecal Analysis

Various diseases of cat can be identified through subjective observation of stool analysis, including dietary changes, food intolerance or allergies, ingestion of inappropriate substances, parasites, bacterial or viral infections, inflammatory bowel disease (IBD), pancreatitis, medications, and stress or anxiety. Especially the identification of parasites that can be transmitted to humans like roundworms, hookworms, and Giardia, which can be observe from diarrhoea (“Cat Faecal Tests and Stool Samples.”, 2022). Moreover, study mention that Feline Coronavirus (FCov) infection, a disease common in crowed environments such as catteries, shelters, and homes with multiple cats, is associated with diarrhoea (Felten et al., 2022). Neglecting or ignoring to observe pet faeces may cause delayed of treatment, pet health condition can be worsened, leading to more severe health issues that may be harder to treat effectively, additionally, higher treatment cost needed. Thus, it is important to conduct subjective observation follow with disease detection with diagnose and objective analysis of faecal in lab, early treatment can be done to minimize spreading infection to other cats and owner, protect owner from zoonotic disease, and reduce the treatment cost.

2.2 Challenges in Faecal Observation for Pet Owner

Implementing routine pet care can be a challenging task for many pet owners, particularly when it comes to monitoring and managing their pet's faeces. Moreover, cats may exhibit discreet elimination habits, complicating the process of observing and assessing their faeces. Furthermore, there is a potential risk of zoonotic diseases associated with handling pet faeces, highlighting the importance of proper hygiene practices.

2.2.1 Challenges in Implementing Routine Pet Care

It is time consume to record and monitor pet faeces, a repetitive task that pet owner need to have patient and resilience to do it every day and have a sharp eye to identify unhealthy faeces. This task can be challenging due to various factors such as the consistency, colour, odour, and frequency of the cat's faeces, which is informative upon seeking veterinary assistance for accurate diagnosis. However, most cat owners have jobs and busy lifestyle, unable to watch at their pets every minute, making timely observation and health monitoring challenging (Cai and Li, 2021).

2.2.2 Challenge due to Cat Natural Behaviour

Additionally, cats may be more discreet about their elimination habits compared to other pets, which they tend to cover their own waste materials due to the potential threat of attracting predators, especially female cats that tend to take time to process their excreta to protect their offspring (Giovanne Ambrosio Ferreira, Lígia Meneguello and Genaro, 2024). Some veterinarians may request picture of the cat's faeces upon seeking veterinary, this elimination habits making it harder for owners to consistently observe and assess their faeces.

2.2.3 Risk in Zoonotic Disease

Zoonotic diseases, those that can be transmitted between animals and humans, pose a risk when owners closely inspect waste boxes and unaware in contacting cat faeces. This risk is particularly evident in cases where cats are fed raw meat, increasing the likelihood of human salmonellosis. Additionally, there is the concern of transmission of the Toxoplasma oocyst parasite through contact with cat faeces. If a woman becomes infected during pregnancy, it can pose permanent harm to the baby (Overgaauw et al., 2020).

2.3 Smart Litter Boxes: A Technology Solution

Smart litter boxes have emerged as innovative solutions for pet owners, offering features like self-cleaning mechanisms and sand level alerts. Current research highlights two main approaches in smart litter box development: integration of biosensors for urinalysis and collection of health data through intelligent computing technology.

2.3.1 Common of Smart Litter Box

Common smart litter boxes in the market and research are focused on self-cleaning mechanisms and sand level alert features. One study focuses on self-cleaning, and alerts related to cat litter depletion using pressure sensors to detect cat movement for automatic self-cleaning. Simultaneously, ultrasonic sensors monitor the cat litter level and trigger auto-refilling (Wang, 2021). Another proposed Smart Pet Litter Box also specializes in excrement removal, utilizing a Passive Infrared motion sensor (PIR) to detect pet presence in the litter box, transmitting data to an Arduino PIC micro-controller for processing, determining if cleaning is needed, and performing the task accordingly (Binti Sazali, Binti Vera Nu @ Veera Nu, And Binti Mokta, n.d.). With self-cleaning mechanisms and sand level alert features, owners can dispose of the cat's waste that packed in waste box once a week instead of scooping cat waste every day, reducing the burden on owners with busy lifestyles and allowing for a reduction in the risk of zoonotic diseases associated with contacting cat faeces. However, these types of smart cat litter boxes do not have functions to observe cat waste. Therefore, owners still need to inspect faeces manually.

2.3.2 Smart Litter Boxes for Pet Health Monitoring

2.3.2.1 Integration of Biosensors for Urinalysis

In research focusing on pet health, a study has emphasized analyte detection through biosensors for urinalysis. This involves using a sodium activation solution to identify sodium levels and employing enzyme and cross-linker solutions to detect glucose levels in feline urine testing. The collected data is stored in big data, and owners and veterinarians can receive alerts through a web app in case of abnormal salt levels (Sun and Vega, 2023). This approach provides insight that can help detect possible diseases such as kidney disease. However, this approach only analyses urine and does not cover faeces, leading to limitations in detecting other important diseases.

2.3.2.2 Health Data Collection

Another approach integrates intelligent computing technology, including face recognition through a convolutional neural network (CNN), to support multi-cat

households and assess health status via big data analysis. The health data collected from the litter box include temperature and weight, achieved through the incorporation of a thermometer and weight sensor. Additionally, the record includes the cat's daily activities, weight changes, and health status, which is then transmitted to the mobile app for the cat owner's reference. The mobile app provides historical statistical information and trends, allowing cat owners to monitor their cat's health and well-being (Cai and Li, 2021). This approach considers multi-cat households and records more data per cat, allowing for greater insight into the cat's health. However, the data recorded by the smart cat litter box, such as weight changes, temperature, and frequency of excretion, may provide limited health status information as it does not include waste analysis to determine if the cat is experiencing constipation, diarrhoea, or normal bowel movements. To assess faeces condition, owners still need to inspect faeces manually.

2.3.3 Problem of Current Smart Litter Box

Through research on smart cat litter boxes, most of them focus on self-cleaning and sand level alerting. While some smart litter boxes provide health monitoring features such as urinalysis and indirectly monitors health status through factors like weight changes, temperature, and frequency of excretion. However, one does not analyse faeces, another does not provide any observe or analysis on waste. These limitations still require owner to manually inspect waste boxes, which undermines the purpose of smart litter boxes designed with self-cleaning capabilities. These boxes should aim to keep owners from direct contact with pet faeces. However, the manual inspection introduces a counterproductive element and poses potential health risks to both humans and animals in terms of zoonotic diseases.

2.4 Machine Learning in Faeces Classification

It is a trend to used machine learning to identify images and forecast health issue in medical sector, including research that focus on analysing and classifying stool to identify human health, which combine with Internet of Things (IoT) to monitor the frequency, volume, and duration of excretion and urinary.

One kind of deep learning model that works particularly well for tasks involving the processing of images and videos is the convolutional neural network (CNN). In a variety of applications, such as single image and video super-resolution, mobile device-based image classification, and medical diagnosis, they have been utilized to produce cutting-edge outcomes.

2.4.1 Convolutional Neural Network (CNN)

CNNs have been utilized in the medical domain to create an EfficientNet-based spoofing detection system for e-health digital twins (Garg et al., 2022). Additionally, Xin et al. (2022) employed them to create a Wavelet Convolution Neural Network based on Attention Mechanism for the classification of EEGs related to epilepsy. CNNs can be used for medical diagnosis and therapy; this algorithm demonstrated state-of-the-art classification accuracy on the Bonn and Bern-Barcelona EEG databases.

Wang and Camilleri (2020) analyse human stool shape and form using the Bristol Stool Form Scale (BSFS). The study utilized a deep Convolutional Neural Network (CNN) trained on clinically scored image by healthcare professionals, which categorizes human stool into constipation, normal, and diarrhoea. This technology specifically emphasizes the measurement of both the form and frequency of stool

Another study, (Zhang et al., 2022), introduces an end-to-end convolutional neural (CNN) framework named StoolNet based on ResNet18, which enable two output branches for colour and shape recognition in stool analysis. Additionally, it incorporates a dual attention mechanism to enhance feature extraction during the analysis. The result show that this end-to-end framework based on ResNet18 have better category discrimination capability on real datasets.

By comparing these two approaches, the second approach offers more features in classifying human stool. It considers shape, form, and colour in the classification process, whereas the first approach only considers shape and form. By incorporating colour into the classification criteria, a more comprehensive insight can be provided, resulting in a more complete classification. Therefore, in the classification of cat faeces in this proposed project, in addition to shape and form constraints, colour constraints will also need to be considered to enhance disease detection in cats.

However, these recent research on faeces classification is mostly on human, where limited resource found on pets and especially cat. This shows the gap in cat faeces classification in pet health monitoring.

2.5 Faeces Classification

Human stool classification commonly employs the Bristol Stool Form Scale (BSFS), categorizing stool into seven types. Similarly, classification of cat faeces can also be categorised into 7 types. In addition to consistency, considering faeces colour is crucial for detecting health issues comprehensively. Cat faeces can be classified into seven colours, which are brown, white, red and black, orange, yellow, and green.

2.5.1 Faeces Shape Classification and Scoring System

The classification of human stool in many research studies uses the Bristol Stool Form Scale (BSFS), a common system that categorizes human stool into 7 categories. Similarly, cat faeces can also be categorized into 7 categories.

Study introduces a grading system for observing feline faeces, categorizing it based on consistency, ranging from 1 (hard, dry) to 7 (watery). This system evaluates the health conditions of cats into categories of diarrhoea, normal, and constipation. Diarrhoea, characterized by a faecal score of 3 or higher, indicates potential bacterial infections, intestinal parasites, or food intolerance. A score of 4 indicates stool that is moist and loses form when picked up but retains its log shape when passed. A score of 5 indicates stool passed in a pile rather than in logs. A score of 6 indicates liquid stool with some texture but no shape, while a score of 7 indicates liquid stool without any texture or shape (“Cat Poop: Health Insights, Cat Poop Chart, Problems, and More”, 2022).

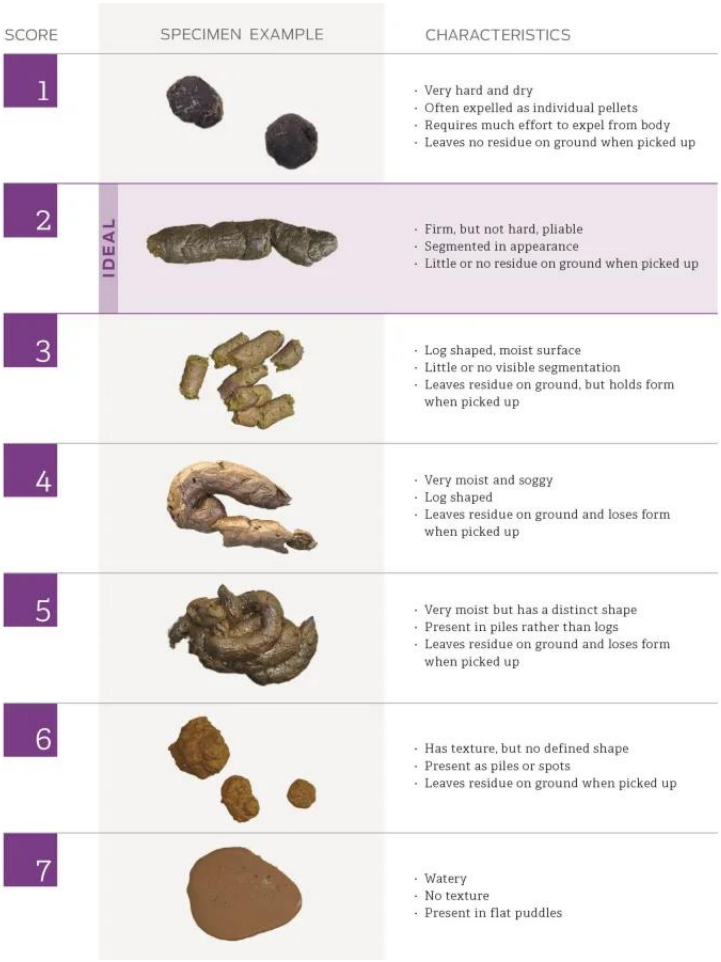


Figure 2.1 Cat Stool Chart Diagram (“Cat Poop: Health Insights, Cat Poop Chart, Problems, and More”, 2022)

2.5.2 Faeces Colour Classification

In addition to shapeless, mushy, or watery stool indicating diarrhoea, other health problems related to faeces coloured should be considered to ensure the detection of possible health issues and provide a more complete insight.

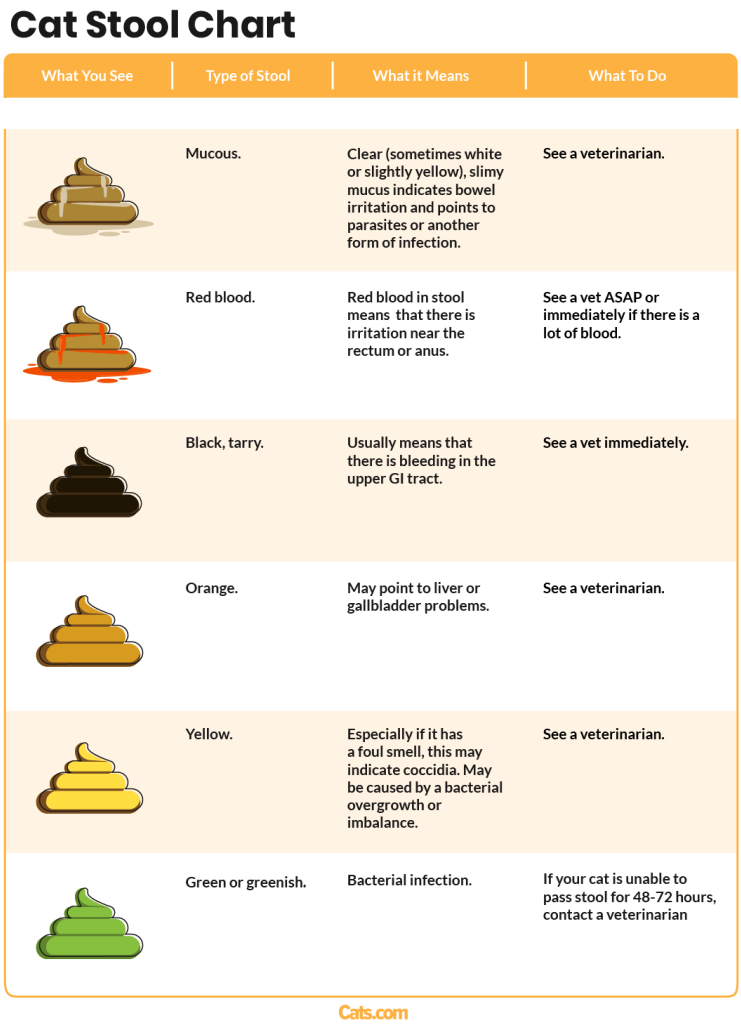


Figure 2.2 Cat Stool Colour Chart (Wedderburn,2022)

The figure (Wedderburn,2022) illustrates cat faeces colour can be categorized into seven coloureds: brown, white, red, black, orange, yellow, and green. While brown coloured typically indicates healthy faeces, other coloureds may suggest various health problems. White faeces with mucus or white flecks may indicate a parasite infestation, while red and black faeces could be a sign of bleeding. Orange-coloured faeces may point to a liver problem, while yellow-coloured faeces may indicate bacterial overgrowth. Lastly, greenish faeces may suggest a bacterial infection or consumption of grass.

2.5.3 Classification Problems

There are limited papers and studies on the classification of cat faeces based on shape, consistency, and coloured. The information available on faeces classification for cats primarily comes from websites, but these sources vary in accuracy and reliability. Further research is needed to validate and refine the classification system, potentially by conducting interviews with veterinarians. This would help ensure that the proposed system is more reliable and accurate.

2.6 Summary

In addition to microscopic and chemical analysis for objective evaluation, faecal analysis involves subjective observation of features like shape and consistency. This makes it an essential tool for health monitoring. Subjective observation is essential for the early identification of health problems in both humans and animals. For example, stool analysis can identify several illnesses in cats, including infections, inflammatory bowel disease, and dietary modifications. Disregarding faecal monitoring can result in higher treatment expenses, worsening health issues, and treatment delays.

For pet owners, however, basic pet care can be difficult to accomplish, particularly when it comes to faeces monitoring. The discrete excretion behaviours of cats pose a challenge to monitoring, and handling their excrement carries a danger of zoonotic illnesses. With features like self-cleaning mechanisms and health data collection, smart litter boxes have become a technological solution. While some models concentrate on urinalysis, others incorporate sophisticated computers to track changes in weight and activity level as indicators of health state. Nevertheless, these technologies are still unable to immediately examine faeces, thus owners must manually inspect them.

Faecal categorization shows potential in using machine learning, namely convolutional neural networks (CNNs). CNNs have been used in studies on human stool analysis to classify stool according to shape, form, and colour, providing thorough insights into medical issues. There is gap in the monitoring of pet health because there is still little study on the classification of faeces in pets, particularly in cats.

In conclusion, while subjective observation is still important, faecal analysis in pet health monitoring may be improved by technology developments like machine learning and smart litter boxes. Nevertheless, more study is required to overcome the drawbacks and restrictions of existing methods and create thorough classification schemes specific to cats.

CHAPTER 3: SYSTEM DESIGN AND SPECIFICATION

3.0 Overview

This report presents a comprehensive analysis and design framework for a smart cat litter box system aimed at monitoring feline health through stool analysis and behaviour tracking. The report begins with an overview of the fact-finding process, which involved observation and interviews to gather insights into the domain of cat faecal analysis and pet health monitoring. Through these methods, key requirements were identified, including the need for real-time monitoring, individualized cat identification, and compatibility with various litter box designs.

The report then delves into the system design phase, where UML diagrams, including use case diagrams, sequence diagrams, and activity diagrams, were employed to model system functionalities and interactions. Use case descriptions provided detailed narratives of user interactions with the system. Furthermore, an Entity-Relationship Diagram (ERD) was crafted to illustrate the system's database structure and relationships.

Additionally, the report outlines the design of the system interface. Considerations were informed by user requirements, ensuring accessibility and ease of use.

3.1 Fact Finding

Fact finding is the process of gathering information and understanding the requirements of a system or project. Fact finding aims to uncover relevant details and insights that contribute to decision-making, problem-solving, and the development of strategies or solutions. This process may involve conducting interviews, observations, document analysis, surveys, and other research methods to collect comprehensive and accurate information. Fact finding is essential for identifying requirements, assessing needs, and informing the design and implementation of new systems or improvements to existing ones (Dennis et al.).

To gather a comprehensive understanding of the system and its requirements, a combination of fact-finding methods, observation and interviews is utilized.

Observation, in the context of requirements gathering, is the systematic process of directly witnessing the activities, behaviours, and interactions of individuals as they perform their tasks in a natural setting. Observation provides insight into the operation of current systems, provide details that may not emerge through interviews alone. It allows analysts to understand how individuals navigate their work processes, identifying challenges, and informing system design(Dennis et al.)

An interview in the context of systems analysis is a meeting between an analyst and an interviewee. It serves as a primary fact-finding technique, allowing gather detailed information about various aspects of the interviewee's work, tasks, objectives, and information needs. The information gathered through interviews is valuable for understanding user requirements, gathering insights, validating assumptions, and making informed decisions during the system analysis and design process. It helps in capturing the perspectives and needs of stakeholders, identifying pain points, and ensuring that the system meets the expectations of its users (Dennis et al.)

By combining observation and interviews, the fact-finding process becomes more comprehensive. Observation offers insights into actual system behaviour and usage patterns, while interviews provide context, explanations, and subjective experiences from those involved. These methods together help uncover a holistic understanding of the system's functioning, user requirements, challenges, and opportunities for improvement, laying a solid foundation for effective system analysis and design.

3.1.1 Observation

The type of observation used to gather requirement is direct non-participant observation. Direct non-participant observation involves actively observing events as they occur in real time without participating in the activities being observed. This approach allows for an in-depth understanding from an external and independent viewpoint, providing insights into behaviours and interactions without preconceived categorizations or evaluations. (Ciesielska et al.)

The field for observation in this context refers to households that own and care for multiple cats, commonly known as multi-cat households. The observation has done in two multi-cat household.

During the observation process, it is crucial to adhere to ethical guidelines, which may include obtaining consent before taking any photographs or recordings of the household environment. This ensures that the privacy and rights of the individuals (both human and animal) being observed are respected.

3.1.1.1 Observation Point/Observation aspect

Observation	Objective
Environment Analysis	
How many cats in the house?	To understand the scope of the litter box usage.
The number of litter box in the house.	To assess accessibility and number of proposed devices to monitor cats.
The layout and setup of the cat litter box. (Open or closed, take pic)	Document the type (open or closed) and placement of litter boxes to understand how the proposed device should be design.
Where the litterbox located? (Take pic)	Capture the specific locations of litter boxes within the household to evaluate factors such as privacy, accessibility, and proximity to other areas.
What is the colour of cat sand used?	To understand the potential challenge might encounter when having colour analysis on cat faeces.
Cat **Behaviour**	
Cat behaves before, during, and after using the litter box?	Observe and document cat behaviour patterns surrounding litter box usage to identify potential challenge in capture image of cat and their excretion.
What is the frequency of litter box cleaning and maintenance?	Determine the regularity of litter box cleaning and maintenance to assess potential challenge in implement electronic device on litter box.
Technology Setup	
Is there any monitoring devices or sensors used in the current litter box?	Determine whether any monitoring devices or sensors are currently employed in the litter box setup to assess existing technology integration and potential compatibility with the smart monitoring system.
Check for connectivity issues or technical challenges faced by cat owners.	Identify issue of current litter box setup to inform the design and implementation of the smart litter box system.

3.1.1.2 Quick interview during observation

Question	Objective
Is the cat sick? What illness do the cat have? What method currently use to assess cat health?	To understand more health assessment practice cat owner done and needed.
Do you inspect your cat faeces often to check their health?	To understand current monitoring practices and potential gaps in health awareness.
What difficulty you face in inspecting cat faeces?	Identify any obstacles when inspecting their cat's faeces to inform the development of the smart litter box system and address user needs.
Do you try to look for a product that help you to inspect cat faeces? Do you use them before? What is the difficulty/ cons/challenges you encounter when using these?	To assess market demand and user preferences. To understand potential pain points and areas for improvement for current technology.
Are there any variations in stool characteristics among different cats within the household?	To understand individual differences and the limitation on stool analysis.

3.1.1.3 Analysis Of Observation

The observation of two household found problems as mentioned below.

Problem 1: ***Number of Litter Box***
In households with multiple cats, it is common practice to have more than one litter box available to accommodate the needs of each cat. One household observed during our study have eight litter boxes. This raises the question: How many IoT devices are required for each litter box, and how do they connect within the system?

Conclusion: In multi-cat households, having multiple litter boxes means that each box should ideally be equipped with its own IoT device to ensure accurate and individualized monitoring. This approach enables the system to differentiate between cats, track their respective health statuses, and identify any anomalies in stool characteristics.

Based on our observations and analysis, it is evident that the system should allow for the connection of more than one litter box, with each box being equipped with its own IoT device. This ensures comprehensive health monitoring for each cat in multi-cat households. Furthermore, all data collected from each edge device should be seamlessly integrated into a centralized database for easy access and analysis by cat owners and veterinary professionals.

Problem 2: Number of Cats
In multi-cat households, distinguishing individual cats based on their faeces poses a significant challenge, it is often challenging for owners to differentiate between the faeces of individual cats. Without a reliable means of identification, owners may struggle to monitor the health and behaviour of each cat effectively.

Conclusion: The proposed system must incorporate features that enable the identification of individual cats based on their faecal matter. This capability will empower cat owners to track the health and well-being of each cat separately, facilitating targeted interventions and ensuring comprehensive health monitoring in multi-cat households.

Problem 3: Litter Box Setup
The households observed utilized a combination of closed and open litter boxes, suggesting a preference for diversity in litter box design. However, this variation in design poses a potential challenge for the installation of edge devices for health monitoring purposes. Closed litter boxes create a dark environment, which may hinder the clear capture of faecal images.

Conclusion: The design of the smart device placement needs to accommodate the diverse litter box types to ensure proper faecal capture. For closed litter boxes, incorporating a light source alongside the camera is essential to facilitate clear image capture in low-light environments. By addressing these considerations, the effectiveness of the health monitoring system can be optimized across various litter box configurations.

Problem 4: Cleaning Practice
During the observations conducted in both households, it was noted that the litter boxes are cleaned and scooped once or twice a week. While this maintenance routine is intended to ensure cleanliness and hygiene, it introduces a potential issue wherein old faecal matter may remain in the litter box until the next cleaning cycle. This presents a challenge for accurate analysis of stool samples, as previous excretions may be erroneously included in the analysis process.

Conclusion: To address this problem, it is imperative that the proposed system possesses the capability to track the exact location of newly deposited excretions within the litter box. By accurately identifying and isolating fresh stool samples, the system can ensure that only relevant and recent data are analysed, thereby enhancing the accuracy and reliability of health assessments conducted based on stool analysis.

Problem 5: Health Assessment
Both households lack effective monitoring devices or sensors in their litter boxes, relying solely on manual observation, which is often insufficient and time-consuming. This deficiency presents challenges in identifying health issues such as diarrhoea and results in delays in intervention, potentially leading to the spread of illnesses among cats.

Conclusion: The identified problem underscores the need for a solution that facilitates real-time monitoring of cat health and usage of litter boxes. Integrating monitoring devices or sensors into litter boxes presents an opportunity to address the observed challenges by providing timely health data and enabling early detection of health issues.

3.1.1.4 Conclusion of Observation

In multi-cat households, the implementation of a comprehensive health monitoring system necessitates equipping each litter box with its own IoT device. This approach enables accurate and individualized monitoring, allowing the system to differentiate between cats, track their respective health statuses, and identify any anomalies in stool characteristics. Our observations and analysis emphasize the importance of enabling connectivity for multiple litter boxes, each equipped with its own IoT device, to ensure thorough health monitoring for each cat. The system should facilitate the identification of individual cats based on their faecal matter, empowering cat owners to track their pets' health separately and enabling targeted interventions. Additionally, considerations such as accommodating diverse litter box types and accurately tracking the location of newly deposited excretions within the litter box are crucial for optimizing the system's effectiveness. Ultimately, the integration of monitoring devices or sensors into litter boxes presents an opportunity to address the identified challenges by providing real-time health data and facilitating early detection of health issues.

3.1.2 Interview

The interview conducted in this project was structured and one-on-one, featuring a veterinarian as the interviewee. Prior to the interview, extensive research was undertaken on the classification of cat faeces, focusing on aspects such as shape and colour. Additionally, a collection of pictures showcasing examples of cat stool was compiled to provide visual aids during the interview process. These preparatory steps aimed to enhance understanding and ensure the accuracy of cat faeces classification discussed during the interview.

3.1.2.1 Proposed Questions and Objectives

Question	Objective
Domain Exploration	
What is the importance of monitoring cat faeces?	Gain insights into the importance of monitoring cat faeces for early health detection. Provide strong support on the proposed system.
How to observe cat stool? What aspect I should take account to make sure my cat is healthy?	Gather attributes and way to observe cat faecal. Gather requirement for faecal analysis.
What other specific sickness or disease that is possible that cause abnormal stool?	Discuss sickness of cat. To see if the proposed system shall include feature of determine specific disease through faecal analysis.
Classification of Cat Faeces	
Show stool classification chart that found from internet. Are these charts correct? What any additional information needed to add?	Inquire about the criteria used by veterinarians to classify cat faeces. Clarify requirements and classification of faecal.
Are there any variations in stool characteristics among different breed of cats?	To understand individual differences and the limitation on stool analysis.
What are the challenges faces in observe stool and making accurate diagnoses?	Explore the challenges faced in observe faecal and making assumption. Gather requirement for proposed system.
Recommendations and Guidelines:	
There is a health monitoring system for cat, what kind of health data is needed for monitoring?	Seek recommendations from the veterinarian regarding the design and implementation of your smart litter box system. To gather requirements and possible feature for the proposed system.

What is the way to take body temperature of cat? Can I use non-contact infrared thermometer for body temperature measurement?	To seek recommendation on the way of temperature collection. Define limitation in body temperature measurement of cat.

3.1.2.2 Interview Analysis

Question 1	What is the importance of monitoring cat faeces?
Answer	Cats can be adept at concealing signs of illness or discomfort. However, monitoring their faeces can offer valuable insights into their well-being, even if they exhibit no apparent symptoms. Detecting issues early allows for proactive measures to maintain your cat's health, such as adjusting their diet or administering medication if necessary.
Conclusion	Therefore, developing a system that can effectively monitor and analyse cat faeces for early health detection is crucial for ensuring the timely detection and management of various health issues in cats.

Question 2	What is the importance of monitoring cat faeces?
Answer	Cats can be adept at concealing signs of illness or discomfort. However, monitoring their faeces can offer valuable insights into their well-being, even if they exhibit no apparent symptoms. Detecting issues early allows for proactive measures to maintain your cat's health, such as adjusting their diet or administering medication if necessary.
Conclusion	Therefore, developing a system that can effectively monitor and analyse cat faeces for early health detection is crucial for ensuring the timely detection and management of various health issues in cats.

Question 3	What other specific sickness or disease that is possible that cause abnormal stool? Can specify or determine the disease by assessing cat stool with chart?
Answer	Parasitic infections like roundworms and tapeworms, bacterial infections such as Salmonella, viral infections like feline panleukopenia virus (FPV), dietary intolerances or allergies, inflammatory conditions like inflammatory bowel disease (IBD), gastrointestinal bleeding or ulcers, malabsorption syndromes such as exocrine pancreatic insufficiency (EPI), and imbalances in the gut microbiota. While observing the stool can offer initial indications of your cat's health status, a comprehensive analysis in a laboratory setting is

	often necessary to pinpoint specific diseases, especially those associated with blood in the stool, viral infections, or harmful bacteria in the gut. These observations empower owners to make informed assumptions about their cat's condition, prompting early interventions such as administering probiotics or vitamins. However, for accurate diagnosis and targeted treatment, professional laboratory analysis remains indispensable.
Conclusion	Limitation of observation is it cannot identify specific disease. Means that the proposed system cannot determine what disease the cat is suffer from the abnormality of stool but can give recommendation on the treatment.

Question 4	Show stool classification chart that found from internet. Are these charts correct? What any additional information needed to add?
Answer	Regarding the classification of stool shape and consistency, the veterinarian mentions that categories 3, 4, and 5 may still be considered normal in some cases, such as when a cat drinks too much water or experiences stress. It is only when the stool reaches categories 6 and 7 that it is definitively considered diarrhoea and indicative of potential health issues like sickness or food intolerance. Similarly, when discussing the classification of stool colour, the veterinarian acknowledges that certain colours may be influenced by the cat's diet, such as green or black stool from consuming grass or dark-coloured foods. Despite this variability, the veterinarian confirms the importance of stool colour in diagnosing potential illnesses. Ultimately, the veterinarian suggests that both charts are useful for stool analysis, with each providing valuable information. However, they recommend combining the two charts to create a more comprehensive understanding of stool characteristics and their potential implications for the cat's health. This approach would allow for a more detailed assessment of stool colour and consistency, helping to identify any abnormalities or signs of illness more accurately.
Conclusion	Integrate both charts to provide a comprehensive reference for stool classification, considering both shape/consistency and colour. This approach will ensure that system can effectively analyse and interpret stool samples for early detection of health issues in cats.

Question 5	Is there any variations in stool characteristics among different breed of cats?
Answer	Variations in poop characteristics among different cat breeds can indeed occur due to a range of factors beyond just breed genetics. For instance, long-haired breeds like Maine Coons or Persians may contend with hairballs, which can influence the appearance and texture of their faeces. Cats with flat faces, such as Persians or Exotic Shorthairs, may have digestive systems structured differently due to their facial anatomy, potentially impacting their bowel movements. Moreover, certain breeds prone to genetic disorders like hypertrophic cardiomyopathy or polycystic kidney disease may exhibit gastrointestinal symptoms that can affect their stool. While breed can contribute to these differences, it is important to recognize that other factors also play significant roles in determining a cat's poop traits.
Conclusion	Breed of cat do not have huge influence in the classification of faecal. Therefore, when analysing stool samples or monitoring faecal health, it is essential to consider the specific characteristics and needs of each cat, regardless of their breed.

Question 6	What are the challenges faces in observe stool and making accurate diagnoses?
Answer	Challenge face when interpreting stool samples and making accurate diagnoses from the variability in stool quality, consistency, and freshness, which can impact the reliability of diagnostic tests. Samples that are contaminated, or degraded stool make it difficult to detect abnormalities.
Conclusion	Overall, the challenge highlights the importance of developing a robust system that can accurately analyse and interpret stool samples real-time.

Question 7	There is a health monitoring system for cat, what kind of health data is needed for monitoring?
Answer	These include the duration and frequency of activities such as walking, running, playing, and resting, as well as the quality of sleep. Additionally, factors such as portion size and frequency of meals and water consumption, weight, body temperature, frequency of litter box usage, characteristics of urination and defecation, heart rate, blood pressure, and the detection of emotions including pain and discomfort are crucial for a holistic understanding of a cat's health status. By incorporating these diverse parameters, veterinarians and owners can gain valuable insights into the overall health and well-being of feline companions.
Conclusion	The proposed system is use litter box to collect data to assess

	health condition of cat. The health data that possible to implement in the proposed system are measurement of body temperature, weighting, frequency of litter box usage, characteristic of urination and defecation.

Question 7	What is the way to take body temperature of cat? Can I use non-contact infrared thermometer for body temperature measurement?
Answer	Rectal thermometers are the most reliable method for measuring a cat's body temperature accurately. Infrared gadgets that measure skin temperature by scanning the fur may not always provide precise readings. Factors such as ambient temperature, humidity, and airflow can interfere with these measurements. Additionally, the varying thickness of a cat's fur, ranging from super fluffy to less dense, can impede the accuracy of infrared thermometers. Thicker fur can pose challenges in obtaining an exact temperature reading. Therefore, rectal thermometers remain the preferred choice for obtaining accurate body temperature measurements in cats.
Conclusion	It is impossible to perform rectal temperature measurements every time the cat goes into the litter box. Infrared thermometer is not feasible to use to measure body temperature, so the proposed system will not include body temperature.

3.1.2.3 Conclusion of Interview

In conclusion, the development of a reliable system for monitoring and analysing cat faeces is imperative for early detection and management of health issues in felines. While odour cannot be detected, attributes such as colour and shape/consistency can be effectively analysed using camera sensors. However, it is important to acknowledge the limitation of this system in identifying specific diseases solely based on stool abnormalities, although it can provide valuable treatment recommendations. Integrating comprehensive reference charts for stool classification, considering both shape or consistency and colour, will enhance the system's ability to interpret stool samples accurately. Breed differences have minimal influence on faecal classification, emphasizing the importance of individualized assessment for each cat. Utilizing litter boxes for data collection allows for monitoring various health parameters, including frequency of litter box usage and characteristics of urination and defecation. While rectal temperature measurements are impractical, other health data can still be gathered effectively. Overall, the development of such a system underscores the importance of real-time analysis for ensuring the well-being of our feline companions.

3.2 System Requirements

After fact finding and analysis, now convert the result of analysis into functional requirements, non-functional requirement, and user requirements.

Functional requirements define the specific actions, behaviours, and functionalities that a system must perform to meet the needs and expectations of its users or stakeholders. These requirements outline the desired capabilities and operations of the system, focusing on what the system should do in terms of processing, data handling, and output generation.

Non-functional requirements pertain to aspects of the system that focus on how well it delivers its functional requirements. These requirements encompass criteria related to performance, system capacity, availability, reliability, scalability, security, and other quality attributes. Non-functional requirements play a critical role in ensuring that the system meets performance standards, user expectations, and quality objectives beyond its basic functionalities.

3.2.1 Functional Requirements

3.2.1.1 Monitoring and Recording:

- The system shall utilize motion sensors to detect the presence of a cat in the litter box area.
- Video recording shall be initiated upon cat entry into the litter box and shall cease upon cat exit.
- Images shall be captured of the cat's face, body, and excretion during each litter box usage.
- Weight and temperature shall be record using weight sensor and during each litter box usage.
- The object detection model shall detect cats and excretions for analysis.

3.2.1.2 Cat Identification

- The system shall identify individual cats using recognition technology upon every entry.
- A cat recognition model shall identify cats, creating or updating profiles accordingly.
- Cat identification data should be linked to their respective health records.
- If a cat is unrecognized, the system shall prompt the user via the mobile app to create a new profile or associate the cat with an existing one.

3.2.1.3 Faeces Analysis

- The system shall analyse cat faeces based on characteristics such as consistency, shape, and colour.
- Faeces shall be categorized into constipation, normal, or diarrhoea based on a predefined grading system.
- Upon detection of abnormal faecal characteristics, the system shall send a pop-up notification to the owner's mobile app.
- Notification messages shall include details of the faecal characteristics and recommended actions for the user.

3.2.1.4 Data Storage and Retrieval

- All collected data, including images and analysis results, should be stored in a database.
- Owners should be able to retrieve historical data and view past health trends for their pets.

3.2.1.5 Mobile Application

- The system shall allow owner to add a new device
- The system shall allow owner to disconnect a device
- The system shall allow owner to add a new cat profile and make edit and remove profile.
- The main dashboard of the mobile app shall display pictures of each cat with their respective names for user selection.
- Selecting a cat shall direct the user to the cat's history record, displaying date, time, images, faecal characteristics, temperature, and weight for each litter box usage.
- The system shall display weight changes in cat profile
- The system shall allow owner to download and share pictures

3.2.2 Non-Functional Requirements

3.2.2.1 Performance:

- The system should respond to user requests promptly (pet profile, download), with minimal latency.
- The system shall process faecal analysis and generate notifications with minimal delay, ideally within seconds.
- Video recording. Image capturing and analysis processes should be optimized for efficiency to minimize processing time.
- The system shall be capable of supporting a minimum of 10 litter boxes simultaneously during peak usage periods.

3.2.2.2 Reliability:

- The system should be reliable and available 24/7 to ensure continuous monitoring of pet health.
- Failover mechanism shall be implemented to handle connectivity failures and ensure data integrity.

3.2.2.3 Scalability:

- The system should be scalable to accommodate a growing number of litter box and cats.

3.3 System Design

3.3.1 Rich Picture Diagram

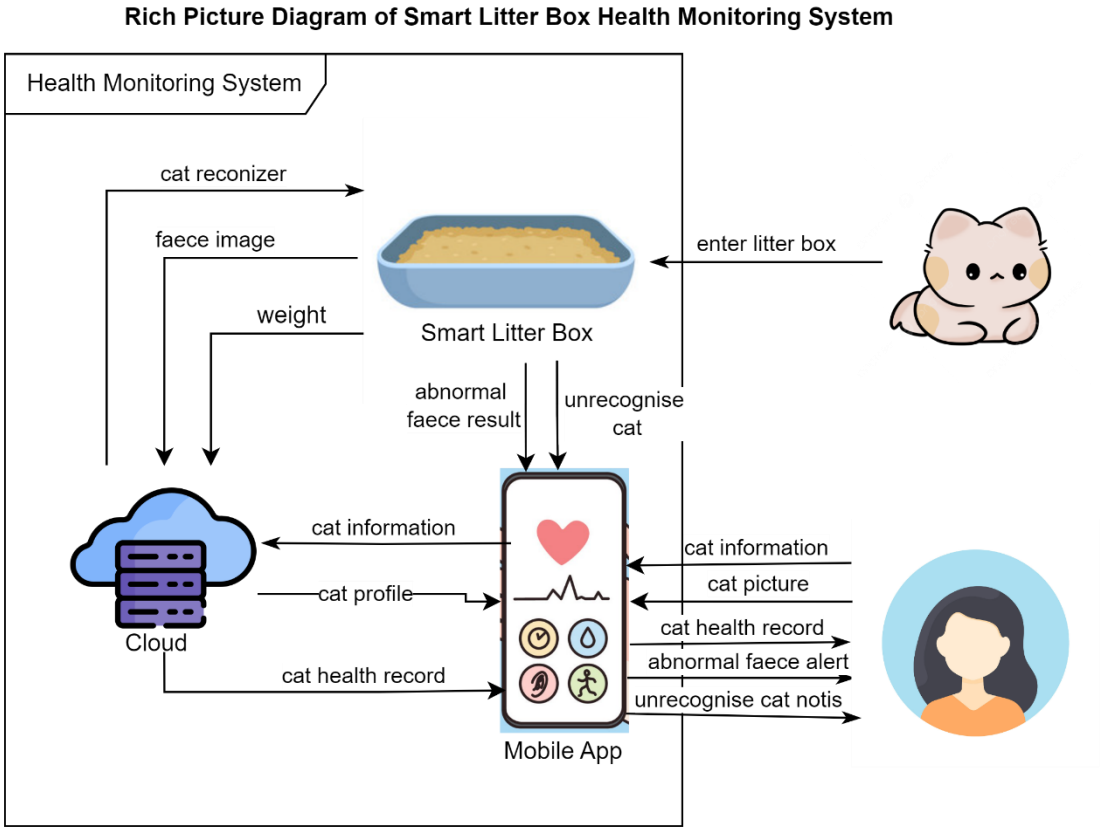


Figure 3.1 Rich Picture Diagram of Health Monitoring System

3.3.2 Use Case Diagram

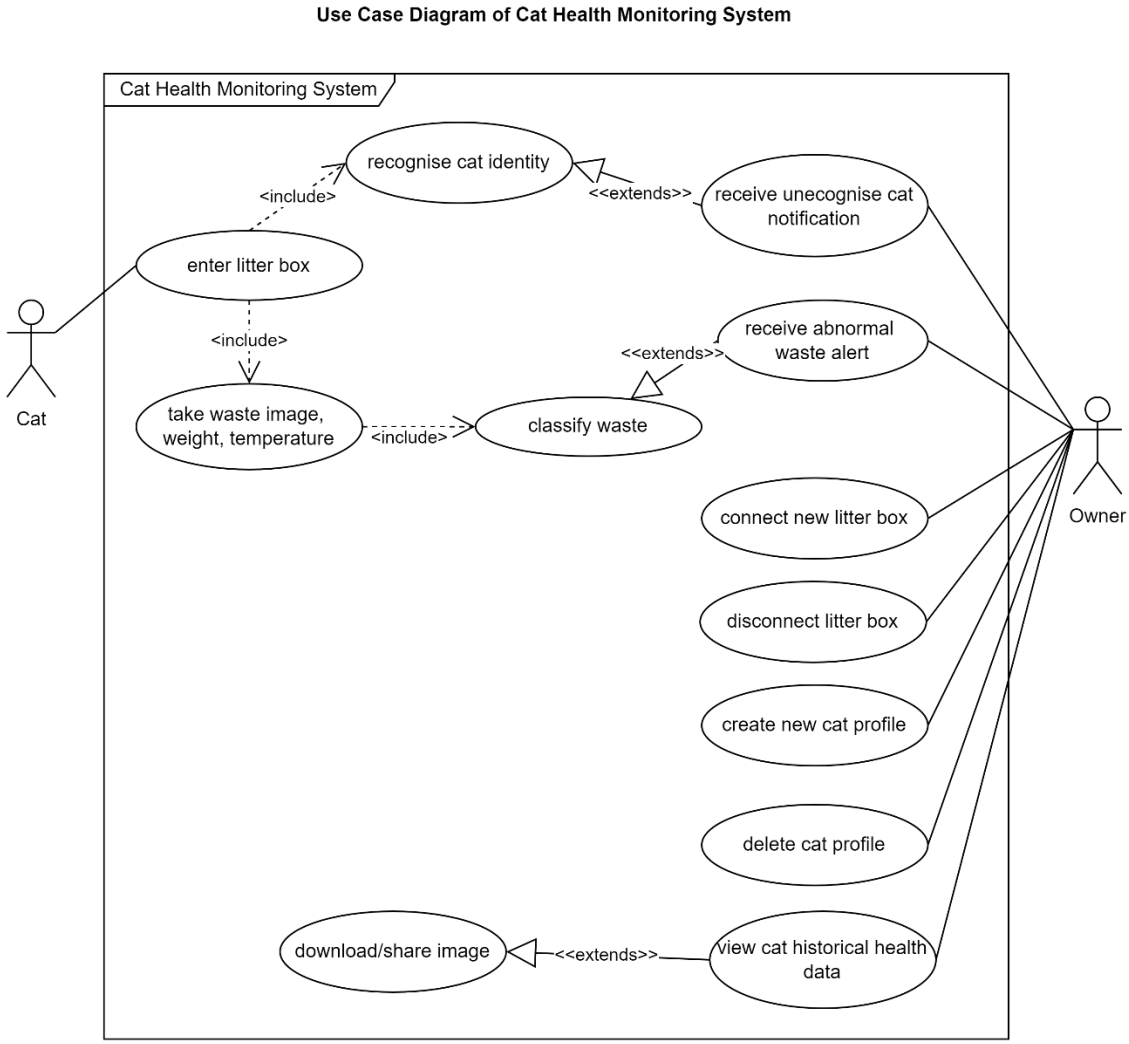


Figure 3.2. Use Case Diagram of Health Monitoring System

3.3.2.1 List of Actors

Actor	Description
Cat Owner	A user who owns one or more cats, interacts with the system through mobile application.
Cat	A user who interacts with the system by using the litter box.
System	The health monitoring system, which include smart litter box and mobile application for monitoring and analysing cat health.

Table 3.1. List of Actors of Health Monitoring System

3.3.2.2 Use Cases

Actors		Use Case	Use Case Description
Owner	initiate	Connect new litter box	The use case involves the cat owner initiating the setup process to connect a new litter box to the system via the mobile app. This use case enables the owner monitor multiple cat litter box when more than one litter box in the household.
	Initiate	Disconnect litter box	The use case involves the cat owner initiating the process to disconnect a litter box that is no longer in use from the system via the mobile app. This use case enables the owner to remove a litter box from the system.
	initiate	Create new cat profile	The use case involves the cat owner initiating the process of adding a new cat profile to the system via the mobile app. This use case enables the owner to register a new cat in the system and provide relevant information for identification and monitoring purposes.
	Initiate	Delete cat profile	The use case involves the cat owner initiating the process to delete a cat profile from the system via the mobile app.
	initiate	View cat historical health data	The use case enables the cat owner to access and review historical health data for a specific cat via the mobile app. This use case allows the owner to monitor past litter box usage events and associated health metrics, facilitating informed decision-making and ongoing pet care.

		Receive abnormal waste alert	The use case is triggered when the smart device detects abnormal characteristics in a cat's waste during the analysis process. This use case involves generating an alert and sending it to the owner's mobile device via the mobile app, notifying them of the detected abnormalities and prompting them to take appropriate action to address the cat's health.
		Receive unrecognised cat notification	This use case occurs when detects a cat using the litter box but cannot recognize it as an existing cat in the system. In such cases, the system generates a notification that sent to the owner's mobile device via the mobile app, informing them that a new cat has been detected and prompting them to create a new profile or select an existing one for the cat.
Cat	initiate	Enter Litter Box	When a cat enters the litter box area, the motion sensors detect its presence and trigger the system to start monitoring and recording. The system captures images of the cat's face, body, and excretion using the camera and performs faecal analysis to assess the health of the cat. The data collected during this process is stored in the corresponding cat profile.

Table 3.2. List of Use Cases

3.3.2.3 Use Case Description

Use Case Description of Connect New Litter Box

Use Case:	Connect New Litter Box	
Priority:	Must have	
Actor:	Owner	
Description:	The use case involves the cat owner initiating the setup process to connect a new litter box to the system via the mobile app. This use case enables the owner monitor multiple cat litter box when more than one litter box in the household.	
Precondition:	The owner has a new cat litter box	
Trigger:	The cat owner navigates to the settings section of the Smart Cat Litter Box mobile app and selects the option to "Add Litter Box."	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 2: Select the litter box **Step 5:** Insert name for the new litter box	**Step 1:** The app scan smart litter box that able to connect nearby via Bluetooth **Step 3:** verifies the connection and functionality of the hardware components of the new litter box **Step 4:** prompt user to setup **Step 6:** Notify user of the successful of connection
Alternate Course:	Alt-Step 3: Verification failed; the litterbox is not successfully connected (Show dialog).	
Conclusion:	The use case concludes when the user receives message of the successful connection of litter box.	
Postcondition:	▪ The new litter box is successfully integrated into the system. ▪ All hardware components are properly connected and functioning. ▪ The system assigns a unique identifier to the newly integrated litter box. ▪ The system begins capturing images, detecting motion, and recording data related to litter box usage events in real-time.	
Business Rules:	▪ Each litter box integrated into the system must have a unique identifier.	
Non-Functional Requirements	▪ The system should be able to scale to accommodate the integration of multiple litter boxes. ▪ The setup process should be user-friendly and intuitive, even for users with limited technical expertise.	

Table 3.3. Use Case Description (Connect New Litter Box)

Use Case Description of Disconnect Litter Box

Use Case:	Disconnect Litter Box	
Priority:	Medium	
Actor:	Owner	
Description:	The use case involves the cat owner initiating the process to disconnect a litter box that is no longer in use from the system via the mobile app. This use case enables the owner to remove a litter box from the system.	
Precondition:	The litter box that going to disconnect is currently connected to the system	
Trigger:	The cat owner navigates to the "Connected Devices" section under the settings of the mobile app.	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 2: Select the litter box that wish to disconnect, click on the corresponding option to remove **Step 4:** confirm to disconnect the selected litter box	**Step 1:** The app lists out all connected litter box with name assigned **Step 3:** prompt user to confirm the decision **Step 5:** Remove the litter box from database, cease connection **Step 6:** Notify user of successful disconnection
Alternate Course:	-	
Conclusion:	The use case concludes when the user receives message of the successful disconnection of litter box.	
Postcondition:	▪ Data collection from the disconnected litter box is halted, no further monitoring activities are conducted for the removed device.	
Business Rules:	-	
Non-Functional Requirements	-	

Table 3.4. Use Case Description (Disconnect Litter Box)

Use Case Description of Create New Cat Profile

Use Case:	Create New Cat Profile	
Priority:	Must have	
Actor:	Owner	
Description:	The use case involves the cat owner initiating the process of adding a new cat profile to the system via the mobile app. This use case enables the owner to register a new cat in the system and provide relevant information for identification and monitoring purposes.	
Precondition:	The owner has a new cat	
Trigger:	The cat owner navigates to the settings section of the mobile app and selects the option to "Add New Cat."	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 2: Enter information about the cat including: Cat's name: the unique identifier for the cat, Age: The age of the cat in years or months, Breed: The breed or type of the cat., Gender: Male / Female **Step 5:** scan various angles of the cat's face, left side, right side, body, and back using the camera of their mobile device **Step 8:** Review information and confirm creation of the new cat profile.	**Step 1:** The app prompts the user to enter essential information about the new cat, including: **Step 3:** Verify name **Step 4:** Directs the user to scan the cat's identity for recognition purposes **Step 6:** Verify scanning **Step 7:** Prompt for confirmation of profile creation **Step 9:** save to database to create a new cat profile. **Step 10:** Notify user of the successful addition of new cat profile
Alternate Course:	Alt-Step 3: The name of cat is existed. (Repeat step 2) Alt-Step 6: The images of cat are not able to verify (Repeat step 5).	
Conclusion:	The use case concludes when the user receives message of the successful addition of new cat profile.	
Postcondition:	▪ The new cat profile is successfully created and added to the system. ▪ The cat owner can now monitor and manage the new cat's health and litter box usage alongside existing profiles within the system.	
Business Rules:	▪ Cat profile must have a unique identifier ▪ Cat name is required field	
Non-Functional Requirements	▪ The system should be able to handle the creation of new cat profiles and scanning of cat identities as the number of cats increases.	

Table 3.5. Use Case Description (Create New Cat Profile)

Use Case Description of Delete Cat Profile

Use Case:	Delete Cat Profile	
Priority:	Medium	
Actor:	Owner	
Description:	The use case involves the cat owner initiating the process to delete a cat profile from the system via the mobile app.	
Precondition:	The cat profile to be deleted must exist within the system	
Trigger:	The cat owner selects the "Delete" button located within the cat profile or navigates to the "List of Cats" section under the settings page in the mobile app.	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 1: select cat profile and corresponding option for deletion **Step 3:** confirms the action	**Step 2:** prompts the owner to confirm the decision to delete the cat profile **Step 4:** update status of the cat to inactive in database **Step 5:** Notify user of the successful deletion of existing cat profile
Alternate Course:	-	
Conclusion:	The use case concludes when the user receives message of the successful deletion of new cat profile.	
Postcondition:	▪ The selected cat profile is successfully deleted from the system. ▪ Data association with the deleted cat profile is terminated, no further monitoring activities or analysis results are attributed to the removed profile. ▪ The deleted cat profile is no longer displayed in the dashboard ▪ The owner retains access to historical health data associated with the deleted cat profile by navigate to the "List of Cats" section under the settings	
Business Rules:	▪ Cat profiles deleted from the system must be permanently removed from all associated data and no longer displayed in the dashboard	
Non-Functional Requirements	-	

Table 3.6. Use Case Description (Delete Cat Profile)

Use Case Description of View Cat Historical Health Data

Use Case:	View Cat Historical Health Data	
Priority:	Medium	
Actor:	Owner	
Description:	The use case enables the cat owner to access and review historical health data for a specific cat via the mobile app. This use case allows the owner to monitor past litter box usage events and associated health metrics, facilitating informed decision-making and ongoing pet care.	
Precondition:	▪ The cat profile for which historical health data is to be viewed must exist within the system. ▪ Historical health data for the selected cat profile must be available in the system.	
Trigger:	The cat owner selects the desired cat profile from the dashboard or navigates to the "List of Cats" section under settings within the app.	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 2: select a cat profile **Step 4:** navigates to the "Historical Health Data" section **Step 6:** perform view action	**Step 1:** display a list of cat profile **Step 3:** display the profile of selected cat **Step 5:** retrieves and displays a chronological list of past litter box usage events associated with the selected cat profile
Alternate Course:	-	
Conclusion:	The use case concludes when the user successfully views the selected cat profile	
Postcondition:	▪ The cat owner successfully accesses and reviews historical health data for the selected cat profile within the system. ▪ The system displays a comprehensive list of past litter box usage events and associated health metrics ▪ The owner has the option to download or share images associated with past events	
Business Rules:	-	
Non-Functional Requirements	▪ The interface for viewing historical health data should be user-friendly and intuitive. ▪ The system should reliably store and retrieve historical health data without errors or data loss.	

Table 3.7. Use Case Description (View Cat Historical Health Data)

Use Case Description of Receive Abnormal Waste Alert

Use Case:	Receive Abnormal Waste Alert	
Priority:	Must have	
Actor:	System (primary), owner (secondary)	
Description:	The use case is triggered when the smart device detects abnormal characteristics in a cat's waste during the analysis process. This use case involves generating an alert and sending it to the owner's mobile device via the mobile app, notifying them of the detected abnormalities and prompting them to take appropriate action to address the cat's health.	
Precondition:	A cat entered the smart litter box	
Trigger:	Abnormal characteristics, such as diarrhoea, blood in stool, or unusual colour or consistency, is detected during the analysis process	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 2: notification appears as a pop-up message on the owner's mobile screen	**Step 1:** generates an alert to notify cat owner
Alternate Course:	-	
Conclusion:	The use case concludes when the user receives the pop-up notification	
Postcondition:	▪ The cat owner receives the alert for abnormal waste characteristics on their mobile device via the mobile app. ▪ The notification provides details of the detected abnormalities	
Business Rules:	▪ The alert includes details of the detected abnormalities, providing information on the specific characteristics observed (shape, consistency, colour)	
Non-Functional Requirements	▪ Real-time notification	

Table 3.8. Use Case Description (Receive Abnormal Waste Alert)

Use Case Description of Receive Unrecognised Cat Notification

Use Case:	Receive Unrecognised Cat Notification	
Priority:	Must have	
Actor:	System (primary), owner (secondary)	
Description:	The use case occurs when smart device detects a cat using the litter box but cannot recognize it as an existing cat in the system. In such cases, the system generates a notification that is sent to the owner's mobile device via the mobile app, informing them that a new cat has been detected and prompting them to create a new profile or select an existing one for the cat.	
Precondition:	A cat entered the smart litter box	
Trigger:	The system fails to recognize the cat as an existing profile within the system	
Typical Course of Events:	**Actor Action**	**System Action**
	Step 4: appears as a pop-up message on the owner's mobile screen **Step 5**: Select an existing profile.	**Step 1:** classify the cat as unrecognised **Step 2**: create a new cat profile for the unrecognised cat **Step 3**: generates a notification to inform the detection of unrecognized cat **Step 6**: System merge the existing cat profile with the unrecognised profile. **Step 7**: System notify on successfully merging
Alternate Course:	**Alt-Step 6:** The cat in new in the house, create a new profile for the unrecognised cat. (Go to Create New Cat Profile Use Case).	
Conclusion:	The use case concludes when the user receive message of successfully merging existing profile.	
Postcondition:	▪ The cat owner receives the notification for the detection of an unrecognized cat on their mobile device via mobile app. ▪ The notification prompts the owner to take action ▪ The owner successfully manages the detection of the unrecognized cat	
Business Rules:	▪ The alert includes the image of the unrecognised cat	
Non-Functional Requirements	▪ Real-time notification	

Table 3.9. Use Case Description (Receive Unrecognised Cat Notification)

Use Case Description of Enter Litter Box

Use Case:	Enter Litter Box	
Priority:	Must have	
Actor:	Cat, System	
Description:	The use case is triggered when a cat enters the litter box area, prompting the smart device to start monitoring and recording the cat's activity. The system captures images of the cat's face, body, and excretion using the camera, performs faecal analysis to assess the cat's health, and stores the collected data in the corresponding cat profile.	
Precondition:	▪ Smart system must be operational and actively monitoring the litter box area for cat activity. ▪ The system has access to the necessary hardware components, including motion sensors and cameras, to capture data.	
Trigger:	Motion detection detect a cat enter the litter box area	
Typical Course of Events:	Actor Action	System Action
	Step 1: Enter litter box **Step 5**: Leave litter box	**Step 2:** initiate recording of cat's activity using camera **Step 3**: recognise cat identity **Step 4**: capture images of cat's face, body, and excretion **Step 6**: performs faecal analysis **Step 7**: store result, images, time, weight to corresponding cat profile
Alternate Course:	**Alt-Step 7:** If the cat is not recognised, generate notification to owner (Go to Receive Unrecognised Cat Notification Use Case) **Alt-Step 7:** If the cat faecal analysis is classified as constipation/diarrhoea, generate notification to owner (Go to Receive Abnormal Waste Alert Use Case)	
Conclusion:	The use case concludes when the system successfully stores the collected data to database	
Postcondition:	▪ The smart device successfully captures images of the cat's face, body, and excretion, performs faecal analysis to assess the cat's health, and stores the collected data in the corresponding cat profile.	
Business Rules:	▪ The system must capture and store comprehensive data, including images and faecal analysis results	
Non-Functional Requirements	▪ The system should efficiently detect cat presence, capture images, perform faecal analysis, and store data without delays.	

Table 3.10. Use Case Description (Enter Litter Box)

3.3.3 Sequence Diagram

Sequence diagram offering a visual depiction of the interaction between objects within a system over time. This modelling techniques provides insights into the dynamic behaviour of a system by illustrating how various components communicate and collaborate to achieve specific tasks or scenarios (Dennis et al.).

The sequence diagram that created to illustrate for proper understanding include Health Monitoring Process, Create New Cat Profile, Connect New Litter Box

3.3.3.1 Health Monitoring Process (Cat Enter Litter Box)

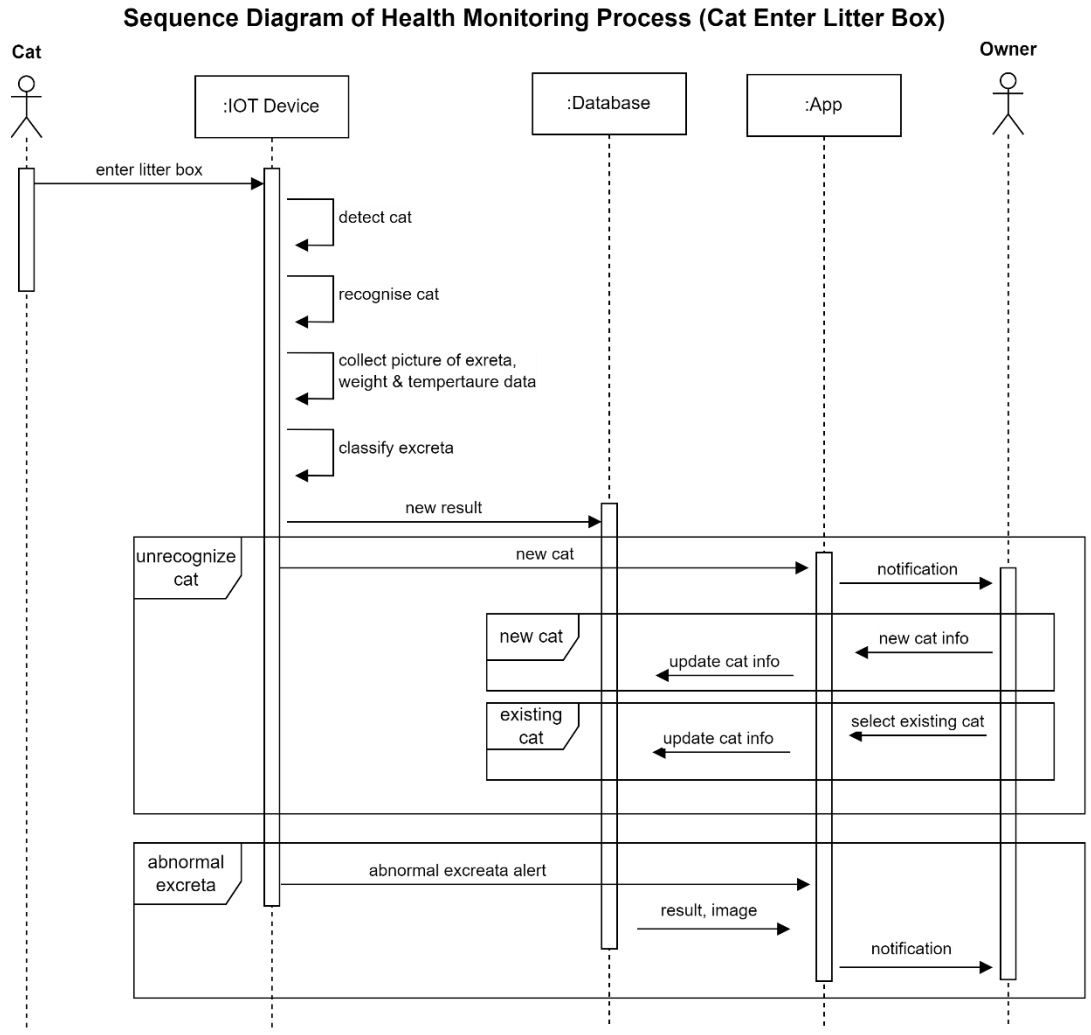


Figure 3.3. Sequence Diagram (Health Monitoring Process - Cat Enter Litter Box)

3.3.3.2 Create New Cat Profile

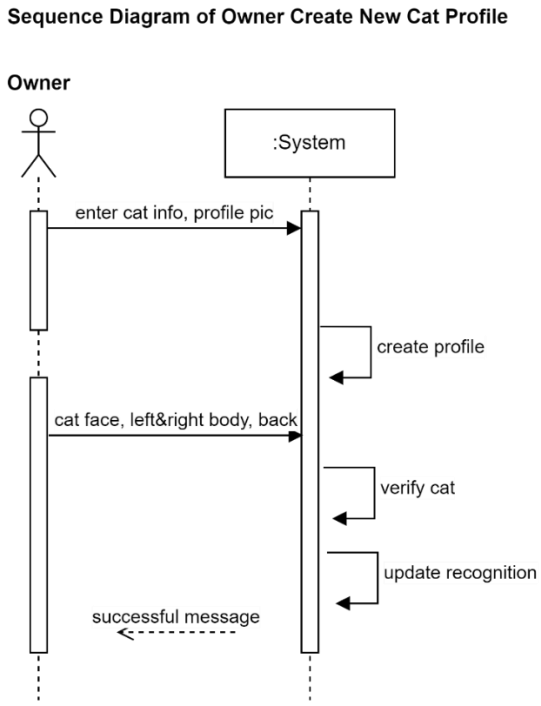


Figure 3.4. Sequence Diagram (Create New Profile)

3.3.3.3 Connect New Litter Box

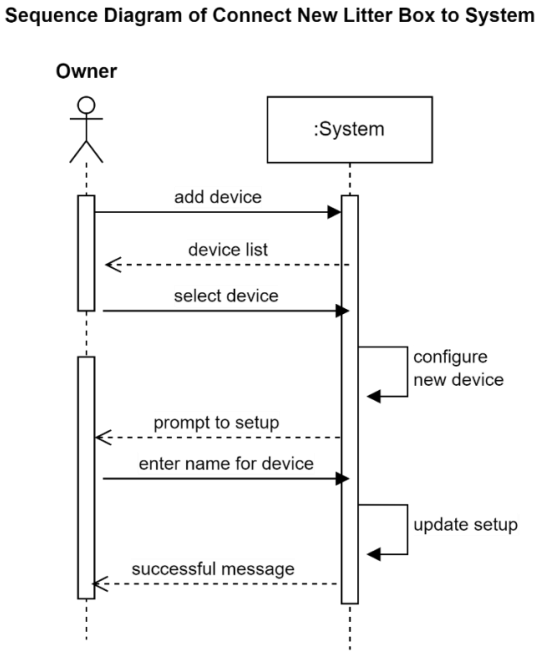


Figure 3.5. Sequence Diagram (Connect New Litter Box)

3.3.4 Activity Diagram

3.3.4.1 Health Monitoring (Cat Enter Litter Box)

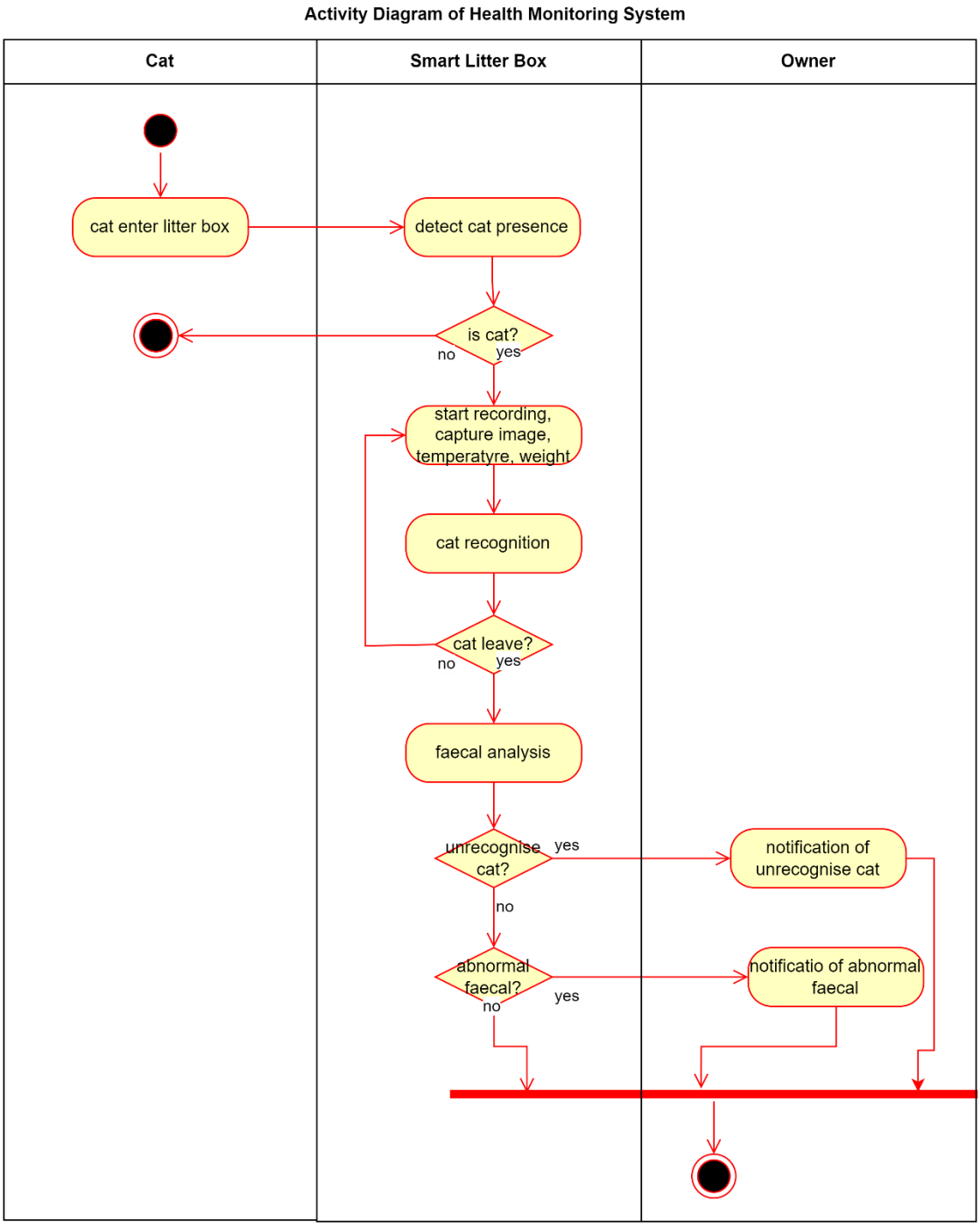


Figure 3.6. Activity Diagram (Health Monitoring System)

3.3.4.2 Handling Detection of Unrecognised Cat

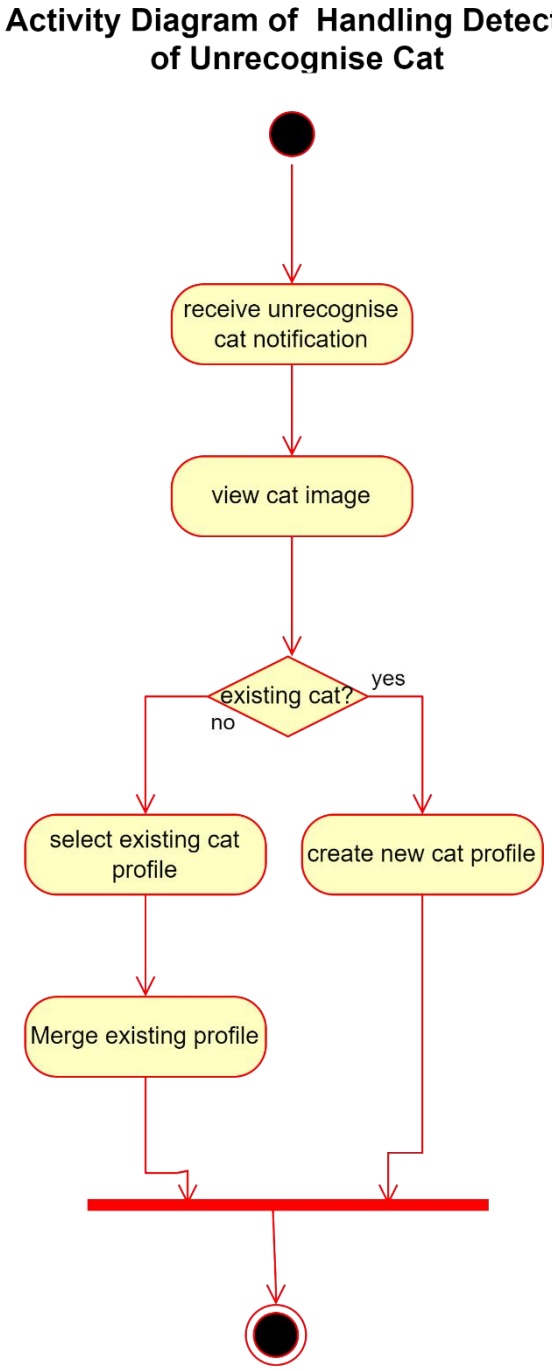


Figure 3.7. Activity Diagram (Handling Detection of Unrecognized Cat)

3.3.4.3 Owner Create New Cat Profile

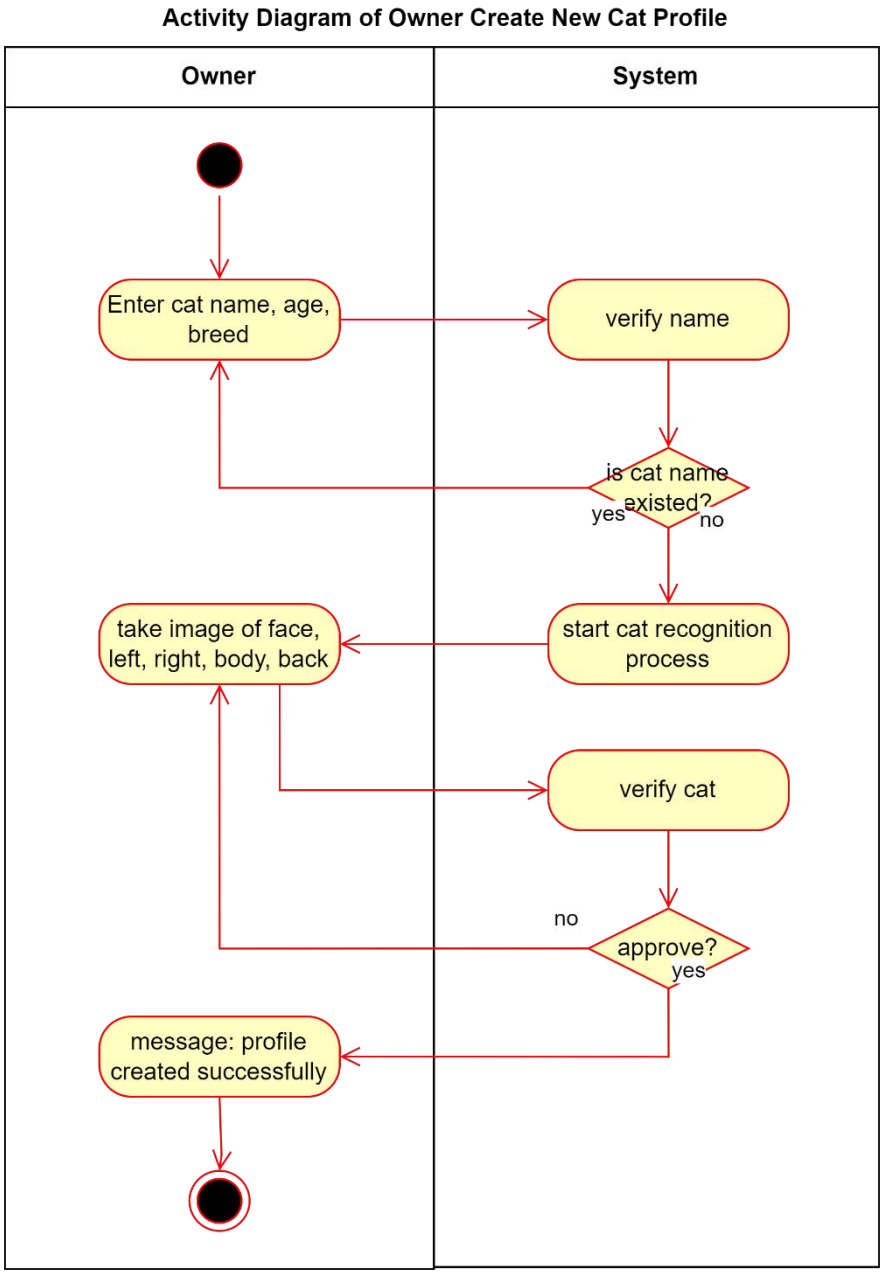


Figure 3.8. Activity Diagram (Owner Create New Cat Profile)

3.3.5 Entity Relationship Diagram (ERD)

3.3.5.1 Business Rule

- Each cat registered in the system must have a unique profile.
- When abnormal characteristics are detected in a cat's waste, an alert notification must be generated.
- The system must retain historical health data for each cat, including past litter box usage events and analysis results.
- Faecal analysis results must be categorized into constipation, normal, or diarrhoea based on predefined criteria.

3.3.5.2 Diagram

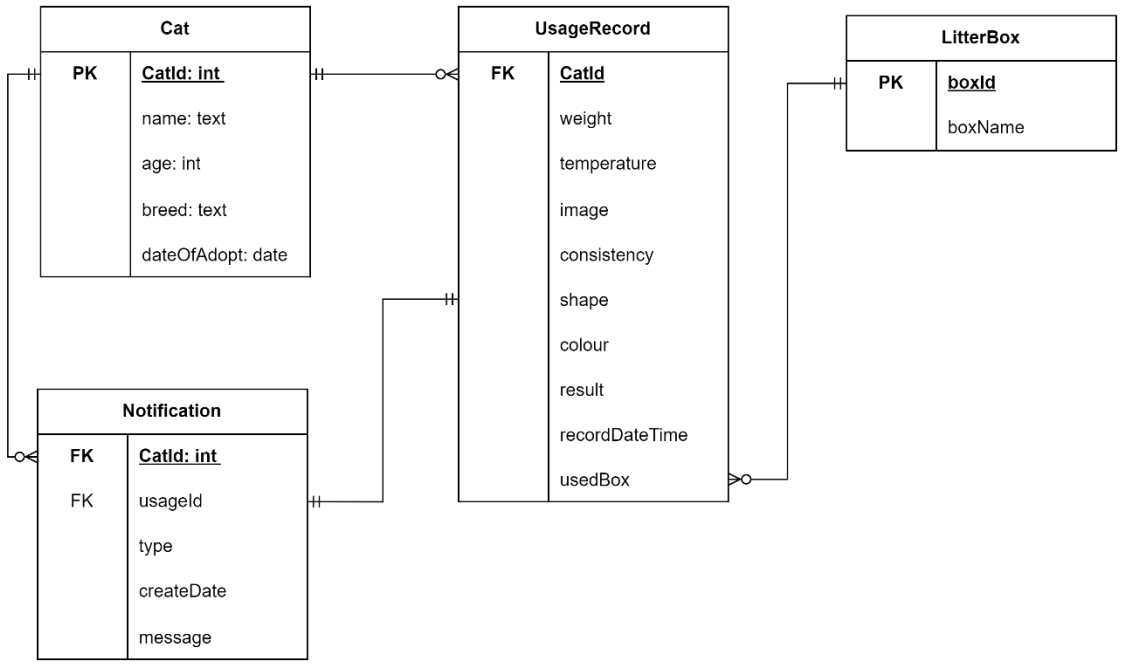


Figure 3.9. Entity Relationship Diagram of Health Monitoring System

3.4 Interface Design

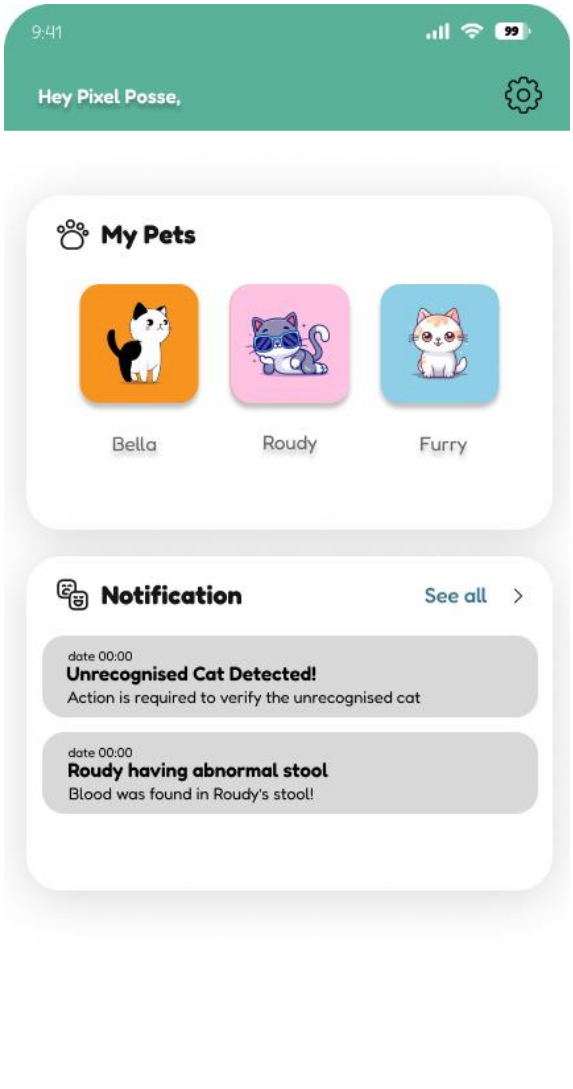


Figure 3.10 User Interface (Home Page)

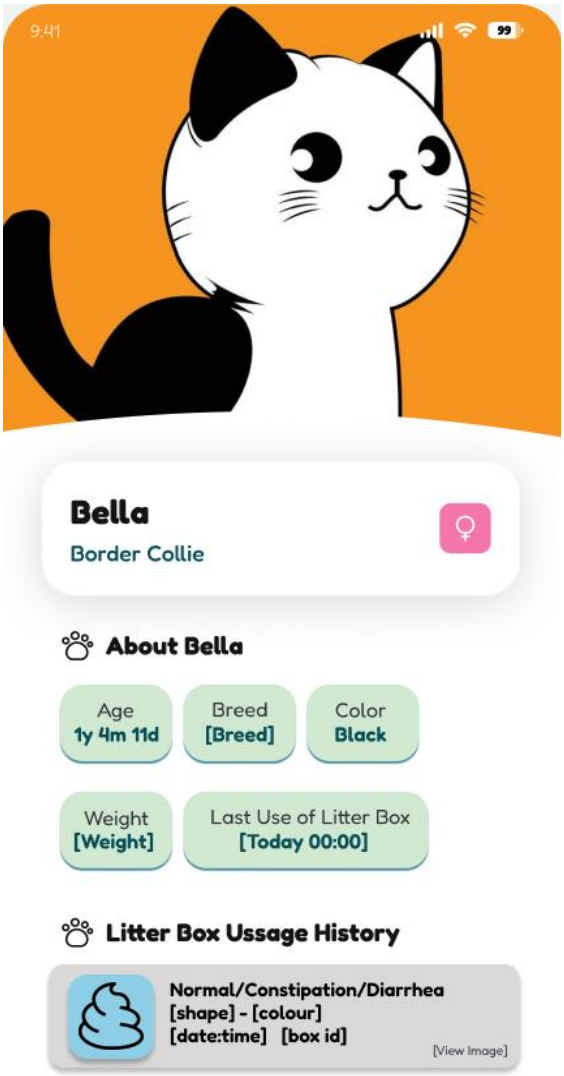


Figure 3.11. User Interface (Cat Profile)

Figure 3.12.User Interface (Waste Details Page)

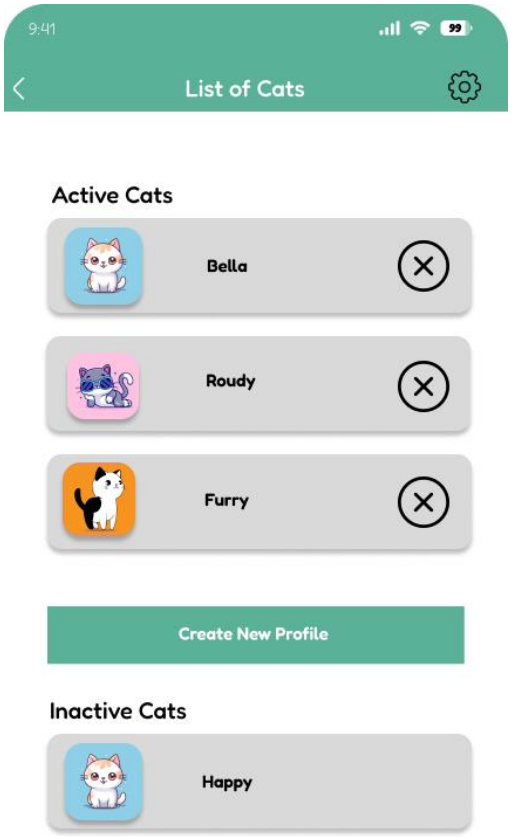


Figure 3.13. User Interface (List of Cats)

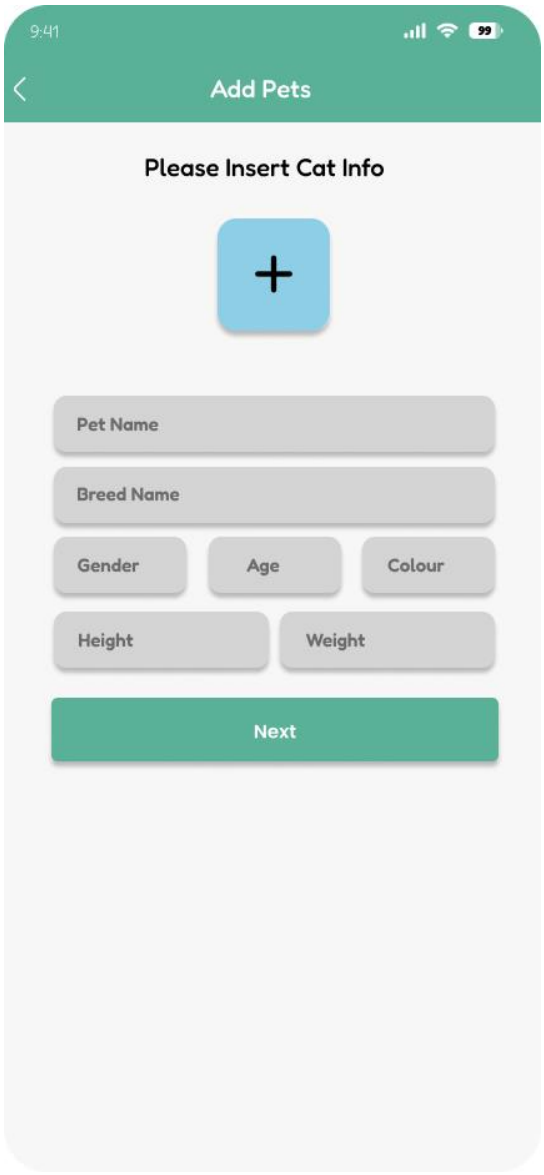


Figure 3.14. User Interface (Create Cat Profile)

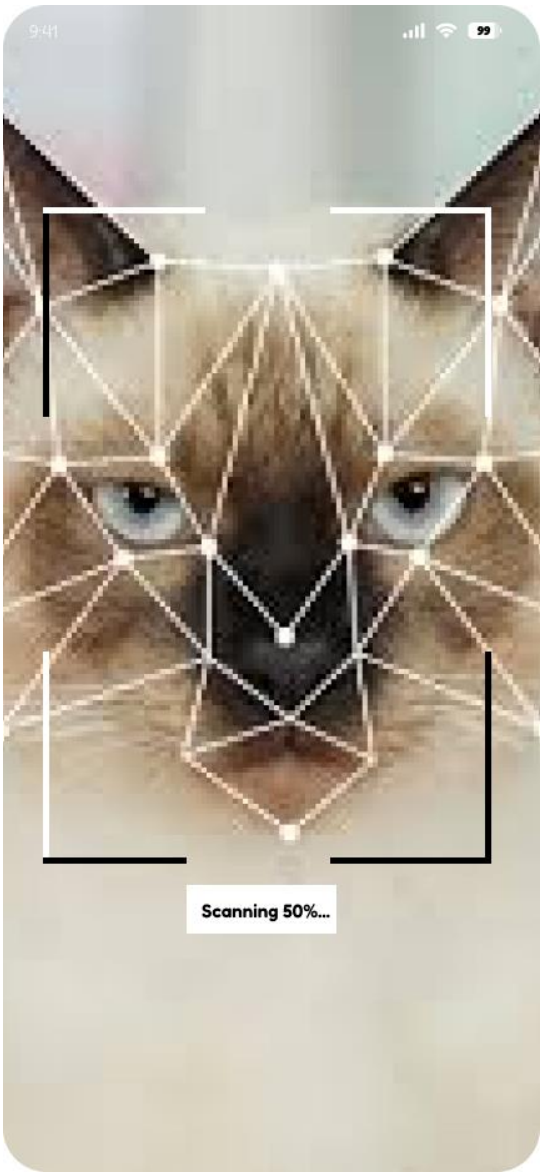


Figure 3.15.User Interface (Cat Face Scanning)

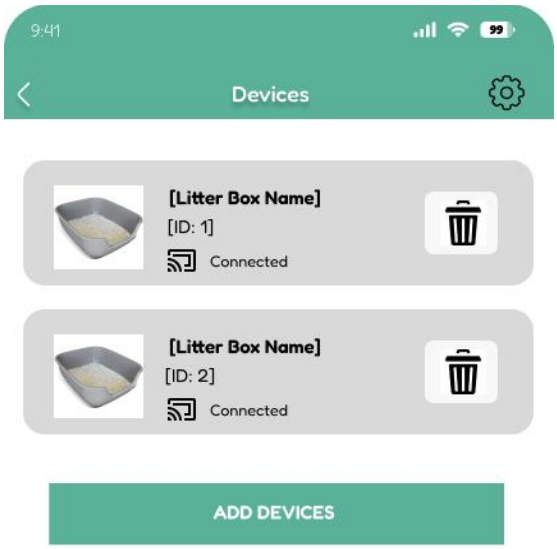


Figure 3.16 User Interface (List of Connected Device)

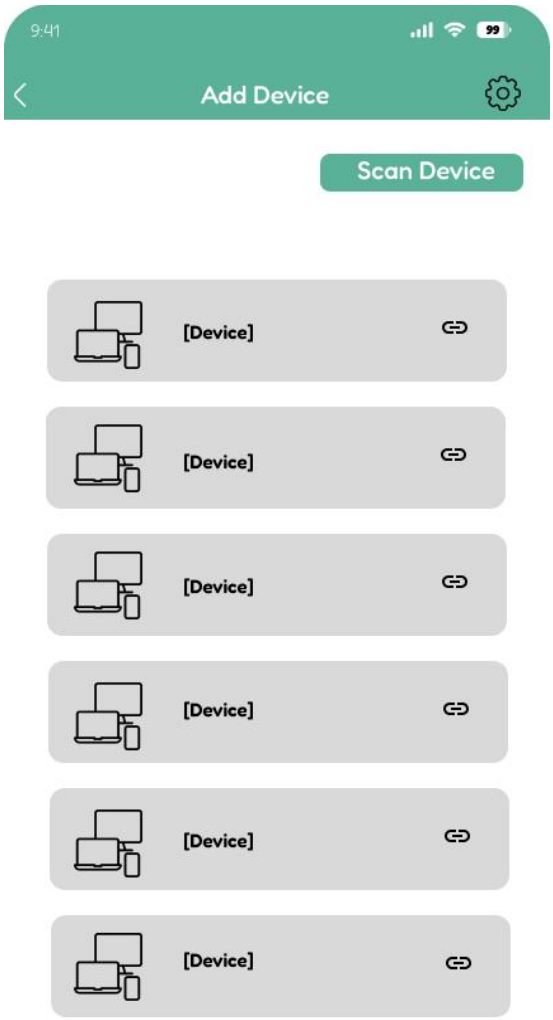


Figure 3.17. User Interface (Add Device)

3.5 Summary

In conclusion, this System Requirements and Specification report is an important document for guiding the development of the proposed system. Through fact-finding techniques, including observation of multi-cat households and consultations with veterinarians, a comprehensive understanding of user needs, and system requirements has been achieved.

The process of requirement specification has been supported by the creation of various diagrams, including UML diagrams such as use case diagrams, sequence diagrams, and activity diagrams. These diagrams illustrating the interactions between system components, identifying key functionalities, and mapping out the flow of activities within the system. Additionally, the development of an Entity-Relationship Diagram (ERD) for the database architecture and user interface mock-ups further enhances the clarity and understanding of system requirements.

Overall, this report serves as a blueprint for the development of faeces monitoring system with the use of smart cat litter box. By clearly defining the requirements and specifications through these visual representations, a clearer vision of the proposed system's capabilities and functionalities are gain when come to implementation and development of the system.

CHAPTER 4: System Design

4.0 Overview

This chapter provides a comprehensive description of the user interfaces designed for the mobile application. Each interface is explained in detail, highlighting the available features and services that enhance the user experience. The tools used to design these interfaces include Figma, which facilitated the creation of intuitive and visually appealing layouts.

4.1 User Interface 1: Home Page

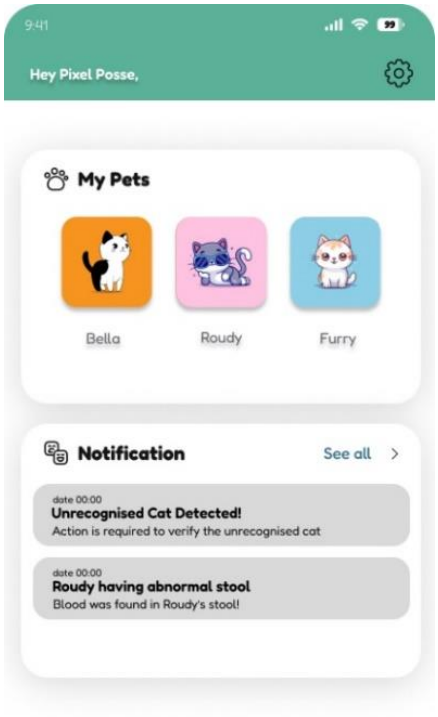


Figure 4.1 User Interface (Home Page)

4.1.1 Interface Description

This interface is the initial page when user open the mobile application. It shows all active cats in grid in the “My Pets” section. In the “Notification” section, unread notifications will be display in list view.

4.1.2 Available Features and Services

Feature include navigate to cat profile page when click on the cat in My Pets section. Besides, navigate to the cat stool details page when click on the notification tile.

4.2 User Interface 2: Cat Profile

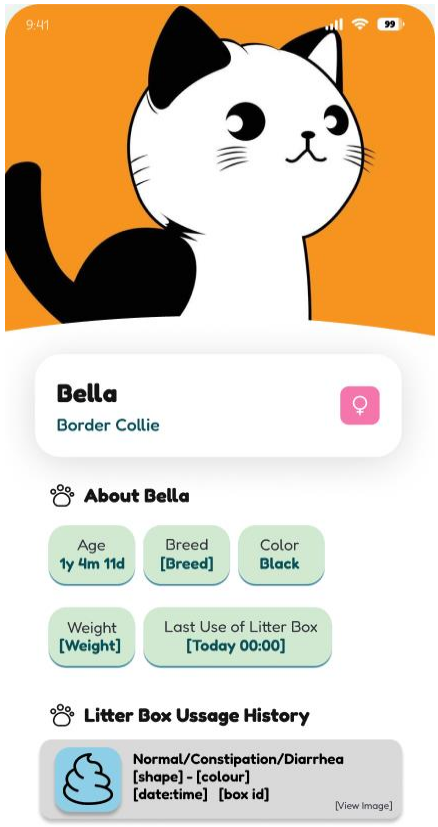


Figure 4.2. Interface of Cat Profile

4.2.1 Interface Description

This interface displays the profile image of cat, follow with name and other cat details that insert by user when creating a cat profile. Besides, the interface displays a list of litterbox usage history in tiles.

4.2.2 Available Features and Services

The feature in this interface includes edit of cat details by clicking the edit button at the top right corner, then user could edit the field age, breed, colour, and gender.

Other feature includes navigate user to stool details page when clicking a tile of usage history.

4.3 User Interface 3: Stool Details Page

Figure 4.3. Interface of View Image

4.3.1 Interface Description

This interface shows the image of the waste, result of analysis of the waste with the shape and colour, and also display when and which litterbox the waste is captured. Other than viewing, the page has download and share button that allow user to download the waste image to gallery, and the share button to share image to social media.

4.3.2 Available Features and Services

The service include in this interface is gallery access where image save when user click on the download button.

Other than that, sharing service which get all available social media in user phone and allow user to select them to share.

4.4 User Interface 4: List of Cats Page

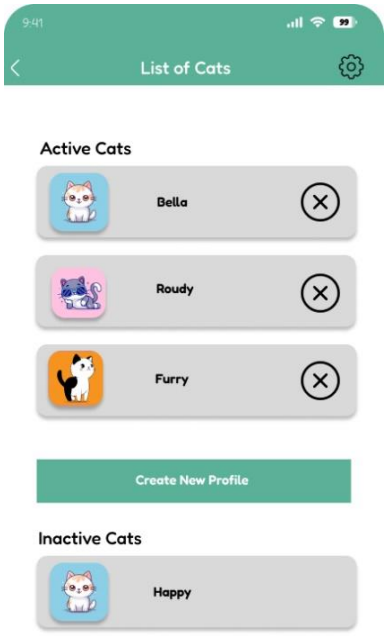


Figure 4.4. List of Cats

4.4.1 Interface Description

This interface displays all cats in a list including inactive cats that have been remove from the system. But the list is separate into two section, which on top is active cat, and bottom section is cats that user have been removed. User can manage active cats in this interface, add new cat and view profile and usage history of inactive cats.

4.4.2 Available Features and Services

Feature that includes in this interface is remove active cat by clicking the delete button beside the corresponding cat tile. Other than that, it will navigate user to create cat profile page after user click on the “CREATE NEW PROFILE” button.

4.5 User Interface 5: Create Cat Profile Page

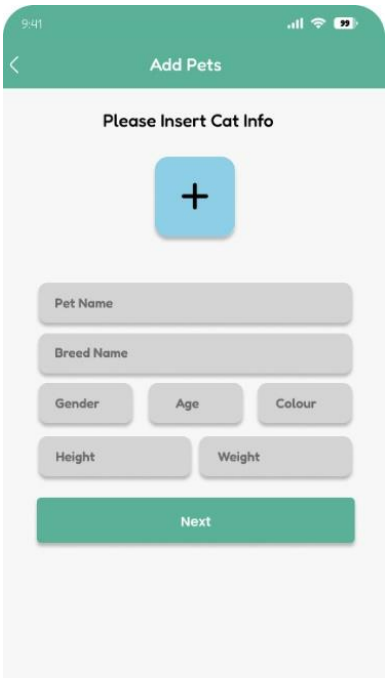


Figure 4.5. User Interface of Create Cat Profile

4.5.1 Interface Description

This interface is a form purpose to let user to insert cat information to create a new cat profile in the system. The field to be fill include add a profile picture, insert cat name, breed, gender, age, colour, and weight.

4.5.2 Available Features and Services

One feature is user can choose to take capture an image or pick an image from gallery to add the cat profile picture.

The feature that includes in this interface is field validation when user click on the “NEXT” button. The validation include profile image and cat name cannot be empty, breed name cannot be numerical, age, height, and weight cannot be alphabetic. Error message will display at the bottom to indicate which validation error user have encountered. If all field is validated, the page will navigate user to create cat profile image capture page.

Services include permission and access to gallery or mobile camera when adding the cat profile image

4.6 User Interface 6: Scanning Page

Figure 4.6. User Interface (Cat Face Scanning)

4.6.1.1 Interface Description

This interface is a camera view that allow user to take picture of their new cat's front, side, and back to add the cat into database.

4.6.1.2 Available Features and Services

The service include in this interface is camera. Which the images capture are then use for identification purpose

4.7 User Interface 7: Manage Devices

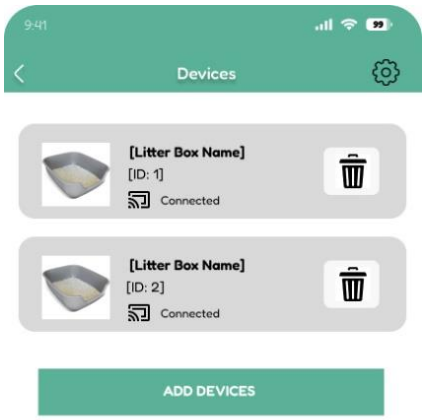


Figure 4.7. User Interface (List of Connected Device)

4.7.1.1 Interface Description

This interface allow user to manage connected cat litterbox by adding new cat litter box and remove the connected cat litterbox from the system.

4.7.1.2 Available Features and Services

Features include adding new cat litterbox by clicking the “ADD DEVICE” button. The next feature is remove the connected cat litterbox from the system by clicking the “trash icon”.

Services such as Bluetooth scanning nearby device is add in this interface which allow users to look for the new cat litterbox for connection.

4.8 Summary

In summary, this chapter outlined seven distinct mobile interfaces that are integral to the system:

Home Page: Displays all active cats and unread notifications, allowing users to navigate to cat profiles or stool details pages.

Cat Profile: Shows detailed information about the cat along with a history of litterbox usage, with links to stool details.

Stool Details Page: Presents an image and analysis of the waste, with options to download or share the image.

List of Cats Page: Lists all cats, both active and inactive, enabling users to manage cat profiles and view usage history.

Create Cat Profile Info Page: A form for entering and validating new cat information, with options for image capture or gallery selection.

Create Cat Profile Image Capture Page: A camera interface for capturing images of the new cat for identification purposes.

Manage Devices: Allows users to add or remove connected cat litterboxes, with Bluetooth scanning for new devices.

Each interface is designed to provide intuitive navigation and essential functionalities, ensuring that users can efficiently manage their cats and monitor their health through the application.

CHAPTER 5: DATA PROCESSING & IMPLEMENTATION

5.0 Overview

This chapter provides a comprehensive view of the tools and technologies utilized, including Python, Flutter, Dart, Google Colab, VS Code, Firebase, Image Label Studio, and YOLOv5. It covers the entire workflow from data collection and labelling to model development and system deployment. Specifically, it highlights the methods used to train and evaluate both object detection and cat recognition models, detailing the steps involved in setting up and managing the system's functionality, including camera integration, mobile application development, and overall system design.

5.1 Development Tools & Technologies

In this section, the tools and technologies used for the development of the project are listed and explained.

5.1.1 Python

Python is a versatile and widely used programming language that is particularly well-suited for data analysis, machine learning, and artificial intelligence projects. Its extensive libraries and frameworks, such as TensorFlow, PyTorch, and OpenCV, facilitate efficient development and implementation of complex algorithms. Python's readability and ease of use make it an ideal choice for rapid prototyping and iterative development in machine learning projects.

5.1.2 Flutter, Dart

Flutter is an open-source UI software development kit created by Google, while Dart is the programming language used to write Flutter applications. Flutter allows for the development of natively compiled applications for mobile, web, and desktop from a single codebase. Using Flutter and Dart ensures a smooth and responsive user interface, which is crucial for applications that require real-time interaction and data visualization.

5.1.3 Google Colab

Google Colab is a cloud-based platform that provides free access to computational resources, including GPUs and TPUs, making it ideal for training machine learning models. It supports Python and offers an interactive environment where code can be written, executed, and shared seamlessly. Google Colab's integration with Google Drive allows for easy data storage and management, facilitating collaborative development and experimentation.

5.1.4 VS Code

Visual Studio Code (VS Code) is a lightweight but powerful source code editor that supports a wide range of programming languages and development tools. It offers features such as debugging, version control integration, and extensions for various programming needs. VS Code's flexibility and customization options make it an excellent choice for writing, testing, and debugging code in diverse project environments.

5.1.5 Firebase

Firebase is a platform developed by Google for creating mobile and web applications. It provides a suite of cloud services, including real-time databases, authentication, and analytics, which streamline backend development and ensure scalable and secure data management. Using Firebase allows developers to focus on building robust and user-friendly applications without worrying about infrastructure and server management.

5.1.6 Image Label Studio

Image Label Studio is an open-source data labelling tool that supports various types of data annotation, including image, text, and audio. It provides a user-friendly interface for creating and managing annotations, which is essential for generating high-quality labelled datasets. Accurate data labelling is critical for training reliable machine learning models, and Image Label Studio facilitates this process with its powerful annotation features and collaboration capabilities.

5.1.7 YOLOv5

YOLOv5 (You Only Look Once, version 5) is a state-of-the-art object detection model that is known for its speed and accuracy. It processes images in real-time, making it suitable for applications that require rapid detection and classification of objects. YOLOv5's architecture and pre-trained weights enable efficient training and deployment of custom object detection models, making it a preferred choice for tasks involving image recognition and classification.

5.2 Data Collection and Label

Figure 5.1 Motion Sensor Camera

A camera system was set up to continuously capture images documenting a cat's interactions within a litter box whenever motion was detected. This setup aimed to gather comprehensive visual data of the cat and the associated stool deposits. From the collected dataset, images featuring the cat's stool were selected. To enhance the dataset's robustness, additional images of various stool types obtained from online sources were incorporated. Both the cat's stool and the supplementary stool samples from the internet were categorized based on their shape and colour attributes and labelled with bounding boxes. This categorization was performed with the assistance of veterinary professionals, who provided expert labelling to ensure the accuracy of the classifications.

5.3 Machine Learning Model Development

5.3.1 Object Detection Model

The object detection model is trained using YOLOv5 with a dataset that includes 14 annotated classes. These classes are: "cat", various stool colours such as "black", "brown", "green", "red", "white flecks", and "yellow", as well as "poop" and "scoop". Additionally, the dataset includes annotations for stool shapes including "firm", "hard", "loose", and "watery", as well as "urine"

The dataset utilized for training consists of 100 images. The training process was conducted on the Google Colab platform.

5.3.2 Prepare Libraries

```
[ ]  !git clone https://github.com/ultralytics/yolov5
     !cd yolov5
```

Figure 5.2. Cloning yolov5

This command uses Git to clone the YOLOv5 repository into the working directory, creating a local copy of the code. This allows access to the YOLOv5 model for object detection tasks. By cloning the repository, it is possible to customize, train, and test the model on various datasets, as well as take advantage of the pre-built functionalities and scripts provided by the YOLOv5 project.

5.3.3 Import Images

The images use for training are split into train, validation, and test manually.

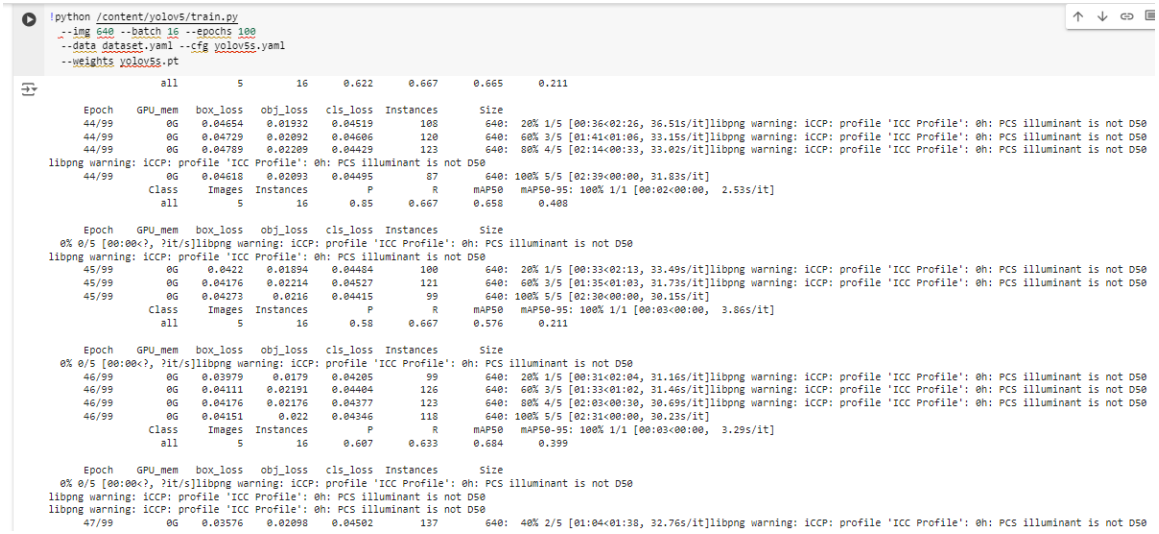
```
# dataset.yaml

train: /content/images/train  # path to training images
val: /content/images/validation      # path to validation images

# Number of classes
nc: 14

# Class names
names: ["cat",
              "color: black",
              "color: brown",
              "color: green",
              "color: red",
              "color: white flecks",
              "color: yellow",
              "poop",
              "scoop",
              "shape: firm",
              "shape: hard",
              "shape: loose",
              "shape: watery",
              "urine"]

lr0: 0.01  # initial learning rate
lrf: 0.1   # final learning rate
momentum: 0.937
weight_decay: 0.0005
```

Figure 5.3. dataset.yaml

The dataset.yaml file is utilized to define the configuration and structure of a dataset in a machine learning project. Within this file, the directories for storing training and validation images are specified, allowing the model to access and process these images during the training and evaluation phases.

Additionally, the file lists all class names pertinent to the dataset. Each class represents a label that the model is trained to detect.

5.3.4 Train



```
!python /content/yolov5/train.py
 --img 640 --batch 16 --epochs 100
 --data dataset.yaml --cfg yolov5s.yaml
 --weights yolov5s.pt

                 all          5         16      0.622      0.667      0.665      0.211

      Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
      44/99         0G    0.04654    0.01932    0.04519        108        640:  20% 1/5 [00:36<02:26, 36.51s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      44/99         0G    0.04729    0.02092    0.04606        120        640:  60% 3/5 [01:41<01:06, 33.15s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      44/99         0G    0.04789    0.02209    0.04429        123        640:  80% 4/5 [02:14<00:33, 33.02s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      44/99         0G    0.04618    0.02093    0.04495         87        640: 100% 5/5 [02:39<00:00, 31.83s/it]
                Class     Images  Instances          P          R      mAP50   mAP50-95: 100% 1/1 [00:02<00:00,  2.53s/it]
                  all          5         16      0.85      0.667      0.658      0.408

      Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
  0% 0/5 [00:00<?, ?it/s]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      45/99         0G     0.0422    0.01894    0.04484        100        640:  20% 1/5 [00:33<02:13, 33.49s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      45/99         0G    0.04176    0.02214    0.04527        121        640:  60% 3/5 [01:35<01:03, 31.73s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      45/99         0G    0.04273     0.0216    0.04415         99        640: 100% 5/5 [02:30<00:00, 30.15s/it]
                Class     Images  Instances          P          R      mAP50   mAP50-95: 100% 1/1 [00:03<00:00,  3.86s/it]
                  all          5         16      0.58      0.667      0.576      0.211

      Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
  0% 0/5 [00:00<?, ?it/s]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      46/99         0G    0.03979     0.0179    0.04205         99        640:  20% 1/5 [00:31<02:04, 31.16s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      46/99         0G    0.04111    0.02191    0.04404        126        640:  60% 3/5 [01:33<01:02, 31.46s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      46/99         0G    0.04176    0.02176    0.04377        123        640:  80% 4/5 [02:03<00:30, 30.69s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      46/99         0G    0.04151      0.022    0.04346        118        640: 100% 5/5 [02:31<00:00, 30.23s/it]
                Class     Images  Instances          P          R      mAP50   mAP50-95: 100% 1/1 [00:03<00:00,  3.29s/it]
                  all          5         16      0.607      0.633      0.684      0.399

      Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
  0% 0/5 [00:00<?, ?it/s]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50
      47/99         0G    0.03576    0.02098    0.04502        137        640:  40% 2/5 [01:04<01:38, 32.76s/it]libpng warning: iCCP: profile 'ICC Profile': 0h: PCS illuminant is not D50

100 epochs completed in 4.391 hours.
Optimizer stripped from yolov5/runs/train/exp2/weights/last.pt, 14.5MB
Optimizer stripped from yolov5/runs/train/exp2/weights/best.pt, 14.5MB

Validating yolov5/runs/train/exp2/weights/best.pt...
Fusing layers...
YOLOv5s summary: 157 layers, 7047883 parameters, 0 gradients, 15.9 GFLOPs
                 Class     Images  Instances          P          R      mAP50   mAP50-95: 100% 1/1 [00:02<00:00,  2.34s/it]
                   all          5         16      0.857      0.633      0.695      0.493
                   cat          5          3      0.795          1      0.995      0.746
          color: brown          5          3      0.732          1      0.995      0.699
            color: red          5          1          1          0          0          0
                  poop          5          5      0.668        0.8      0.938      0.598
           shape: firm          5          3      0.948          1      0.995      0.715
          shape: loose          5          1          1          0      0.249      0.199
Results saved to yolov5/runs/train/exp2
```

Figure 5.4 YOLOv5 Object Detection Training

This command initiates the training process of a YOLOv5 object detection model with the specified settings: an image size of 640x640 pixels, a batch size of 16 images per batch, and 100 training epochs. It uses the dataset configuration defined in dataset.yaml, the model architecture specified in yolov5s.yaml (located in the cloned repository), and pre-trained weights loaded from yolov5s.pt, which are also included in the cloned repository.

5.3.4.1 Result Of Object Detection Model

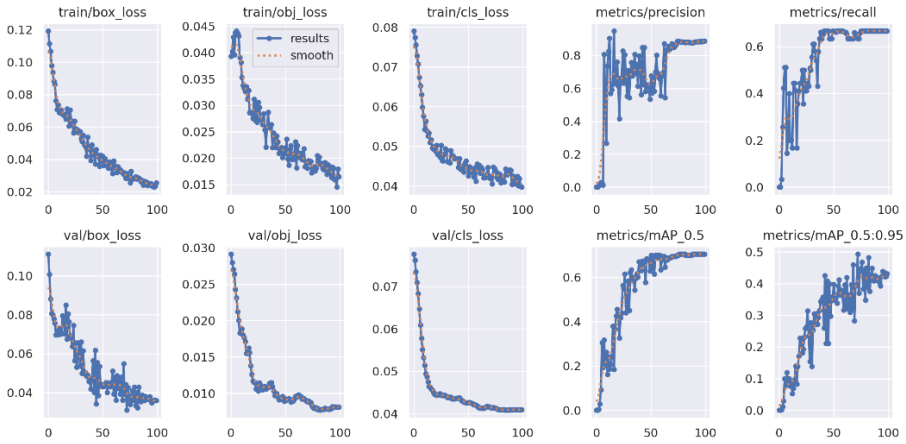


Figure 5.5. YOLOv5 Training Loss

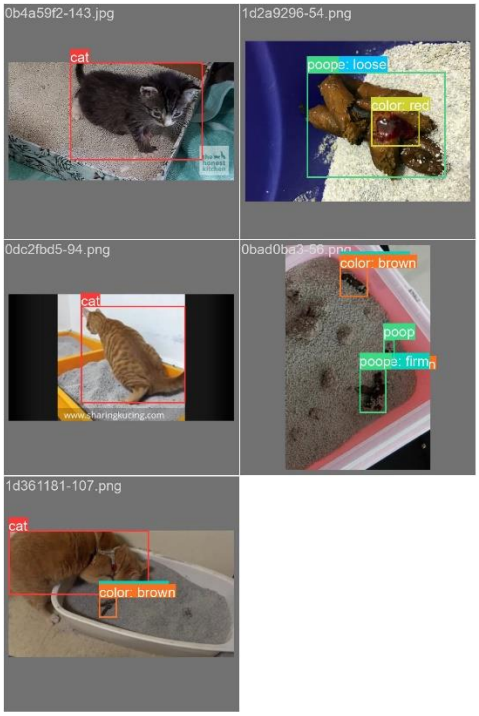


Figure 5.6. Validation with Actual Label

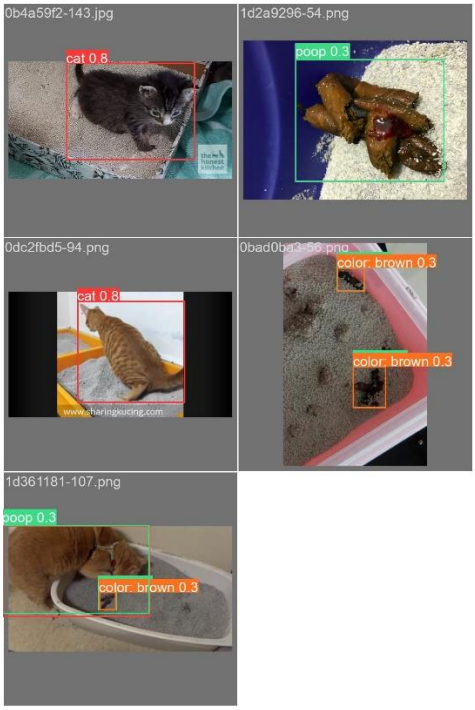


Figure 5.7. Validation with Predicted Label

The YOLOv5s model shows varying performance across different classes. It performs well on some classes like "cat" and "shape: firm," achieving high precision and recall. However, it struggles with others, such as "color: red" and "shape: loose," where the model either fails to detect instances or has poor precision and recall.

5.3.5 Cat Recognition Model

5.3.5.1 Import Libraries

```
[ ]  import tensorflow as tf
     from tensorflow.keras.models import Sequential
     from tensorflow.keras.layers import Conv2D, MaxPooling2D, Flatten, Dense, Dropout
     from tensorflow.keras.preprocessing.image import ImageDataGenerator
     import os
```

Figure 5.8. Import Libraries

The imported libraries are crucial for constructing and training a convolutional neural network (CNN) using TensorFlow and Keras. TensorFlow serves as the foundational framework for model training and evaluation, offering robust and scalable tools for deep learning. Keras, integrated within TensorFlow, streamlines the model-building process by providing a high-level API that simplifies the creation and management of neural network layers. Additionally, the ImageDataGenerator class plays a significant role in data augmentation and pre-processing, facilitating real-time transformation of image data to enhance model robustness and generalization. Together, these libraries and tools collectively support the efficient development and implementation of advanced image classification models.

5.3.5.2 Pre-processing

```
[ ] train_datagen = ImageDataGenerator(
        rescale=1./255,
        shear_range=0.2,
        zoom_range=0.2,
        horizontal_flip=True
    )

    validation_datagen = ImageDataGenerator(rescale=1./255)

    train_generator = train_datagen.flow_from_directory(
        'images/train',
        target_size=(150, 150),
        batch_size=4,
        class_mode='categorical'
    )

    validation_generator = validation_datagen.flow_from_directory(
        'images/validate',
        target_size=(150, 150),
        batch_size=4,
        class_mode='categorical'
    )
```

```
Found 38 images belonging to 4 classes.
Found 13 images belonging to 4 classes.
```

Figure 5.9. Data Generator

The ImageDataGenerator class is used to generate batches of tensor image data with real-time data augmentation. Augmentation and pre-processing include rescale, shear, zoom, and horizontal flip is performed. Pixel values of the images is normalized by scaling them to the range [0, 1], achieved by dividing each pixel value by 255. Additionally, applies random shearing transformations within a 20% range, which aids in the model's generalization by simulating various viewpoints. It also performs random zooms within a 20% range to enhance the model's invariance to minor scale changes. Furthermore, images are randomly flipped horizontally, which increases the variety of the dataset and improves the model's robustness, particularly when the horizontal orientation of objects is not fixed.

For the validation dataset, only normalization is applied using rescale=1./255. The validation data is not augmented to ensure that the evaluation of the model's performance is conducted on data that is as close as possible to the real-world distribution.

The training and validation data generators are created to read images and apply the specified augmentations and pre-processing steps. These generators resize all images to a standardized dimension of 150x150 pixels, ensuring uniform input size compatible with the neural network architecture. The batch size is configured to 4, which is appropriate given the relatively small size of the dataset.

5.3.5.3 Build CNN Model

```
[ ]  model = Sequential()

     model.add(Conv2D(32, (3, 3), activation='relu', input_shape=(150, 150, 3)))
     model.add(MaxPooling2D((2, 2)))

     model.add(Conv2D(64, (3, 3), activation='relu'))
     model.add(MaxPooling2D((2, 2)))

     model.add(Conv2D(128, (3, 3), activation='relu'))
     model.add(MaxPooling2D((2, 2)))

     model.add(Flatten())
     model.add(Dense(512, activation='relu'))
     model.add(Dropout(0.5))
     model.add(Dense(train_generator.num_classes, activation='softmax'))
```

```
[ ]  model.compile(optimizer='adam',
                   loss='categorical_crossentropy',
                   metrics=['accuracy'])
```

```
[ ]  model.summary()
```

```
Model: "sequential_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_6 (Conv2D)           (None, 148, 148, 32)      896

 max_pooling2d_6 (MaxPoolin  (None, 74, 74, 32)        0
 g2D)

 conv2d_7 (Conv2D)           (None, 72, 72, 64)        18496

 max_pooling2d_7 (MaxPoolin  (None, 36, 36, 64)        0
 g2D)

 conv2d_8 (Conv2D)           (None, 34, 34, 128)       73856

 max_pooling2d_8 (MaxPoolin  (None, 17, 17, 128)       0
 g2D)

 flatten_2 (Flatten)         (None, 36992)             0

 dense_4 (Dense)             (None, 512)               18940416

 dropout_2 (Dropout)         (None, 512)               0

 dense_5 (Dense)             (None, 4)                 2052

=================================================================
Total params: 19035716 (72.62 MB)
Trainable params: 19035716 (72.62 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

Figure 5.10. Build CNN Model

The convolutional neural network (CNN) model is constructed using the Sequential API from Keras, which facilitates the linear stacking of layers to build the network architecture. The model begins with a Conv2D layer that applies 32 convolutional filters, each with a 3x3 kernel size, using the ReLU activation function. This layer processes input images of size 150x150 pixels with three colour channels (RGB). The subsequent MaxPooling2D layer performs down-sampling with a 2x2 pooling window, reducing the spatial dimensions while retaining important feature information.

The model continues with an additional Conv2D layer featuring 64 filters, followed by another MaxPooling2D layer, and then a third Conv2D layer with 128 filters, again succeeded by a MaxPooling2D layer. These convolutional and pooling layers sequentially extract increasingly complex features from the input images, enabling the network to learn hierarchical representations.

Following the convolutional layers, the model incorporates a Flatten layer to transform the 2D feature maps into a 1D vector, which is then passed to a fully connected Dense layer with 512 units and ReLU activation. A Dropout layer with a dropout rate of 0.5 is included to mitigate overfitting by randomly setting half of the neurons to zero during training. The final layer is a Dense layer with a number of units equal to the number of classes in the dataset, employing the softmax activation function to produce probability distributions over the classes.

The model is compiled with the Adam optimizer, which adapts the learning rate during training, and uses categorical cross-entropy as the loss function, appropriate for multi-class classification problems. The performance of the model is evaluated based on accuracy, which measures the proportion of correctly classified instances.

5.3.5.4 Train Model

```
# Ensure non-zero steps

history = model.fit(
    train_generator,
    steps_per_epoch=10,
    epochs=25,
    validation_data=validation_generator,
    validation_steps=10
)
```

```
Epoch 1/25
10/10 [==============================] - ETA: 0s - loss: 0.5526 - accuracy: 0.8421WARNING:ten
10/10 [==============================] - 9s 839ms/step - loss: 0.5526 - accuracy: 0.8421 - va
Epoch 2/25
10/10 [==============================] - 7s 687ms/step - loss: 0.6265 - accuracy: 0.7895
Epoch 3/25
10/10 [==============================] - 9s 852ms/step - loss: 0.6448 - accuracy: 0.7895
Epoch 4/25
10/10 [==============================] - 7s 671ms/step - loss: 0.3745 - accuracy: 0.8158
Epoch 5/25
10/10 [==============================] - 9s 846ms/step - loss: 0.2545 - accuracy: 0.9211
Epoch 6/25
10/10 [==============================] - 7s 674ms/step - loss: 0.6939 - accuracy: 0.7895
Epoch 7/25
10/10 [==============================] - 9s 818ms/step - loss: 0.5985 - accuracy: 0.7368
Epoch 8/25
10/10 [==============================] - 8s 764ms/step - loss: 0.3384 - accuracy: 0.8947
Epoch 9/25
10/10 [==============================] - 7s 670ms/step - loss: 0.3546 - accuracy: 0.8421
Epoch 10/25
10/10 [==============================] - 9s 827ms/step - loss: 0.3011 - accuracy: 0.8947
Epoch 11/25
10/10 [==============================] - 7s 686ms/step - loss: 0.1385 - accuracy: 0.9474
Epoch 12/25
10/10 [==============================] - 7s 676ms/step - loss: 0.1079 - accuracy: 0.9211
```

Figure 5.11. CNN Model Training

This configuration trains the CNN model for 25 epochs, with the model updating its weights based on 10 batches of training data per epoch and assessing its performance on 10 batches of validation data after each epoch.

5.3.5.5 Evaluation

```
[ ]  loss, accuracy = model.evaluate(validation_generator)
     print(f'Validation Loss: {loss}')
     print(f'Validation Accuracy: {accuracy}')
```

```
4/4 [==============================] - 1s 305ms/step - loss: 0.8812 - accuracy: 0.8462
Validation Loss: 0.8812367916107178
Validation Accuracy: 0.8461538553237915
```

Figure 5.12. CNN Validation Accuracy

The near equality of training and validation metrics suggests that the model has achieved a balanced performance, effectively generalizing to new data without significant overfitting. The validation accuracy and loss closely matching the training metrics imply that the model performs consistently across both training and validation datasets.

In summary, the model demonstrates good performance with an accuracy of around 84.62% on both training and validation sets, and a consistent loss value. This indicates that the model has learned effectively from the training data and maintains its performance on unseen validation data.

5.3.5.6 Result of Cat Identity Prediction

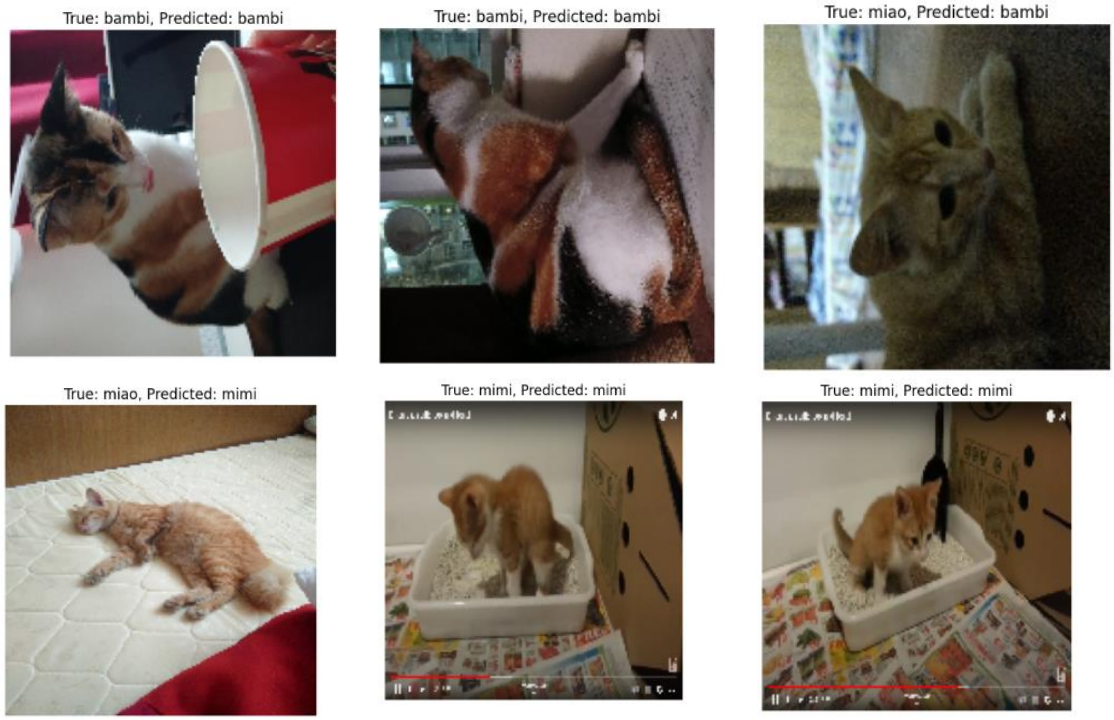


Figure 5.13. Result of Cat Identity Prediction

5.4 System Development

5.4.1 Camera

The code that handles the camera and model is written in python.

5.4.1.1 Functions

```python
def detect_poop_conditions(detection_results):
    # Initialize variables
    color = None
    shape = None

    # Define the possible categories
    color_categories = ['black', 'green', 'brown', 'red', 'white flecks', 'yellow']
    shape_categories = ['firm', 'hard', 'loose', 'watery']

    # Parse detections
    for _, row in detection_results.iterrows():
        label = row['name'].lower()  # Get label and make it lowercase for comparison

        # Check if the label matches any color category
        if label in color_categories:
            color = label

        # Check if the label matches any shape category
        if label in shape_categories:
            shape = label

    # Handle cases where no specific color or shape is detected
    if not color :
        color = 'unable to recognize'

    if not shape:
        shape = 'unable to recognize'

    return color, shape
```

Figure 5.14. detect_poop_condition function

The detect_poop_conditions function is designed to analyse the results from a YOLOv5 object detection model to identify specific characteristics of detected poop based on its color and shape. It takes as input a pandas Data Frame containing the detection results, where each row represents a detected object with attributes such as the class label and confidence scores. The function initializes variables for color and shape, defining lists of possible categories for each. As it processes each detection, it checks if the detected object's label matches any of these predefined categories. If a match is found, the corresponding variable is updated with the detected value. If neither color nor shape is detected, the function assigns the value 'unable to recognize' to both variables. Finally, the function returns a tuple containing the detected color and shape, or 'unable to recognize' for both if no specific characteristics are identified.

```python
def identify_cat(frame):
    # Preprocess the frame for TensorFlow Lite model
    input_data = cv2.resize(frame, (input_details[0]['shape'][1], input_details[0]['shape'][2]))
    input_data = np.expand_dims(input_data, axis=0)
    input_data = input_data.astype(np.float32) / 255.0

    # Set tensor
    interpreter.set_tensor(input_details[0]['index'], input_data)

    # Run inference
    interpreter.invoke()

    # Get output
    output_data = interpreter.get_tensor(output_details[0]['index'])
    return output_data  # Process output_data to get the identity or None if not recognized
```

Figure 5.15 identify cat function

The identify_cat function is responsible for recognizing the identity of a cat within a given image frame using a TensorFlow Lite model. It runs inference on the model by invoking the interpreter. After inference, the function retrieves the output tensor, which contains the model's prediction results. The function returns this output data, which should be further processed to determine the cat's identity or to recognize if the cat is not in the model's database.

```python
def assess_poop_condition(color, shape):
    if color == 'brown' or shape in ['firm', 'loose']:
        return 'normal'
    elif shape == 'watery':
        return 'diarrhea'
    elif shape == 'hard':
        return 'constipation'
    else:
        return 'abnormal color'
```

Figure 5.16. assess_poop_condition function

The assess_poop_condition function is designed to evaluate the condition of detected poop based on its color and shape and categorize it into a specific condition. The function takes two parameters: color and shape, which represent the detected color and shape of the poop, respectively.

The function checks if the color is 'brown' or if the shape is either 'firm' or 'loose'. If any of these conditions are met, it returns 'normal', indicating that the poop is considered to be within the typical range of healthy conditions. If the shape is 'watery', the function returns 'diarrhoea', If the shape is 'hard', it returns 'constipation'. For any other combination of color and shape that does not match these predefined categories, the function returns 'abnormal color'.

5.4.2 Main Code

```
# Load YOLOv5 model
yolo_model = torch.hub.load('ultralytics/yolov5', 'custom', path='litterbox_detection.pt')

# Load TensorFlow Lite model
interpreter = tf.lite.Interpreter(model_path='cat_identifier.tflite')
interpreter.allocate_tensors()
```

Figure 5.17. Load models

```
# Initialize webcam
cap = cv2.VideoCapture(0)

# Variables for tracking
last_cat_detection = None
cat_detected = False
last_detection_time = datetime.now()

while True:
    ret, frame = cap.read()
    if not ret:
        break

    # Perform YOLOv5 inference
    results = yolo_model(frame)

    # Process detections
    detections = results.pandas().xyxy[0]

    cat_detected = any(detection['name'] == 'cat' for _, detection in detections.iterrows())
    poop_detected = any(detection['name'] == 'poop' for _, detection in detections.iterrows())

    if cat_detected:
        last_cat_detection = datetime.now()
        # Identify cat
        identity = identify_cat(frame)
        if identity is None:
            identity = 'unknown'

    if poop_detected:
        color, shape = detect_poop_conditions(detections)
        if not color and not shape:
            color, shape = 'unable to recognize', 'unable to recognize'
        condition = assess_poop_condition(color, shape)
    else:
        color, shape = None, None
        condition = None

    # Check for no cat detection
    if cat_detected:
        last_detection_time = datetime.now()
```

```
137     if datetime.now() - last_detection_time > timedelta(seconds=5):
138         # Send data to Firebase
139         data = {
140             'timestamp': datetime.now(),
141             'cat': identity,
142             'color': color,
143             'shape': shape,
144             'condition': condition
145         }
146         db.collection('poop_detection').add(data)
147         
148         # Send notification if the condition is not 'normal'
149         if condition != 'normal':
150             send_notification(condition)
151 
152     # Display frame with detections
153     cv2.imshow('YOLOv5 Webcam Detection', frame)
154 
155     if cv2.waitKey(1) & 0xFF == ord('q'):
156         break
157 
158 cap.release()
159 cv2.destroyAllWindows()
```

Figure 5.18. Main Code

The provided code integrates YOLOv5 for object detection and TensorFlow Lite for cat identification within a real-time video feed from a webcam. The custom trained YOLOv5 model for detecting cat, faeces, shape and colour, and a TensorFlow Lite model for identifying cats is load. It initializes a webcam feed to capture live video frames.

In the main loop, each frame from the webcam is processed to perform object detection using YOLOv5. The results are analysed to determine if a cat or poop is detected. If a cat is detected, the script updates the timestamp of the last cat detection and uses the TensorFlow Lite model to identify the cat, defaulting to 'unknown' if the return of identify_cat function is none. For detected poop, the function `detects_poop_conditions` is used to determine the color and shape, which are then assessed to categorize the condition as 'normal', 'diarrhoea', 'constipation', or 'abnormal colour' using the `assess_poop_condition` function.

If no cat is detected for more than 5 seconds, the script sends the collected data, including timestamp, cat identity, color, shape, and condition, to a Firebase Firestore database. Additionally, if the condition is not 'normal', it triggers a notification to send notification to user mobile. The video frame with detections is displayed in a window, and the loop continues until the user presses 'q' to quit.

5.4.3 Mobile Application

This mobile application is developed using Flutter, Dart language.

5.4.3.1 Home Page

```
// cat tiles
if (cats.isNotEmpty)
  Padding(
    padding: const EdgeInsets.only(left: 20, right: 20),
    child: GridView.builder(
      shrinkWrap: true,
      gridDelegate:
          const SliverGridDelegateWithFixedCrossAxisCount(
        crossAxisCount: 3,
        crossAxisSpacing: 10,
        mainAxisSpacing: 50,
      ), // SliverGridDelegateWithFixedCrossAxisCount
      itemCount: cats.length,
      itemBuilder: (context, index) => CatTileSquare(
        cat: cats[index],
        onTap: () => navigateToCatDetailsPage(index),
      ), // CatTileSquare
    ), // GridView.builder
  ) // Padding
else
  Center(
    child: Text(
      "You have no cats.",
      style: GoogleFonts.fredoka(
        fontWeight: FontWeight.bold,
        fontSize: 25,
        color: greyForTile,
      ),
    ), // Text
```

Figure 5.19. List out all active cats

The following block of code is designed to display all active cats retrieved from the database in a grid view. Each button, representing a cat, allows the user to navigate to the corresponding cat profile upon being tapped. Additionally, a text message is displayed in the event that no active cats are found in the database.

```
309                 // notification tiles
310                 if (unviewNotifications.isNotEmpty)
311                   ListView.builder(
312                     shrinkWrap: true,
313                     scrollDirection: Axis.vertical,
314                     itemCount: unviewNotifications.length,
315                     itemBuilder: (context, index) => NotificationTile(
316                       notification: unviewNotifications[index],
317                       onTap: () => navigateToNotificationDetailsPage(index),
318                     ), // NotificationTile
319                   ) // ListView.builder
320                 else
321                   Container(
322                     height: 50,
323                     padding: EdgeInsets.only(left: 10, right: 10),
324                     child: _seeAllTextButton(25),
325                   ), // Container
```

Figure 5.20. List out unread notification

The provided block of code is designed to display all unread notifications. Upon interacting with a notification, the user is navigated to a page where they can view the full text of the message.

5.4.3.2 List of Usages of Litterbox in Cat Profile

```
134         Container(
135           height: 300,
136           padding: EdgeInsets.only(left: 50, right: 50),
137           child: cat.usages != null
138               ? ListView.builder(
139                   itemCount: cat.usages!.length,
140                   itemBuilder: (context, index) => UsageTile(
141                     usage: cat.usages![index],
142                     onTap: () {
143                       Navigator.push(
144                         context,
145                         MaterialPageRoute(
146                           builder: (context) =>
147                               StoolDetailsPage(usage: cat.usages![index]),
148                         ), // MaterialPageRoute
149                       );
150                     },
151                   ), // UsageTile
152                 ) // ListView.builder
153               : Center(
154                   child: Text('No usages available'),
155                 ), // Center
156         ), // Container
```

Figure 5.21. List of litter box usage history

The provided block of code displays a list of litter box usage history along with the corresponding results of cat waste. Each item in the list is represented as a usage tile, which, when clicked, navigates the user to a page displaying the full image of the cat waste.

5.4.3.3 Download or Share Image of Cat Waste

```
78                  Row(
79                    mainAxisAlignment: MainAxisAlignment.spaceAround,
80                    children: [
81                      ElevatedButton.icon(
82                        onPressed: () async {
83                          await downloadImage();
84                        },
85                        icon: Icon(Icons.download),
86                        label: Text("Download"),
87                      ), // ElevatedButton.icon
88                      ElevatedButton.icon(
89                        onPressed: () async {
90                          await shareImage();
91                        },
92                        icon: Icon(Icons.share),
93                        label: Text("Share"),
94                      ), // ElevatedButton.icon
95                    ],
96                  ), // Row
```

Figure 5.22. Layout of download and share button

```
105 Future<void> downloadImage() async {
106   try {
107     final byteData = await rootBundle.load('images/cat icon.png');
108     final Uint8List bytes = byteData.buffer.asUint8List();
109
110     final directory = await getTemporaryDirectory();
111     final String imagePath = '${directory.path}/cat_icon.png';
112     final File imgFile = File(imagePath);
113     await imgFile.writeAsBytes(bytes);
114
115     final result = await GallerySaver.saveImage(imagePath);
116     if (result != null && result) {
117       print("Image saved to gallery");
118     } else {
119       print("Error saving image to gallery");
120     }
121   } catch (e) {
122     print("Error downloading image: $e");
123   }
124 }
```

Figure 5.23 Download Image Function

```dart
Future<void> shareImage() async {
  try {
    final byteData = await rootBundle.load('images/cat icon.png');
    final Uint8List bytes = byteData.buffer.asUint8List();

    final directory = await getApplicationDocumentsDirectory();
    final File imgFile = File('${directory.path}/cat_icon.png');
    await imgFile.writeAsBytes(bytes);

    await FlutterShare.shareFile(
      title: 'Share Cat Icon',
      filePath: imgFile.path,
    );
  } catch (e) {
    print("Error sharing image: $e");
  }
}
```

Figure 5.24. Share Image Function

This page displays an image of the cat waste, along with detailed information at the bottom, including the condition, colour, shape, and capture date of the waste. In addition to viewing the image, users can utilize two features: download and share. The download feature allows users to save the waste image to their gallery, while the share feature enables users to share the image across all social media platforms.

5.4.3.4 Add Cat (Information)

```dart
child: catProfileImagePath == null
    ? IconButton(
        onPressed: _showImagePickerDialog,
        icon: Icon(
          Icons.add,
          size: 80,
          color: Colors.white, // Icon color
        ), // Icon
      ) // IconButton
    : Image.file(File(catProfileImagePath!)),
```

Figure 5.25. Button to pick image from gallery

```
children: <Widget>[
  GestureDetector(
    child: Text('Take a Photo'),
    onTap: () async {
      Navigator.of(context).pop();
      final pickedFile =
          await _picker.pickImage(source: ImageSource.camera);
      setState(() {
        if (pickedFile != null) {
          catProfileImagePath = pickedFile.path;
        }
      });
    },
  ), // GestureDetector
  Padding(padding: EdgeInsets.all(8.0)),
  GestureDetector(
    child: Text('Choose from Gallery'),
    onTap: () async {
      Navigator.of(context).pop();
      final pickedFile =
          await _picker.pickImage(source: ImageSource.gallery);
      setState(() {
        if (pickedFile != null) {
          catProfileImagePath = pickedFile.path;
        }
      });
    },
  ), // GestureDetector
], // <Widget>[]
```

Figure 5.26 _showImage PickerDialog function

The above code allow user to choose to take a photo or pick a image from gallery as the new cat profile picture and display it after taking photo or done picking picture from gallery.

5.4.3.5 Add Cat (Take Image for Whole Body)

```dart
Future<void> _initializeCamera() async {
  final cameras = await availableCameras();
  final firstCamera = cameras.first;

  _controller = CameraController(
    firstCamera,
    ResolutionPreset.high,
  );

  _initializeControllerFuture = _controller!.initialize();
  if (mounted) {
    setState(() {});
  }
}
```

Figure 5.27. Camera Initializer

```dart
child: FloatingActionButton(
  shape: CircleBorder(),
  child: Icon(Icons.circle, color: Colors.grey, size: 50),
  onPressed: () async {
    try {
      await _initializeControllerFuture;

      final image = await _controller!.takePicture();

      setState(() {
        imagePaths.add(image.path);
        if (currentStep < instructions.length - 1) {
          currentStep++;
        } else {
          // All pictures taken, handle accordingly
          Navigator.push(
            context,
            MaterialPageRoute(
              builder: (context) =>
                  DisplayPicturesScreen(imagePaths: imagePaths),
            ), // MaterialPageRoute
          );
        }
      });
    } catch (e) {
      print(e);
    }
  },
), // FloatingActionButton
```

Figure 5.28. Floating button for image taking

To capture a full-body image of the cat, four pictures are required: one from the front, one from the back, and one from each side (left and right). The provided code block checks the number of pictures taken each time the floating button is clicked and displays a new instruction accordingly.

5.4.3.6 Manage Cats

```
107             // list of all active cats
108             Expanded(
109               child: ListView.builder(
110                   itemCount: activeCats.length,
111                   itemBuilder: (context, index) =>
112                       CatTile(cat: activeCats[index], onTap: () {})), // ListView.builder
113             ), // Expanded
114
115             // list of all inactive cats
116             Expanded(
117               child: ListView.builder(
118                   itemCount: inactiveCats.length,
119                   itemBuilder: (context, index) =>
120                       CatTile(cat: inactiveCats[index], onTap: () {})), // ListView.builder
121             ), // Expanded
122
123             // add new cat button
124             Container(
125               height: 50,
126               width: 400,
127               decoration: BoxDecoration(
128                   color: primaryColor, borderRadius: BorderRadius.circular(10)), // BoxDecoration
129               child: TextButton(
130                 child: Text("Add Cat",
131                     style: TextStyle(color: Colors.white)), // Text
132                 onPressed: () {
133                   // navigate to add new cat info page
134                   Navigator.pushNamed(context,"/addcatinfopage");
135                 },
136               ), // TextButton
```

Figure 5.29. List of cats

On the cat list page, there are two sections: the top section displays a list of active cats, while the bottom section shows a list of removed cats. Users can manage the cats by removing those that are no longer in the household. However, the information of removed cats is not deleted, allowing users to still view their usage history and profile. At the bottom of the page, there is a button for adding a new cat. When clicked, the user is navigated to the add_cat_info_page.

5.4.3.7 Manage Litterbox

```
SizedBox(height: 20),
Expanded(
  child: ListView.builder(
      itemCount: devices.length,
      itemBuilder: (context, index) =>
          DeviceTile(device: devices[index], onTap: () {})), // ListView.builder
), // Expanded
Container(
  height: 50,width: 400,
  decoration: BoxDecoration(color: primaryColor, borderRadius: BorderRadius.circular(10))
  child: TextButton(
    child: Text("New Litterbox", style: TextStyle(color: Colors.white)),
    onPressed: () {
      _startScan();
    _showNearbyDevices(context);
    },
  ), // TextButton
) // Container
```

Figure 5.30. Manage Litterbox

```
FlutterBlue flutterBlue = FlutterBlue.instance;
List<BluetoothDevice> nearbyDevices = [];

void _startScan() {
  flutterBlue.startScan(timeout: Duration(seconds: 4));

  flutterBlue.scanResults.listen((results) {
    setState(() {
      nearbyDevices = results.map((r) => r.device).toList();
    });
  });

  flutterBlue.stopScan();
}
```

Figure 5.31. scan nearby device function

```
89  void _showNearbyDevices(BuildContext context) {
90    showModalBottomSheet(
91      context: context,
92      builder: (context) => ListView.builder(
93        itemCount: nearbyDevices.length,
94        itemBuilder: (context, index) {
95          final device = nearbyDevices[index];
96          return ListTile(
97            title: Text(device.name),
98            subtitle: Text(device.id.toString()),
99            onTap: () {
00              // Handle device selection
01              Navigator.pop(context);
02            },
03          ); // ListTile
04        },
05      ), // ListView.builder
06    );
07  }
```

Figure 5.32. Display nearby devices

The provided code presents a layout for displaying all connected devices. At the bottom of the layout, there is a button that allows the user to add a new litter box to the system. By clicking this button, the system begins scanning for all nearby devices and displays them for the user to select from. Once a device is selected, it is added to the system.

5.5 Overall System

5.5.1 Home Page

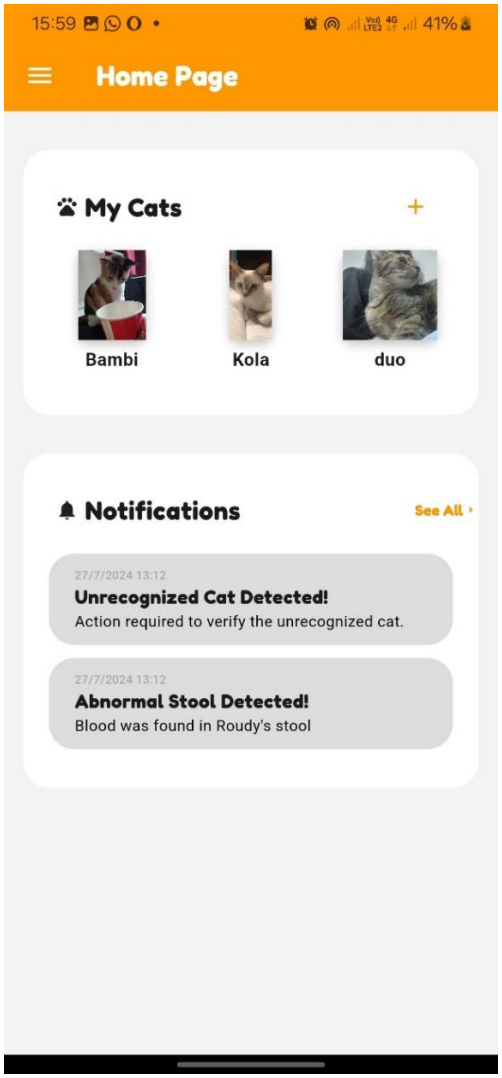


Figure 5.33. Developed Interface (Home Page)

This page serves as the initial screen when the user opens the application. It lists all active cats, allowing the user to view a cat's profile by clicking on the cat's image. The subsequent section is the notification section, which displays all unread notifications.

5.5.2 Side Navigation Bar

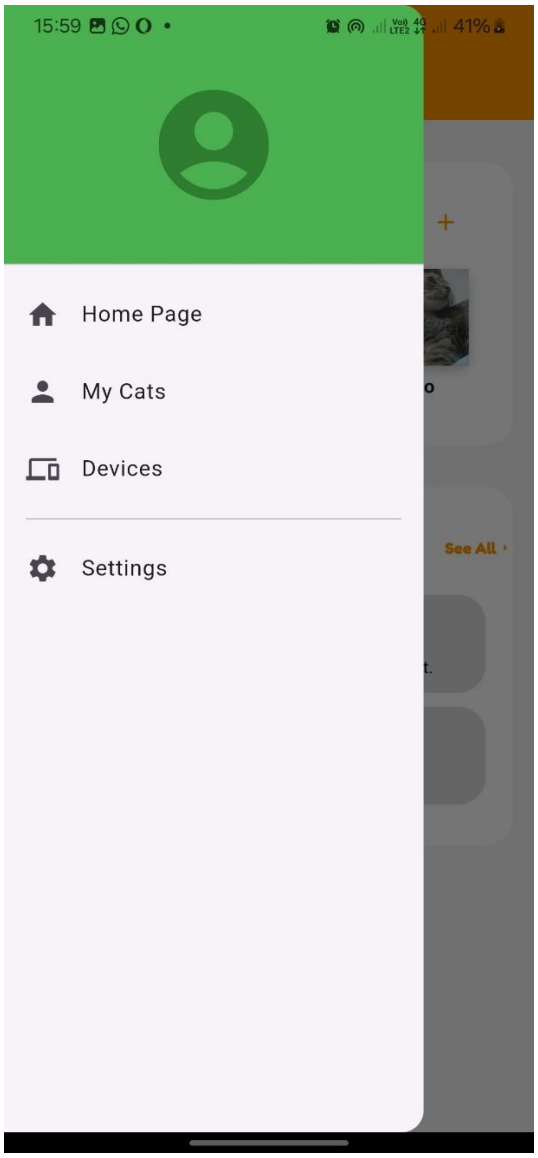


Figure 5.34. Developed Interface (Side Navigation Bar)

The side navigation bar enables the user to navigate to the Cat List page and the Device List page.

5.5.3 Cat Profile Page

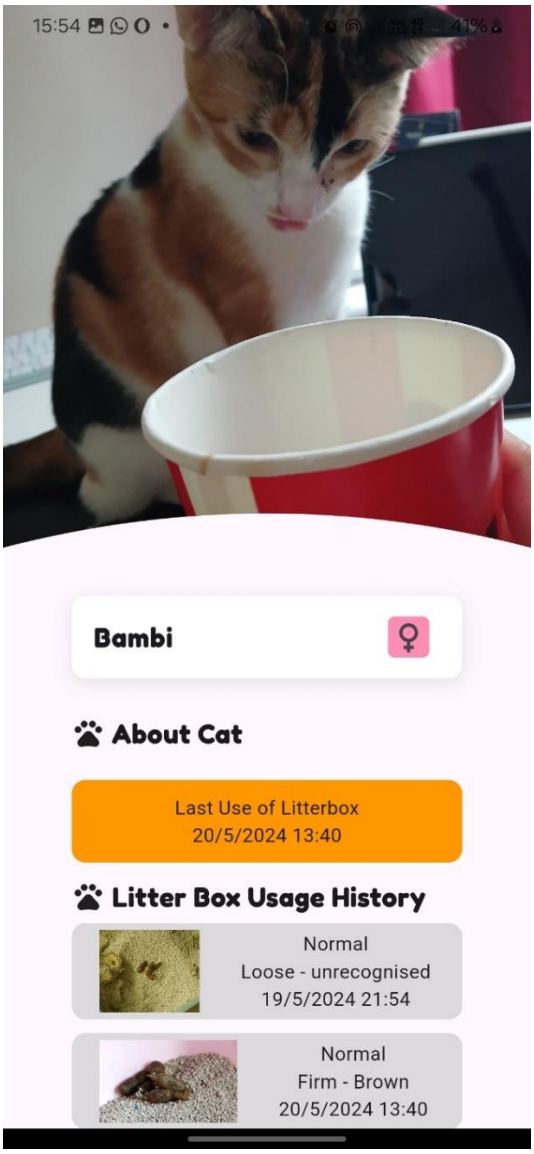


Figure 5.35. Developed Interface (Cat Profile Page)

This page allows the user to view the litter box usage history for the cat. By clicking on an entry in the usage history, the user is navigated to the Waste Details page, where they can view the full image and detailed information of the selected usage.

5.5.4 Waste Details Page

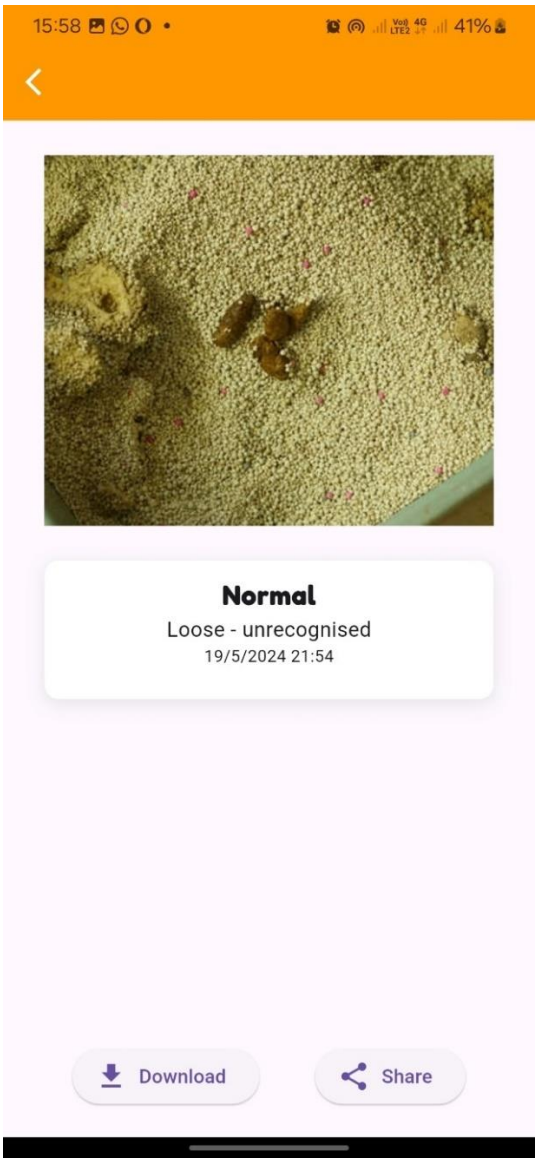


Figure 5.36. Developed Interface (Waste Details Page)

This page allows the user to view the image of the cat's waste along with the classification results. At the bottom of the page, there are two buttons: the "Download" button, which saves the image to the phone's gallery, and the "Share" button, which enables the user to share the image on social media.

5.5.5 Manage Cat Page

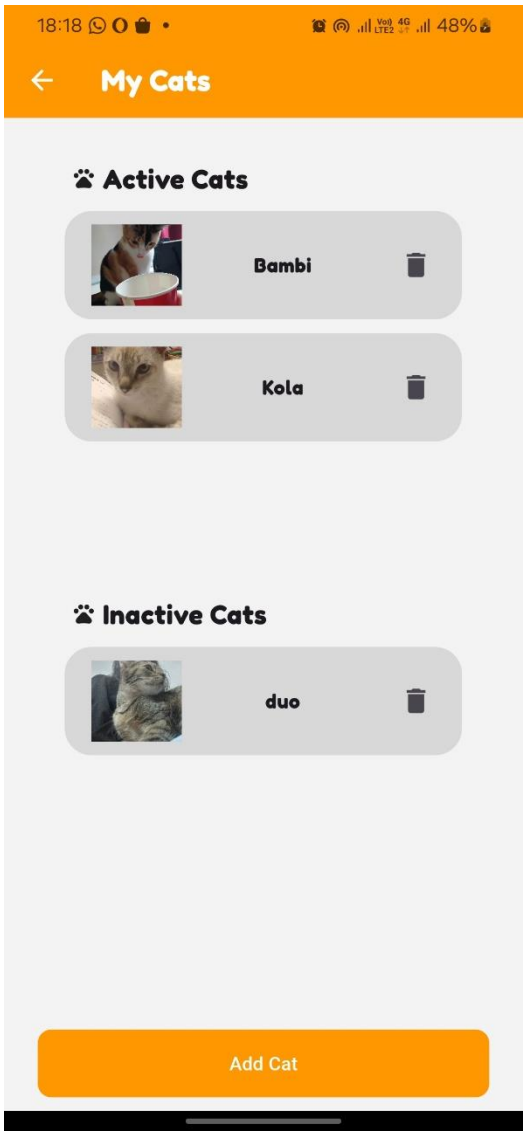


Figure 5.37 Developed Interface (List of Cats)

The Manage Cat page displays all active cats in the household in the top section, and all inactive cats (those that have been removed and are no longer in the household) in the bottom section. By clicking the "Remove" button, a cat is removed from the active list. At the bottom of the page, there is a button that allows the user to add a new cat to the household, which navigates the user to the add_cat_info_page.

5.5.6 Add New Cat

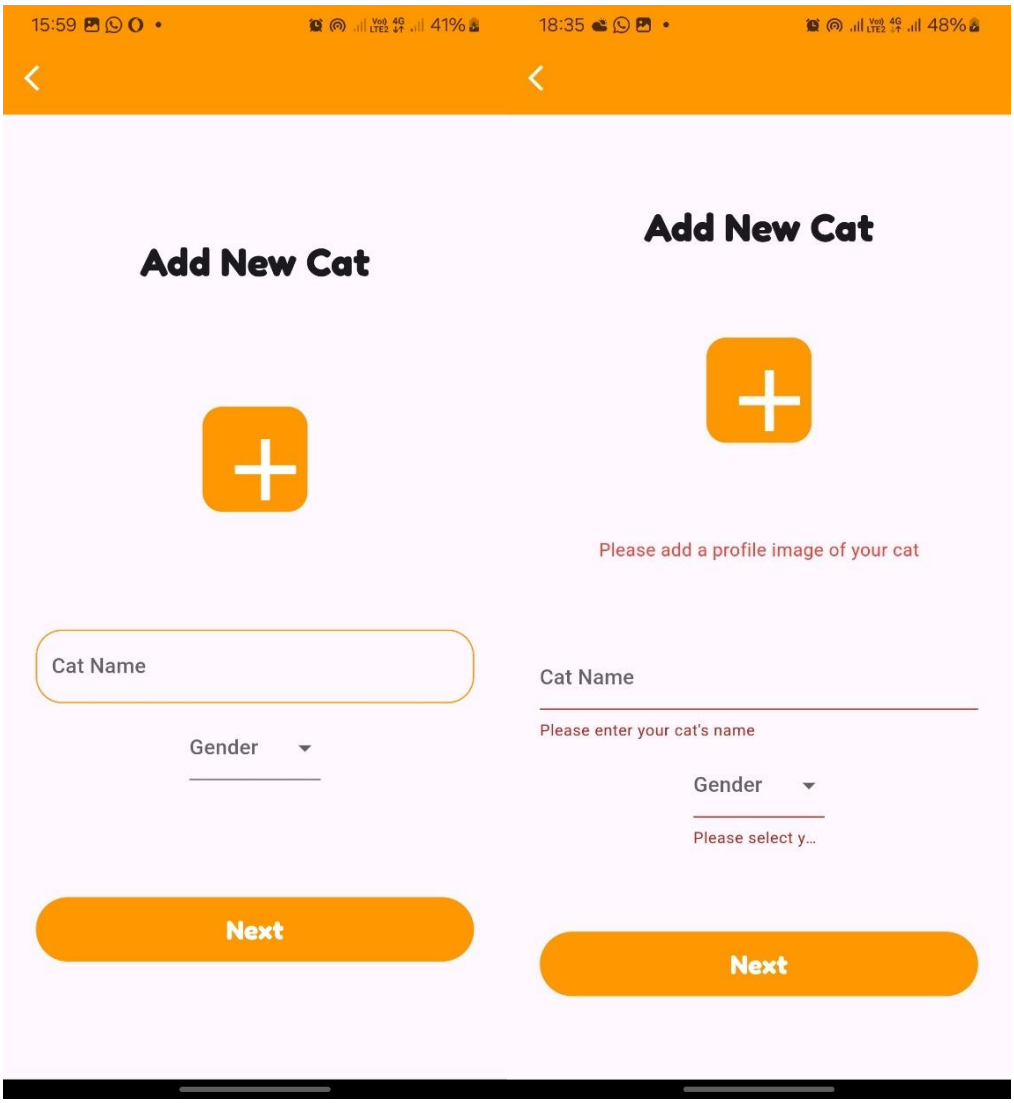


Figure 5.38. Developed Interface (Create Ca Profile Page)

This page is designed for users to add a new cat to the system. To successfully add a new cat, the user must provide the cat's profile image, name, and gender. If any of these required fields are left empty and the user clicks "Next," an error message will be displayed to prompt the user to fill in the missing information.

5.5.7 Camera View

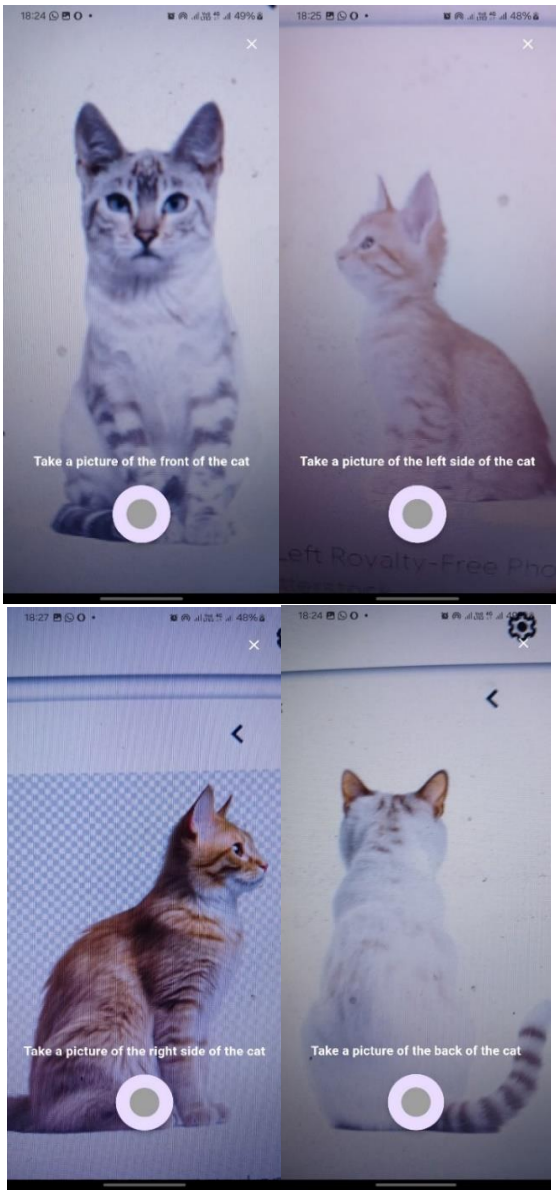


Figure 5.39. Developed Interface (Camera View)

This page is accessed after the user clicks the "Next" button on the add_cat_info_page. It activates the in-app camera, prompting the user to capture four images of the cat: one from the front, one from the left, one from the right, and one from the back. Once all four images are successfully taken, the new cat profile is created.

5.5.8 Manage Litter Box

Figure 5.40. Developed Interface (Manage Litterbox Page)

This page is designed to manage litter boxes within the system, allowing users to add new litter boxes or remove existing ones. To add a new litterbox to the system, Bluetooth need to be switch on to scan the near by litter box for connection.

5.6 Summary

In summary, Chapter 4 offers an in-depth exploration of the data processing and implementation phases of the project. The chapter begins with an overview of the essential development tools and technologies, emphasizing their roles in facilitating efficient and effective project execution. It then details the data collection and labelling processes, the development and training of machine learning models using YOLOv5 for object detection and a CNN for cat recognition, and the integration of these models into a functional system. The chapter further discusses the development of a mobile application for user interaction and the overall system's layout and functionality. By addressing both technical and practical aspects, this chapter underscores the project's comprehensive approach to creating a robust and user-friendly system for managing cats and litter boxes.

CHAPTER 6: TESTING AND EVALUATION

6.0 Overview

In this chapter, we detail the comprehensive testing and evaluation process undertaken for the Smart Cat Litter Box system. The goal of this testing phase is to validate the functionality, performance, and reliability of the system across various use cases. Testing is crucial to ensure that the system meets its functional requirements and performs as expected under different scenarios. This chapter presents the testing plan, which includes detailed test cases for key functionalities such as creating and deleting cat profiles, receiving abnormal waste alerts, and handling unrecognized cat notifications. Each test case is designed to assess whether the system behaves as expected and to identify any areas needing improvement.

6.1 Testing Plan

Test Case ID	Test Case Description	Testing Technique	Pass/Fail Criteria
TC - 1	Connect New Litter Box	Use Case Testing	Fail
TC - 2	Disconnect Litter Box	Use Case Testing	Not Executed
TC - 3	Create New Cat Profile	Use Case Testing	Pass
TC - 4	Delete Cat Profile	Use Case Testing	Pass
TC - 5	View Litter Box Usage History	Use Case Testing	Pass
TC – 6	Receive Abnormal Waste Alert	Use Case Testing	Fail
TC – 6.1	Receive Abnormal Waste Alert: Diarrhoea	Unit Testing	Pass
TC – 6.2	Receive Abnormal Waste Alert: Constipation	Unit Testing	Pass
TC – 6.3	Receive Abnormal Waste Alert: Blood in stool	Unit Testing	Pass
TC – 6.4	Receive Abnormal Waste Alert: Green Stool	Unit Testing	Pass
TC – 6.5	Receive Abnormal Waste Alert: Black Stool	Unit Testing	Pass
TC - 7	Receive Unrecognised Cat Notification	Use Case Testing	Fail
TC – 7.1	Receive Unrecognised Cat Notification	Unit Testing	Pass

Table 6.1 Cat Waste Monitoring System Test Plan

6.2 Use Case Testing

Test Case ID	TC - 1	**Test Case Description**	Connect New Cat Litter Box		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Fail

	Prerequisites			**Test Data**
	A new cat litter box is available and powered on, with Bluetooth enabled.			Litter Box Name: "CozyBox"
	The mobile device is connected to the internet and Bluetooth is enabled.			

Test Scenario				
Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Click on the "Add Litter Box" button.	The app initiates a scan for available smart litter boxes nearby via Bluetooth.	Scanning	Pass
2	List all available nearby devices	Litterbox name "LitterBox" show in the list	Not showing any device	Fail
3	Insert a name for the new litter box "CozyBox"	prompts the user to enter a name	Not Executed	Not Executed
4	View the list of connected devices	The new litterbox named "CozyBox" In the list	Not Executed	Not Executed

Table 6.2. Use Case Testing (Connect New Cat Litter Box)

Test Case ID	TC - 2	**Test Case Description**		Disconnect Litter Box	
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Not Executed

	Prerequisites			**Test Data**
	The litter box to be disconnected is currently connected to the system.			Litter Box Name: "CozyBox"
	The mobile device is connected to the internet.			

Test Scenario	

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
	View the list of connected devices	"CozyBox: is in the list		Suspended
	Click on the delete button beside the "CozyBox"	prompts the user to confirm the disconnection decision.		Suspended
	Click "Confirm"	The "CozyBox" removed from the list		Suspended
	Notification of successful disconnection	Notification shows up		Suspended

Solution
This use case is not executed due to the incomplete execution of Test Case TC-1, on which it depends. To assess the functionality of this use case, a thorough codebase review will be conducted to ensure that it operates correctly.

Table 6.3. Use Case Testing (Disconnect Litter Box)

Test Case ID	TC - 3	**Test Case Description**	Create New Cat Profile		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Cat Name: Mimi
	mobile device with a functioning camera.			Gender: Female

Test Scenario	

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Click Next Button	Error messages show up that profile image, name and gender is required field	Error messages show up	Pass
2	Pick profile image from gallery	Select an image from gallery and show on screen	Selected image show on screen	Pass
3	Change image by "take a photo"	The camera shows up	Unable to click the button	Fail
4	Insert Name, and gender and click net	Direct to camera page	Camera pages show up	Pass
5	Take front image	Text instruction show "Take front image of cat"	Instruction shows	Pass
6	Click image capture button #1	Image is taken, and text changed to "Take left side image of cat"	Instruction shows	Pass
7	Click image capture button #2	Image is taken, and text changed to "Take right side image of cat"	Instruction shows	Pass
8	Click image capture button #3	Image is taken, and text changed to "Take back side image of cat"	Instruction shows	Pass
9	Click image capture button #4	Image taken, direct to view image page	A new cat profile created	Fail
10	Click on retake image	Go back camera page to take image	Not execute	Not execute
11	View cat list	New cat is show up on in the list	New cat in the list	Pass

Table 6.4. Use Case Testing (Create New Cat Profile)

Test Case ID	TC - 4	**Test Case Description**	Delete Cat Profile		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The cat profile to be deleted exists within the system.			Cat Name: Duo
	The mobile device is connected to the internet.			

Test Scenario				
Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Go to the list of cat page	List of cats show up including the cat	List show up properly	Pass
	Select delete button beside the cat's name	Dialog appear for confirmation	Dialog showed	Pass
	Click confirm to delete	Dialog show for successful deleted	Dialog showed	Pass
	View the list again	The cat was removed from the active list and appear in inactive list	The deleted cat appears at bottom of inactive list	Pass

Table 6.5. Use Case Testing (Delete Cat Profile)

Test Case ID	TC - 5	**Test Case Description**		View Litter Box Usage History	
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The cat profile for which historical health data is to be viewed exists in the system.			Cat Profile: "Bambi
	The mobile device is connected to the internet.			Historical Health Data: Past litter box usage events and associated health metrics

Test Scenario

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Select the cat profile	The app displays the profile details for the cat	Profile details display	Pass
2	Scroll down to "Litter Box Usage History"	A list of usage history display	A list of usage history	Pass
3	Click on one usage	Direct to waste details page	The waste information shows up	Pass
4	Click download button	Image is download to gallery	Image is download to gallery	Pass
5	Click share button	Share to social media	Not executed	Not executed

Table 6.6. Use Case Testing (View Litter Box Usage History)

Test Case ID	TC - 6	**Test Case Description**	Receive Abnormal Waste Alert		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Fail

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Diarrhoea image
	Hardware camera is working			Blood in stool image
				Brown and firm stool image

Test Scenario

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Place image in front of camera	The system detects the abnormal characteristics	Not executed	Not executed
2	system generates an alert for abnormal waste characteristics.	pop-up message should appear on the owner's mobile device with details of the detected abnormalities.	Not executed	Not executed
3	Click on the notification	The page of stool information show up	Not executed	Not executed

Solution

This use case failed due to the malfunctioning of the hardware camera, which impeded the detection of waste abnormalities. To address this issue and ensure the functionality of the system, the model will be tested independently of the hardware. This involves reviewing the codebase to verify if the model can accurately predict abnormalities and subsequently send notifications to the user. This approach aims to validate the predictive capabilities and notification mechanisms of the system in the absence of reliable hardware performance.

Table 6.7. Use Case Testing (Receive Abnormal Waste Alert)

Test Case ID	TC – 6.1	**Test Case Description**	Receive Abnormal Waste Alert: Diarrhoea		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	2

Tester's Name	Chin Wei Zhen	**Date Tested**	4/8/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Abnormal stool image: diarrhoea
	One existing cat profile			(Colour: Yellow, Shape: Watery)
				Cat: Miao

Test Scenario

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Parse image to the model	Perform shape and colour classifying	Get colour: yellow, shape: watery	Pass
2	Perform if else statement to get the condition of stool	Return diarrhoea and abnormal stool colour	Result as expected	Pass
3	Create usage and save to database	New usage saved to database	Saved to database	Pass
4	generates an alert for abnormal waste characteristics.	pop-up message should appear on the owner's mobile device with details of the detected abnormalities.	Notification show up with the name of cat and the condition of stool	Pass
5	Click on the notification	The page of stool information show up	Stool info show up	Pass

Table 6.8 Use Case Testing (Receive Abnormal Waste Alert: Diarrhoea) Version 2

Test Case ID	TC – 6.2	**Test Case Description**	Receive Abnormal Waste Alert: Constipation		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	2

Tester's Name	Chin Wei Zhen	**Date Tested**	4/8/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Abnormal stool image: constipation
	One existing cat profile			(Colour: Black, Shape: Hard)
				Cat: Miao

Test Scenario				
Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Parse image to the model	Perform shape and colour classifying	Get colour: black, shape: hard	Pass
2	Perform if else statement to get the condition of stool	Return constipation and abnormal stool colour	Result as expected	Pass
3	Create usage and save to database	New usage saved to database	Saved to database	Pass
4	generates an alert for abnormal waste characteristics.	pop-up message should appear on the owner's mobile device with details of the detected abnormalities.	Notification show up with the name of cat and the condition of stool	Pass
5	Click on the notification	The page of stool information show up	Stool info show up	Pass

Table 6.9 Use Case Testing (Receive Abnormal Waste Alert: Constipation) Version 2

Test Case ID	TC – 6.3	**Test Case Description**	Receive Abnormal Waste Alert: Blood in stool		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	2

Tester's Name	Chin Wei Zhen	**Date Tested**	4/8/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Abnormal stool image: blood stool
	One existing cat profile			(Colour: Red, Shape: Loose)
				Cat: Miao

Test Scenario

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Parse image to the model	Perform shape and colour classifying	Get colour: red, shape: watery	Pass
2	Perform if else statement to get the condition of stool	Return blood in stool	Result as expected	Pass
3	Create usage and save to database	New usage saved to database	Saved to database	Pass
4	generates an alert for abnormal waste characteristics.	pop-up message should appear on the owner's mobile device with details of the detected abnormalities.	Notification show up with the name of cat and the condition of stool	Pass
5	Click on the notification	The page of stool information show up	Stool info show up	Pass

Table 6.10 Use Case Testing (Receive Abnormal Waste Alert: Blood In Stool) Version 2

Test Case ID	TC – 6.4	**Test Case Description**	Receive Abnormal Waste Alert: Green Stool		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	2

Tester's Name	Chin Wei Zhen	**Date Tested**	4/8/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Abnormal stool image: green stool
	One existing cat profile			(Colour: Green, Shape: Firm)
				Cat: Miao

Test Scenario

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Parse image to the model	Perform shape and colour classifying	Get colour: green, shape: normal	Pass
2	Perform if else statement to get the condition of stool	Return abnormal stool colour"	Result same as expected	Pass
3	Create usage and save to database	New usage saved to database	Saved to database	Pass
4	generates an alert for abnormal waste characteristics.	pop-up message should appear on the owner's mobile device with details of the detected abnormalities.	Notification show up with the name of cat and the condition of stool	Pass
5	Click on the notification	The page of stool information show up	Stool info show up	Pass

Table 6.11 Use Case Testing (Receive Abnormal Waste Alert: Green Stooll) Version 2

Test Case ID	TC – 6.5	**Test Case Description**	Receive Abnormal Waste Alert: Black Stool		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	2
Tester's Name	Chin Wei Zhen	**Date Tested**	4/8/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			Abnormal stool image: green stool
	One existing cat profile			(Colour: Green, Shape: Firm)
				Cat: Miao

Test Scenario

Step #	Step Details / Test Procedure	Expected Results	Actual Results	Pass / Fail / Not Executed / Suspended
1	Parse image to the model	Perform shape and colour classifying	Get colour: green, shape: normal	Pass
2	Perform if else statement to get the condition of stool	Return 'Constipation and abnormal stool colour"	Result same as expected	Pass
3	Create usage and save to database	New usage saved to database	Saved to database	Pass
4	generates an alert for abnormal waste characteristics.	pop-up message should appear on the owner's mobile device with details of the detected abnormalities.	Notification show up with the name of cat and the condition of stool	Pass
5	Click on the notification	The page of stool information show up	Stool info show up	Pass

Table 6.12 Use Case Testing (Receive Abnormal Waste Alert: Black Stooll) Version 2

Test Case ID	TC - 7	**Test Case Description**	Receive Unrecognised Cat Notification		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	1
Tester's Name	Chin Wei Zhen	**Date Tested**	27/7/2024	**Test Case (Pass/Fail/Not Executed)**	Not Executed

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			"Whiskers" (Profile ID: 1)
				"Fluffy" (Profile ID: 2)

Test Scenario	

Step #	**Step Details / Test Procedure**	**Expected Results**	**Actual Results**	**Pass / Fail / Not Executed / Suspended**
1	Place a picture of unregister cat image in front of camera	The system classifies the cat as unrecognized	No cat found	Fail
2	notification for the unrecognized cat notification appears as a pop-up message on mobile screen.	pop-up message should appear	Not executed	Not Executed
3	Verify that the notification includes details of the unrecognized cat	Notification should include an image of the unrecognized cat and prompt the owner to create a new profile	Not executed	Not Executed
4	Direct to create new cat profile	Direct to create profile page	Not executed	Not Executed

Table 6.13. Use Case Testing (Receive Unrecognised Cat Notification)

Test Case ID	TC – 7.1	**Test Case Description**	Receive Unrecognised Cat Notification		
Created By	Chin Wei Zhen	**Reviewed By**		**Version**	2
Tester's Name	Chin Wei Zhen	**Date Tested**	4/8/2024	**Test Case (Pass/Fail/Not Executed)**	Pass

	Prerequisites			**Test Data**
	The mobile device is connected to the internet.			New cat image
				Stool image

Test Scenario

Step #	Step Details / Test Procedure	Expected Results	Actual Results	Pass / Fail / Not Executed / Suspended
1	Parse image to the model	The model return result of unrecognised cat	Unrecognised cat	Pass
	The unrecognised cat with the result of stool info save to database	New usage and cat profile created	New usage and new cat profile created with name unrecognised	Pass
2	notification for the unrecognized cat notification appears as a pop-up message on mobile screen.	pop-up message should appear	Notification on home page	Pass
3	Verify that the notification includes details of the unrecognized cat	Notification should include an image of the unrecognized cat and prompt the owner to create a new profile	Unrecognised cat image show up	Pass
4	Direct to create new cat profile	Direct to create profile page	Cat profile page show up	Pass

Table 6.14 Use Case Testing (Receive Unrecognised Cat Notification) Version 2

6.3 User Acceptance

System Name	Cat Waste Monitoring System		
Testing Start Date	4/8/2024	**Testing End Date**	4/8/2024
Testing End Date	12.00 pm	**Testing End Time**	12.30 pm
Name of Tester	Chin Wei Min	**Type of User (for tester)**	Cat Owner

Test No.	**Description of Tasks**	**Steps to Execute**	**Expected Results**	**Pass**	**Fail**	**Defect / Comments / Additions**
APPLICATION 1: ADD NEW CAT PROFILE						
1	Open “Add New Cat” page	Click on add icon in home page	The page shows			Comment: the button is too small
2	Add cat profile by choose from gallery	Click on the camera, and click “Choose from gallery”	Gallery shows			
3		Select a picture	The picture display on screen			
4	Insert cat information	Insert cat name, select cat gender, click “Next	Navigate to camera page			
5	Take picture of cat by following the instruction	Take picture of the front, left, right, back of cat	All images with cat information displayed as summary for confirmation			Comment: The instruction is too vague. Do I need to fill my cat in the frame, or take image from far also can?
6	Confirm to add the new cat	Click on ‘confirm’ button	Navigate to home page, with the new cat picture and name show up in “My Cats” section			Addition: need a revert button that allow recapture of specific image.

APPLICATION 2: REMOVE CAT PROFILE						
1	Go to “Cat List” Page	Open the cat list from side navigation bar	The page shows with a list of cats			
2	Remove the cat	Click on the ‘delete’ icon on the right of the cat’s tile	Dialog show up for confirmation			
3	Confirm delete	Click on the ‘Delete’ selection in the dialog	The deleted cat moved to inactive cats’ list			
		Go to ‘home page’	The deleted cat does not appear on ‘My Cat’ section			
APPLICATION 3: ADD LITTER BOX						
1	Go to ‘Litter Box List’ page	Open the litterbox list from side navigation bar	The page show s a list of connected litterboxes			
2	Add new litterbox	Click on the ‘New Litterbox’ button	Dialog shows all nearby device that able to connect to			Defect: the application shutdown
		Select the litterbox, give it a name	Dialog shows and prompt for name			Comment: not executed
		Click ‘Add’ button	The new cat litterbox appear on the list			Comment: not executed
APPLICATION 4: RECEIVE ABNORMAL WASTE NOTIFICATION						
1	Receive notification	Notification show in home page	Notification show with title, the name of cat that related to, and the condition of its waste			Comment: user need to open the app to view new notification
2	View notification	Click on the notification tile	Details of the waste including condition, shape,			Comment: Consider to add the litterbox id that the waste

			colour, date and time taken will show			found
APPLICATION 5: VIEW WASTE INFORMATION (DOWNLOAD)						
1	(Continue) Download the image	Click on the download button	The image will be downloaded to phone gallery			
APPLICATION 6: VIEW WASTE INFORMATION (SHARE)						
1	(Continue) Share the image	Click on the share button	A list of social media show for selection			Defect: No social media selection show
APPLICATION 7: RECEIVE UNRECOGNISED CAT NOTIFICATION						
1	Receive notification	Notification show in home page	Notification show with title, and subtitle 'further action needed'			Comments: user need to open the app to view new notification
2	View notification	Click on the notification tile	Image of the unrecognized cat display on screen			
3	Create profile	Click on the button 'create new profile"	The create cat profile page show, with the unrecognized cat image initialized.			
GENERAL QUESTIONS / COMMENTS						
	Not able to edit cat profile (name, profile image) after adding a cat to the system. Should consider allow user to edit profile					

Table 6.15 User Acceptance Testing (Application)

6.4 Summary

The comprehensive testing and evaluation process for the Smart Cat Litter Box system detailed in this chapter aims to validate its functionality, performance, and reliability across diverse use cases. The testing plan includes a thorough assessment of critical functionalities, such as creating and deleting cat profiles, receiving abnormal waste alerts, and handling unrecognized cat notifications. Each test case is meticulously designed to ensure the system behaves as expected and identifies areas for improvement.

Several test cases (e.g., TC-1 and TC-2) revealed connectivity issues with the litter box, which hindered subsequent tests. The system performed well in creating and deleting cat profiles (TC-3, TC-4), demonstrating reliable functionality in these areas. However, significant issues were noted in the abnormal waste alert functionality (TC-6), primarily due to hardware camera malfunctions. Despite this, unit testing of specific alert conditions (e.g., diarrhoea, constipation) showed successful detection and notification, indicating the robustness of the underlying model. The unrecognized cat notification feature (TC-7) also faced initial failures due to hardware issues, but subsequent tests validated the model's capability to detect and notify about unrecognized cats effectively.

User acceptance testing highlighted usability concerns, such as small button sizes and vague instructions, suggesting areas for user interface improvement. Overall, the evaluation process highlights the system’s potential while identifying critical areas needing refinement, particularly in hardware integration and user interface design.

CHAPTER 7: Conclusion

7.0 Overview

This chapter provides a comprehensive discussion on the significance, constraints, and future enhancements of the developed pet care system. The significance section outlines the key benefits of the system. The constraints section addresses the various challenges encountered during the development and integration of the system. Finally, the future enhancement section presents potential improvements to further advance the system's capabilities.

7.1 Significance

7.1.1 Enabling Efficient Pet Care for Busy Owners

The developed system significantly enhances pet care efficiency for owners with demanding schedules. By automating stool detection and analysis, it allows pet owners to manage their time more effectively without sacrificing their pet's well-being. This integration into daily routines minimizes the need for manual inspection and intervention, making it easier to balance professional and personal commitments. Additionally, with real-time monitoring and alerts, the system alleviates the stress and worry of tracking a pet's health, providing owners with peace of mind and enabling them to focus on other important aspects of their lives.

7.1.2 Integration with Auto-Cleaning Litter Boxes

The system could integrate with auto-cleaning litter boxes enhances functionality by adding a layer of automation and efficiency. This integration allows the system to provide real-time data on stool conditions directly to the litter box's cleaning mechanism, ensuring it remains in optimal condition. Automatic updates and notifications about the litter box's state improve hygiene, prevent zoonotic disease.

7.1.3 Enabling Early Treatment Through Abnormal Faeces Detection

The system's ability to detect and alert owners to abnormal faeces is essential for effective health monitoring and early intervention. Abnormalities in stool can signal various health issues, and timely detection enables prompt veterinary consultation, which is crucial for addressing potential problems swiftly. By providing early warnings about potential health concerns, the system supports preventive care, allowing for the management of health issues before they escalate. This proactive approach not only improves treatment outcomes but also helps reduce overall healthcare costs. Ultimately, early detection contributes to the pet's well-being, ensuring that they receive the necessary care in a timely manner and leading to a healthier, happier life.

7.2 Constraints

7.2.1 Integration Issues with Custom Models

The integration of the custom cat identification model encountered significant challenges due to package version conflicts. These issues have prevented the successful incorporation of the model into the system, highlighting difficulties in aligning software dependencies and ensuring compatibility between different components.

7.2.2 Hardware Resource Limitation

The limited hardware resources GPU available for training pre-trained models necessitated the development of a custom model from scratch. This constraint has implications for training efficiency and model performance, as the lack of adequate computational power has impacted the ability to perform extensive training and optimization.

7.2.3 Custom Model Limitation

The custom model, trained using self-collected stool images, may exhibit suboptimal performance in real-world scenarios. Since the self-collected image are from same environment. The quality and representativeness of the training data, combined with the lack of robust training infrastructure, could lead to performance issues when deployed in practical applications.

7.2.4 Challenges with ESP32 Camera Integration

Uploading code to the ESP32 Camera presented significant challenges, primarily due to compatibility and operational issues with the C++ code written in the Arduino IDE. These difficulties complicated the integration process and hindered progress. Additionally, the ESP32 Camera experienced an unforeseen malfunction that has proven difficult to diagnose and resolve, further become the problem. As a result, a contingency plan, or Plan B, was developed to address the hardware issue. This plan involves rewriting the camera code in Python, a shift that necessitates additional time for research and development to ensure a functional and reliable solution. The transition to Python, along with the need to guarantee compatibility with the new codebase, adds complexity and extends the project timeline.

7.2.5 Challenges in Building the Scanning Page for Cat Image Capture

Challenge encountered during the development of the mobile application was building a scanning page capable of automatically detecting and capturing images of the cat's face, front, back, and side. The goal was to facilitate the seamless addition of new cats into the system through an automated image capture process.

However, achieving reliable and accurate auto-detection in various conditions proved difficult. There are technical limitations which AI feature need to be added to recognised the position if a cat for scanning, which no pretrained model found and develop a model is time consuming. The final implementation included text instructions guiding users on how to take the necessary images of their cat. A button was provided for users to manually capture images of the cat's face, front, back, and side.

7.3 Future Enhancement

7.3.1 Utilization of Pre-Trained Models for Real-World Adaptation

To improve the system's performance in real-world scenarios, integrating pre-trained models and fine-tuning them on domain-specific data is essential. This approach leverages established model architectures and knowledge while adapting them to the unique conditions and variations of the target environment. By retraining these models with data that more accurately reflects real-world conditions, the system's accuracy and robustness can be significantly enhanced.

7.3.2 Integration of Additional Sensors

To provide a more comprehensive analysis of feline health, the integration of additional sensors into the smart cat litter box is proposed. Sensors such as weight sensors and temperature sensors could offer valuable supplementary data. Weight sensors can track changes in the cat’s weight, which may indicate health issues or fluctuations, while temperature sensors can monitor the ambient environment within the litter box. The collection of these additional data points will enable a more holistic understanding of the cat’s health and improve the system's overall diagnostic capabilities.

7.3.3 Multi-Cat Detection and Localization

current system is limited to detecting only one cat at a time within the litter box. Future enhancements should focus on refining the model to enable the detection and localization of multiple cats simultaneously. This improvement will involve optimizing the object detection algorithms to distinguish and track multiple individuals, which is critical for households with more than one cat. Enhancing the system's ability to handle multiple cats will provide more accurate and useful analysis for users with multi-cat households.

7.3.4 Detection of Newly Created Stool

The system currently faces challenges in detecting newly deposited stool if the litter box has not been cleaned after previous use. This limitation can result in the analysis being performed on older stool, which may not accurately reflect the

current state of the cat's health. Future enhancements should focus on improving the object detection capabilities to differentiate between new and old stool. This includes refining algorithms to better identify and locate newly created stool, ensuring that the system provides accurate and timely health assessments based on the most recent data.

7.3.5 User Authentication

Adding an authentication feature to the system will allow users to sign in and log in. With authentication, the system can support multiple user profiles, allowing different members of a household to access and monitor the pet's health data. user can have customized settings and preferences, improving the overall user experience. With authentication, users can access their accounts from different devices without worrying about losing data. If users change their phones, they can still log in to their accounts and retrieve all their data, ensuring continuity and ease of access. This feature eliminates concerns about data loss and enhances the convenience of using the system across multiple devices. Adding user authentication is a crucial future enhancement that will enhance personalization, and user management.

7.4 Summary

This chapter explores the significance, constraints, and future enhancements of the pet care system. The system enhances pet care efficiency by automating stool detection and analysis, integrating with auto-cleaning litter boxes for improved functionality and hygiene, and providing critical alerts for early intervention in health issues. However, development challenges included integration issues with custom models, hardware resource limitations, and problems with ESP32 Camera compatibility and malfunctions. Future enhancements aim to address these constraints by utilizing pre-trained models for better real-world adaptation, incorporating additional sensors for comprehensive health analysis, refining multi-cat detection capabilities, and improving the identification of newly created stool for accurate health assessments. Overall, the chapter underscores the system's impact, acknowledges development challenges, and suggests directions for future improvements.

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APPENDIX A: GANTT CHART


TimelineGanttOverviewSection
26 February, 2024 | 14:06:15
Q1 2024
Q2 2024
Q3 2024
Q4 2024
Documentation
Fact Finding / Requirement Analysis and Design
Model Development
Mobile Application Development
User Acceptance Testing
Powered by

APPENDIX B: FACT FINDING DOCUMENT

Observation: Zhi Wei's House

Observer(s): Chin Wei Zhen
Date of Observation: 7 April 2024
Location: Zhi Wei's Household
Number of cats: 8
Number of litter box: 8
The layout and setup of the cat litter box. (Open or closed, take pic):
All open




Where the litterbox located? (Take pic)
All litter box is located at the back, a wide space, beside washing machine.
What is the colour of cat sand used?
Grey
What is the frequency of litter box cleaning and maintenance?
Sometimes once a week, twice a week, or a month.
Is there any monitoring devices or sensors used in the current litter box?
No monitoring devices or sensors.
Check for connectivity issues or technical challenges faced by cat owners.
The house has strong WIFI connection.

Quick interview during observation
Is the cat sick? What illness do the cat have? What method currently use to assess cat health?
Most of the cat the house is healthy, but some of the cat might have diarrhoea. They bring cats to doctor to assess health.
Do you inspect your cat faeces often to check their health?
No. It is time consuming; they do not have the time.
What difficulty you face in inspecting cat faeces?
even they found abnormality, they cannot spot which cat is suffering.

They are busy with work, cannot inspect everyday
The owner cannot tell if the stool if normal or not.
They cannot give any prove of image when vet ask for image.
Do you try to look for a product that help you to inspect cat faeces? Do you use them before? What is the difficulty/cons/challenges you encounter when using these?
They desperately need a product that can help them to check the stool status, and record which cat used the litter box. But litterbox in the market is too expensive. Some litter boxes claim to have camera, but they do not give any evidence they can properly capture and classify cat stool.

Observation Documentation: Wei Min's House

Observer(s): Chin Wei Zhen
Date of Observation: 15 March 2024

Location: Wei Min's Household
Number of cats: 10
Number of litter box: 3
The layout and setup of the cat litter box. (Open or closed, take pic):
closed litter box, 1 open litterbox

Where the litterbox located? (Take pic)
I litter box is placed in front of the bathroom. Another 2 are in bedroom.
What is the colour of cat sand used?
Grey

What is the frequency of litter box cleaning and maintenance?
Twice a week. Cleaning process 1. Rinse with clear water to wash off remaining sand. 2. Detergent to wash with sponge, clean the stain of waste. 3. Wash off the soap. 4. Spray alcohol to kill bacteria. 5. Put under the sun until it dry. 5. Resemble the litterbox
Is there any monitoring devices or sensors used in the current litter box?
No monitoring devices or sensors.
Check for connectivity issues or technical challenges faced by cat owners.
The house has strong WIFI connection.

Quick interview during observation
Is the cat sick? What illness do the cat have? What method currently use to assess cat health?
There are 3 cats with positive covid, but not active. 2 cats suffer from genetic disease, their immune system is very weak.
Cats with positive covid need care, they will suffer if the virus become negative.
Cats with genetic disease do not like to eat food.
Some cats will run out from the house and return shortly, they might have diarrhoea after return from outside due to eating food from outside. When diarrhoea happen, owner have to give probiotic to cats. The problem is owner might not know who are having diarrhoea, and she cannot know immediately.
One case is, one cat run out from the house, and come back 2 days later. She is having diarrhoea, but the owner she so not knows, it then spread to other cats, causing every cat in the house suffer from diarrhoea. At the beginning, they do not know. They knew it after one week, when one cat does not eat, and the cat rectal is red. They immediately bring the cat to vet, the veterinarian explains to them, and treat the cat with antibiotic injection. She then needs to deworm every cat, give prebiotic. But until today, they do not know which cat having diarrhoea first, they can only make assumption that the cat that have the severe symptom is the first who have diarrhoea.
Now, they inspect the cat litter box manually to check if there is any abnormal stool.

Do you inspect your cat faeces often to check their health?
But they do not check every day, even they found abnormality, they cannot spot which cat is suffering. And the owner is busy with work, she cannot inspect every day, sometimes she is lazy also.
What difficulty you face in inspecting cat faeces?
even they found abnormality, they cannot spot which cat is suffering.
They are busy with work, cannot inspect everyday
The owner cannot tell if the stool if normal or not.
Do you try to look for a product that help you to inspect cat faeces? Do you use them before? What is the difficulty/cons/challenges you encounter when using these?

They desperately need a product that can help them to check the stool status, and record which cat used the litter box.

Transcript of Interview

Interviewee: Doctor Joanne
Date of Interview: 1 April 2024
Interview Method: In-person
Duration of Interview: 30 minutes
Interviewer: Chin Wei Zhen

Wei Zhen: Do you think it is important to monitor stool?

Veterinarian: Yes, it is. Cats can be sneaky about showing when they are sick or uncomfortable. But by keeping an eye on their poop, you can get a clue about how they are feeling, even if they are not acting any different. It is important to spot earlier so you can take action to keep your cat healthy, like changing their diet or giving them medicine if needed.

Wei Zhen: How to observe cat stool? What aspect I should take account to make sure my cat is healthy?

Veterinarian: You can look at the consistency, colour, and odour to determine if your cat is sick. If your cat's poop looks weird—like it is a different colour, too hard or too soft, stinky, or comes out more or less often—it could mean your cat is sick. If stool is too hard, gives them more water, if stool is too soft, give them prebiotic and keep an eye on them. If things start looking more normal, then your cat is recovering. But if they are still having issues, further diagnosis is needed.

Wei Zhen: What other specific sickness or disease that is possible that cause abnormal stool?

Veterinarian: The specific health issues can be worm in belly like roundworms and tapeworms, treatment is dewormed. Sometimes, bad germs like Salmonella or others can make your cat sick. Certain viruses like FPV can mess with your cat's tummy. These viruses can cause serious belly problems and need to be treated fast. Sometimes, if your cat's tummy does not like what they are eating, their stool can tell us. Changes in colour, smell, or how hard or soft it is might mean their food is not agreeing with them. If your cat's gut is all swollen and angry, this could mean they have something like inflammatory bowel disease, which needs to be managed carefully. If there's blood in your

cat's poop, it is a sign that something is not right. Stool tests can help find out where the blood's coming from and what is causing it.

[Give the veterinarian to view the chart]

Wei Zhen: These charts are taken from internet. Do you agree to this chart on classify the shape and consistency of cat stool?

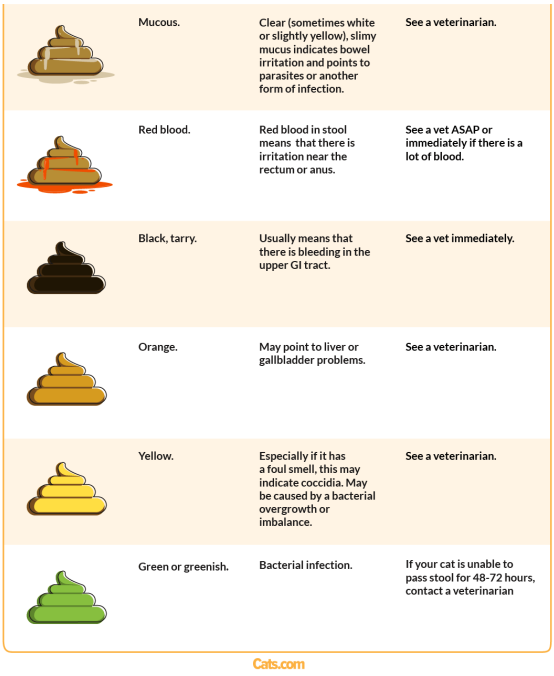
Veterinarian: The chart is correct and detailed; you can use the chart to classify stool and see is your cat is suffering from diarrhoea.

Wei Zhen: From the diagram, above 3 is considered as diarrhoea and need treatment?

Veterinarian: 3,4, and 5 is still ok, maybe cat drank too much water, or is stress, just give some prebiotic. But 6 and 7 diarrhoeas, means your cat is in sick, or food intolerance, cat that new to the house and feel stress or changed of diet will also have stool 6 and 7.

Wei Zhen: How about the chart of classification on colour od stool? are they accurate?

Veterinarian: Emm… Sometime, the colour of food the cat eat will reflect on the stool. Green and black colour of stool might because the cat ate grass, or food that dark in colour.



	Mucous.	Clear (sometimes white or slightly yellow), slimy mucus indicates bowel irritation and points to parasites or another form of infection.	See a veterinarian.
	Red blood.	Red blood in stool means that there is irritation near the rectum or anus.	See a vet ASAP or immediately if there is a lot of blood.
	Black, tarry.	Usually means that there is bleeding in the upper GI tract.	See a vet immediately.
	Orange.	May point to liver or gallbladder problems.	See a veterinarian.
	Yellow.	Especially if it has a foul smell, this may indicate coccidia. May be caused by a bacterial overgrowth or imbalance.	See a veterinarian.
	Green or greenish.	Bacterial infection.	If your cat is unable to pass stool for 48-72 hours, contact a veterinarian

Cats.com

Wei Zhen: So, is the chart useful?

Veterinarian: Yes. Colour of stool is important in determine if the cat is sick. Even though stool colour might relate to the colour of food the cat eats, but owner still need to keep an eye on them. Both charts descript detail on the colour with possible sickness.

Wei Zhen: Which one is better?

Veterinarian: Both charts do mention important information. You can combine these two charts together; this will provide a more detailed information colour of stool.

Wei Zhen: So, I can specify or determine the disease by assessing cat stool with chart?

Veterinarian: Not exactly. Actual stool analysis in lab is required to determine the specify disease especially disease that associate with blood in stool, virus, bad bacteria in gut… The observation of stool can only give owner a clue, allow owner to make assumption on what happen to the cat, and give early treatment such as probiotic, vitamins.

Wei Zhen: Is there any variations in stool characteristics among different breed of cats.

Veterinarian: Yes. Different breeds of cats can have varying poop characteristics, influenced by factors beyond just their breed. For instance, long-haired breeds like Maine Coons or Persians might deal with hairballs, which can affect the appearance and consistency of their poop. Cats with flat faces, such as Persians or Exotic Shorthairs, might have digestive systems structured differently due to their facial anatomy, potentially impacting their poop. Additionally, certain breeds prone to genetic disorders like hypertrophic cardiomyopathy or polycystic kidney disease may experience gastrointestinal symptoms that can alter their stool. So, while breed can play a role, it is not the sole determinant of a cat's poop traits.

Wei Zhen: What are the challenges faces in interpreting stool samples and making accurate diagnoses?

Veterinarian: The thing is, poop can be all over the place in terms of how it looks, feels, and how fresh it is. If a stool is contaminated or not fresh, it is tough to spot any problems. Contamination can happen during collection or handling, while poop breaking down over time can also mess things up.

Wei Zhen: There is a health monitoring system for cat, what kind of health data is needed for monitoring?

Veterinarian: Actually, the health monitor of animal is same as human. Health data need to include to have a full assessment of the health of cat include the duration, walking, running, playing, and resting frequency, quality of sleep, portion and frequency of meal and water consumption, weight, body temperature, frequency of litter box using, characteristic of urination and defecation, heart rate, blood pressure, detect emotion include pain, discomfort…

Wei Zhen: What is the way to take body temperature of cat? Can I use non-contact infrared thermometer for body temperature measurement?

Veterinarian: We measure cat body temperature using rectal thermometer, this method gives the most accurate body temperature of a cat. Using infrared gadgets that measure skin temperature by scanning the fur might not always give you the right numbers. Because things like how warm or cold it is around the cat, how humid it is, and if there is a breeze can mess with those readings. And since cats come in all four types – some super fluffy, some not so much – that fur makes it harder for the infrared thermometer to get a good read. Thicker fur can especially make the temperature it shows not quite spot-on.

APPENDIX C: SUPERVISORY METTING REPORT

SUPERVISORY MEETING REPORT

Meeting No	:	1	**Date:**	:	25 Jan 2024
Start Time	:	3.00pm	**End Time:**	:	3.30pm

Review of actions from the last supervisor meeting: None
Identification of any issues: Discussion on the topic for the project Discussion on the title
Actions set for the next meeting: Confirm project title Discuss proposal

Student's Name & Signature: **Date:**	
Supervisor's Name & Signature: **Date:**	

SUPERVISORY MEETING REPORT

Meeting No	:	2	**Date:**	:	25 February 2024
Start Time	:	3.00pm	**End Time:**	:	3.30pm

Review of actions from the last supervisor meeting: Change to a more appropriate topic
Identification of any issues: Discussion on the proposal Discussion on the start of Documentation 1
Actions set for the next meeting: Discuss Documentation 1

Student's Name & Signature: **Date:**	
Supervisor's Name & Signature: **Date:**	

SUPERVISORY MEETING REPORT

Meeting No	:	3	**Date:**	:	7 March 2024
Start Time	:	3.00pm	**End Time:**	:	3.30pm

Review of actions from the last supervisor meeting: None
Identification of any issues: Discuss on documentation 1 (Chapter 1 & 2) Discuss on the machine learning algorithm Discuss on literature review
Actions set for the next meeting: None

Student's Name & Signature: **Date:**	
Supervisor's Name & Signature: **Date:**	

SUPERVISORY MEETING REPORT

Meeting No	:	4	**Date:**	:	25 April 2024
Start Time	:	3.00pm	**End Time:**	:	3.30pm

Review of actions from the last supervisor meeting: None
Identification of any issues: Discuss the use case description table Confirm the final diagram for Chapter 3
Actions set for the next meeting: None

Student's Name & Signature: **Date:**	
Supervisor's Name & Signature: **Date:**	

SUPERVISORY MEETING REPORT

Meeting No	:	5	**Date:**	:	26 June 2024
Start Time	:	3.00pm	**End Time:**	:	3.30pm

Review of actions from the last supervisor meeting: None
Identification of any issues: Camera (ESP32) broken, discuss on alternative plan
Actions set for the next meeting: Tell about the plan

Student's Name & Signature: **Date:**	
Supervisor's Name & Signature: **Date:**	

SUPERVISORY MEETING REPORT

Meeting No	:	6	**Date:**	:	1 July 2024
Start Time	:	3.00pm	**End Time:**	:	3.30pm

Review of actions from the last supervisor meeting: None
Identification of any issues: Discuss the alternative plan Discuss what to change on project Change from Arduino code to Python code,
Actions set for the next meeting: None

Student's Name & Signature: **Date:**	
Supervisor's Name & Signature: **Date:**	

APPENDIX D: PRE-VIVA PRESENTATION POSTER

Faculty of Data Science and Information Technology (FDSIT)

INTI International University

SMART CART LITTER BOX IN MONITORING FAECES FOR EARLY HEALTH DETECTION USING MACHINE LEARNING ALGORITHM

There are two methods for analyzing faeces: subjective observation of stool characteristics and objective microscopic and chemical analysis. While daily microscopic and chemical testing is challenging, subjective observation is crucial for identifying early health issues in humans and animals.

Various cat diseases, such as dietary changes, food intolerance, parasites, infections, and stress, can be detected through stool analysis. Parasites like roundworms and Giardia, which can be transmitted to humans, Feline Coronavirus (FCov) infection, common in crowded environments, is associated with diarrhea.

TARGET AUDIENCE

Cat Owner

Cat Cafe

PROBLEM STATEMENT

01 **Busy owner** cannot constantly monitor their cats faecal to ensure the health of their pets.

02 **Lack of information to determine** if cat faecal is in normal state, as factors such as consistency, colour, odour and frequency need to be counted.

03 **Challenge to observe multi-cat** when the house have more than two cats, owner unable to identify which cat is sick by observe faecal when cats are sharing litterbox

04 **Lack of faecal analysis feature**, most of the smart litter box focus on self-cleaning and sand filling. Lack of capability to directly "see" and "analyze" feces, which could provide valuable information about a cat's health status.

05 **Risk in zoonotic disease** when owners closely inspect cat feces, even without direct contact, still posing a health risk to owners.

OBJECTIVE

01 **Integrates a range of sensors** including:
- camera sensor for image capture of cat and faeces,
- infrared sensor to detect cat's presence.

02 **Incorporate cat recognition machine learning model** that capable to recognizing cat, giving the result to identify which cat has used the litterbox for further record

03 **Incorporate faecal analysis machine learning model** that capable to analyse cat faecal, categorize it in shape, colour, length, and overall condition.

04 **User-friendly mobile application** to visualize captured image and result of analyse

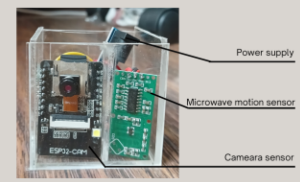
SYSTEM FEATURE

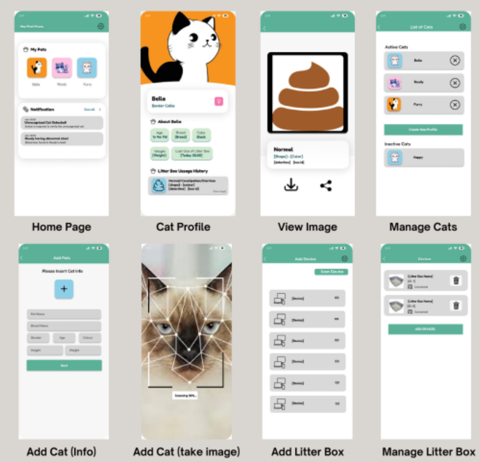
- Alert owner when detect abnormal faecal
- Identify which cat used litterbox
- Captured waste image is save to correcponsing cat profile.
- Aanalyse and categorise faecal into shape and form
- View analysed result and image of faecal
- Support multiple litterbox sensor connection
- Able to add or remove cat from list
- Able to manage existing litterbox, including adding and remove

SYSTEM STRENGTH

- Support multi-cat household
- Owner could receive immediate notification of faecal information
- Allow owner maintain busy lifesyle, reduce the time and effort.
- Reduce the risk of zoonotic disease
- Can be use in both Android and IOS platform

SYSTEM DESIGN





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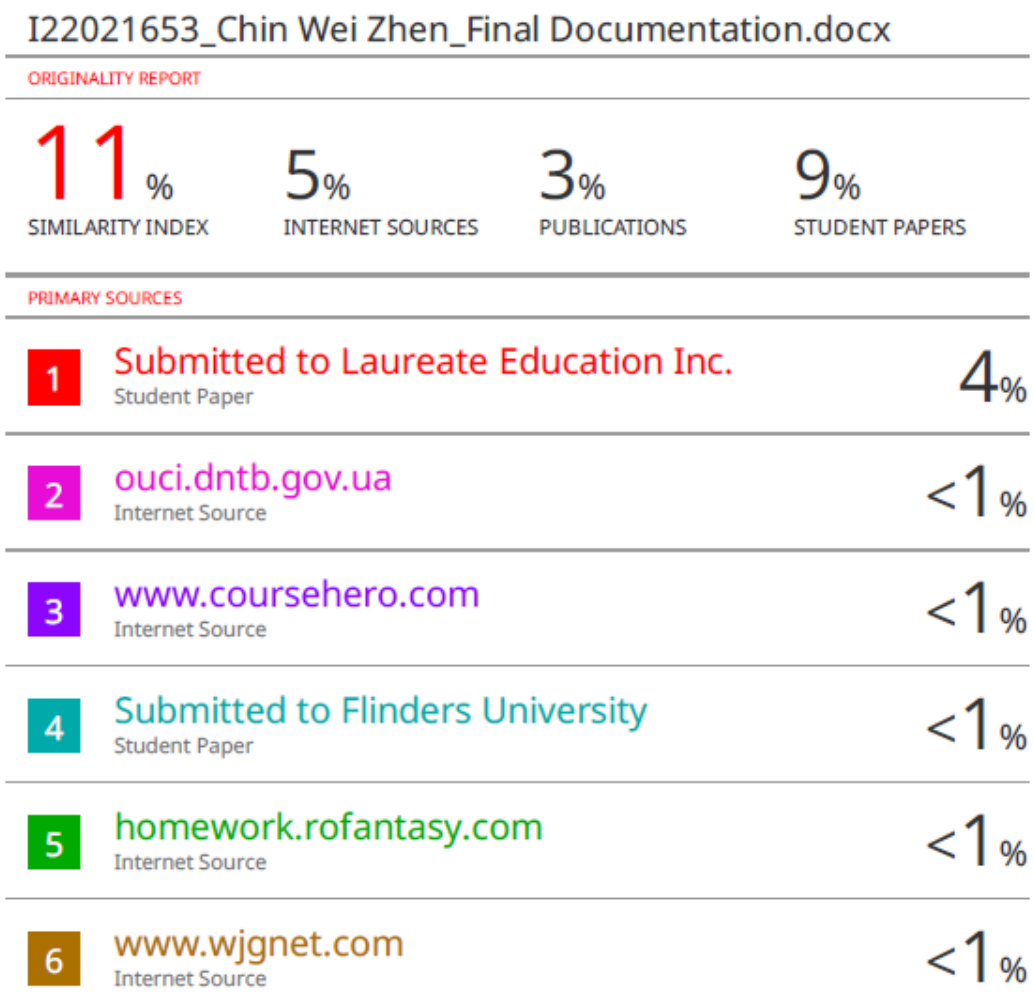
STUDENT DETAILS

Name : Chin Wei Zhen **Student ID :** I22021653
Project ID : FDSIT-INTI-IU-BCSI-JUN-2024-0003
Contact number : 010 - 874 1966
Course Code : FYP4202 Project II
Session : 6H1 JUN2024

APPENDIX E: TURNITIN SIMILARITY REPORT



I22021653_Chin Wei Zhen_Final Documentation.docx

ORIGINALITY REPORT

11%	5%	3%	9%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Laureate Education Inc. Student Paper	4%
2	ouci.dntb.gov.ua Internet Source	<1%
3	www.coursehero.com Internet Source	<1%
4	Submitted to Flinders University Student Paper	<1%
5	homework.rofantasy.com Internet Source	<1%
6	www.wjgnet.com Internet Source	<1%