Exploring The Use Of AI Technology To Help Owners Remotely Accompany And Care For Their Cats

Yueming Gao

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ABSTRACT

There are many domesticated cats in Canada. Caregivers need to provide domesticated cats with a safe space and daily games that simulate hunting because of cats' hunting nature, and they should also be mindful of the amount of exercise and food they eat to prevent obesity. However, many carers are too busy with their lives, resulting in them not being able to provide an ideal life for their cats. This thesis project will use the Research through Design (RtD) approach to explore how to employ COCO object detection model, Arduino, and Internet of Things (IoT) to design for the domestic cat's needs when people aren't at home. The research project iterated on four prototypes: 1) a safe space for cats - the Cat Castle. 2) a smart cat teaser to mimic the hunting game, which uses COCO object detection and Arduino. 3) An auto feeder to encourage cats to exercise more. 4) Integration of the above three prototypes to form an early-stage smart and cat-friendly environment. Finally, the prototype is designed to meet some of the cat's needs and it can also accompany the cat when the carer is not at home. This study can provide some exploratory experience in the animal-computer interaction (ACI) field of research on related topics.

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CHAPTER 1 INTRODUCTION

There are currently an estimated 8.5 million pet cats in Canada (CAHI, 2022). Some caretakers are busy with their jobs, and some of them lack time to care for their cats. Nowadays, there are some researches focused on how to apply smart technology to enhance animal well-being. Smart technology refers to a networked system linking physical devices to computers for data collection, analysis, exchange and processing (Jukan et al., 2017). With the advancement of smart technology, an increasing number of smart pet devices have been developed to provide convenience to pet caretakers. Sales of smart pet products grew by 11% to $565 million in 2018(Danziger, 2019). Thus, the demand for smart pet devices is on the rise. This thesis aims to design a smart system that takes an animal-centred perspective.

Indoor cats are selected as the target focus for this study because their restricted indoor activities often lead to a lack of sufficient exercise. This smart system will be designed with play and care as the main focus. It will have a modular structure that is easy to build, allowing caregivers to create an engaging smart environment for their cats. Additionally, the design will incorporate computer vision models and Arduino technology to explore the interaction between the smart system and indoor cats. This will enhance the lives of indoor cats, particularly when they are home alone.

The project belongs to Animal-computer interaction (ACI) research. It is designed for cat's needs. Some evidence shows that cats usually need some space to make them feel safe, do daily hunting exercises and reduce the risk of obesity (Hattori, 2020; Lewis & Scheibmayr, 2021; Scherk, 2016; Shyan-Norwalt, 2005). So, my research project will focus on the three needs to explore how to employ computer vision technology, Arduino technology and Internet of Things (IoT) technology to enhance indoor cats' lives. Also, it is designed as easy-to-build assemble pieces for caretakers, which means the caretaker can customize their own cat castle to their cats. As a result, this project can also belong to the DIY/Maker community or even consumer products.

1.1 Motivation

The ubiquity of smart technology today has revolutionized various aspects of human life, offering convenience and efficiency. From smart speakers and vacuum cleaners to intelligent home robots, these innovations have undoubtedly improved the human experience. However, while humans have readily embraced these advancements, our feline companions may not feel the same level of comfort. Mangat et al.(2022) found that house cats probably feel stressed when the domestic robot runs in the home. Their research shows that pets are also potential users of smart devices in domestic spaces. They also demonstrated there is little research about how to interact between cats and the smart device. Therefore, the advent of human smart homes may cause some threats to cats. The challenge is to set up a smart home environment for pet owners to be more suitable for cats' living. Research (Mangat et al., 2019) suggests that indoor cats react with vigilance towards intelligent social robots. This reaction is likely because such robots are designed mainly for humans, neglecting the needs of our pets who share our living spaces.

If humans can live better lives through smart technology, why should our pets be left behind? Recognizing this disparity, a burgeoning field known as Animal Computer Interaction (ACI) has emerged. ACI seeks to utilize computer technology to enhance the well-being of animals (Mancini, 2017). This field emphasizes placing animals at the center of research, aligning with the user-centred principles typically applied in human-computer interaction (Mancini, 2013). ACI aims to promote equality between animals and humans in the realm of research.

Motivated by this knowledge, the objective of this research is to develop an animal-centric smart environment system that not only engages and entertains cats but also assists in their care. This thesis project will focus on addressing the specific needs and well-being of cats. While many smart devices are designed with humans in mind, even pet care products tend to prioritize human convenience, such as automatic feeders. Therefore, this research explores the potential of animal-centric design integrated with smart technology, aiming to create products specifically designed for cats.

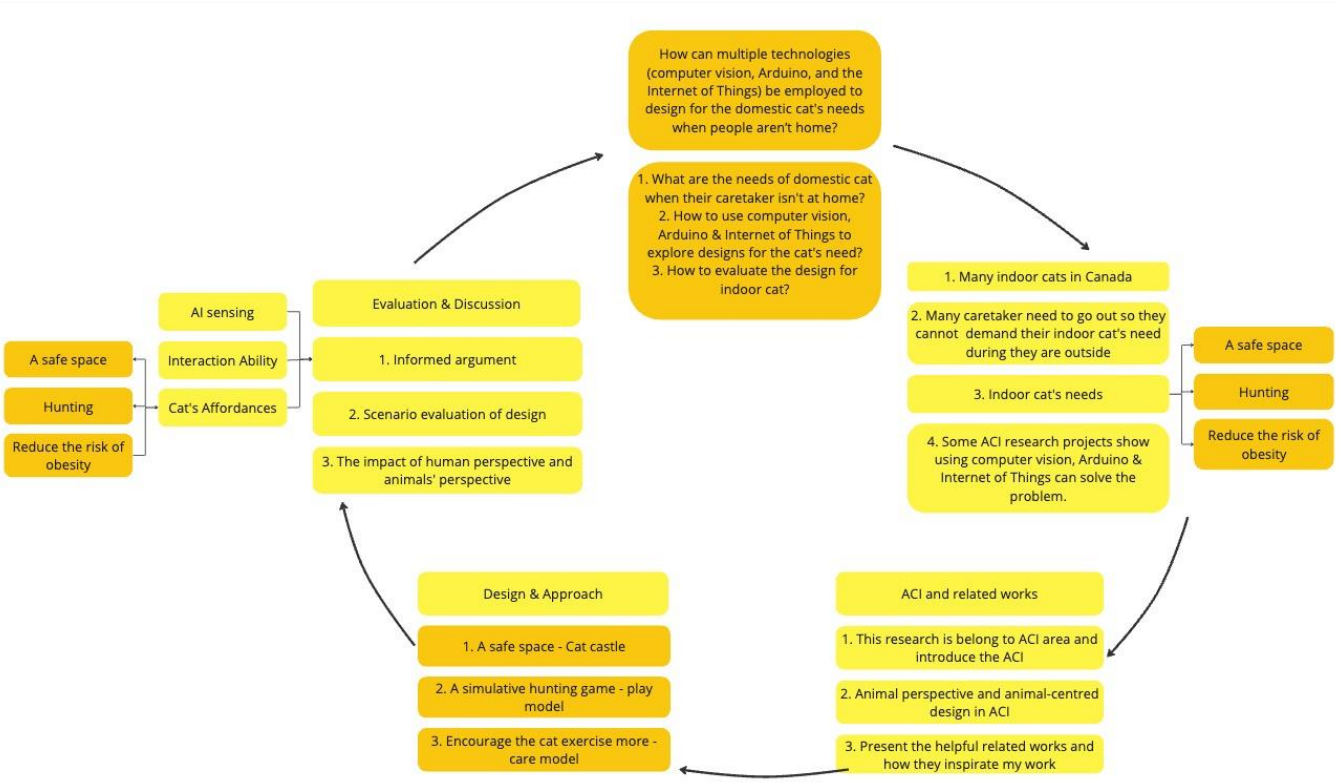


Figure 1. The structure of the thesis

1.2 Research Summary

1.2.1 The Problem

The design of the smart pet system lacks an animal-centered perspective. Most of the research and design efforts are focused on caretakers - humans instead of their pets, which leads to smart pet devices prioritizing the needs of humans rather than pets. Additionally, most people return to their routine after the COVID-19 pandemic, but their pets are still at home waiting for their caretaker to come back to play with them and care for them. This paper specifically focuses on indoor cats as the target audience. This is because indoor cats constitute most of the total number of pet cats in Canada. Therefore the issue of their limited exercise opportunities when they are home alone due to restricted space for activities.

1.2.2 Hypothesis

Currently, researchers in the field of Animal Computer Interaction (ACI) are trying various computer technologies to help improve the well-being of non-human species. For Indoor cats, they need a space to feel safe, daily games to simulate hunting, and care to maintain a healthy weight. Computer vision, Arduino and Internet of Things technology can be useful for building a cat-friendly environment. The environment can support some play and care functions in their lives while they are at home alone.

1.2.3 Research Questions

1) Main research question:

How can multiple technologies (computer vision, Arduino, and the Internet of Things) be employed to design for the domestic cat's needs when people aren't home?

2) Sub-questions:

This research aims to answer the main question by the following sub-questions:

- **a.** What are the needs of domestic cats when their caretaker isn't at home?
- **b.** How to use computer vision, Arduino & Internet of Things to explore designs for the cat's needs?
- **c.** How to evaluate the design for indoor cats?

1.2.4 Goal and Objectives

For my research, I combine AI technology and Arduino technology to provide a solution to build a smart system for cats. This system aims to play with and care for cats while they are at home alone.

- Application of a computer vision model to watch and see cats.
- Design a cat-friendly environment.
- Design some models that can play with and care for cats, which are driven by Arduino
- Combine the computer vision model and Arduino technology as a smart system and build in a cat-friendly environment.
- The thesis project evaluation aims to improve future projects through better learning.

1.2.5 Approach And Method

The research explores the possibility of a cat-friendly smart system through the method of Research Through Design (Forlizzi, 2012), which can play with and care for domestic cats. The research will follow the ACI principle to protect the legal rights of research subjects, even if they are non-human species. This research project will iterate from simple basic designs to full prototypes. During this process, each prototype iteration will be evaluated, and the evaluation opinions will be considered into the new design. This can help improve the prototyping of research projects.

1.2.6 Project Contributions

The primary contribution will be to propose a design of smart system for pets using animal-centred perspective. Since smart pet devices and systems are serving pets rather than humans, such designs must be approached from the perspective of animals.

Furthermore, the code and laser-cut file will be shared in the appendix. It will allow caretaker who is interested in the project to build their own smart cat castle. It will also welcome caretakers, related researchers, and any people who care for indoor cats to contribute their ideas and creativities together on the project.

1.2.7 Intended Audience

This study's target audience is people (e.g., pet owners, pet researchers, people interested in cat wellbeing, and people designing for cats) who are focused on domestic cats and spend most of their time indoors. They care about the well-being of indoor cats and want to improve their quality of life.

1.2.8 Intended User

First, the cat castle is designed for the cat's well-being. Second, it is designed for people who own indoor cats and care about their cats' well-being and would like to create a smart environment for their cats. Indoor cats do not need to face complex and dangerous natural environments and have less space for activities, but they have the problem of less exercise. In addition, many caretakers need to go out a lot and cannot accompany their cats for exercise, such as in some simulated hunting games. This puts them at increased risk of obesity.

1.2.9 Scope and Limitation

This paper will focus on the preliminary research and design methodology and will not include the evaluation of live animals.

While this thesis acknowledges the inclusion of components to facilitate caretaker usage, the primary focus remains on catering to cats' needs, with humans serving as the secondary target audience.

The level of AI (Artificial Intelligence) mentioned in this thesis is not high and is still in its infancy in AI for detecting cats and AI for analyzing cat behaviours. In particular, COCO object detection, Arduino, and Internet of Things (IoT) approaches are used.

Additionally, as we only had 9 months to complete the entire project and thesis, most of my time was spent on prototyping. This limited the amount of time I could spend on observing and researching cats, which may have resulted in some bias due to these limitations.

1.2.10 Chapter Overview

The subsequent chapters will address: Chapter 2 - the health risks faced by indoor cats in modern family life and the potential of technology to promote healthier behaviours. This thesis project will adhere to the principles of ACI and employ AI technology and Arduino sensor technology to create an animal-centred design. Chapter 3 - The Research through Design (RtD) methodology will be employed to explore the application of smart technology in this domain. Chapter 4 - the thesis will outline the iterative progress of each generation of prototypes. Finally, Chapter 5 will assess the feasibility of smart products in enhancing the well-being of cats, discuss areas for improvement, and explore potential future applications of this project. Chapter 6 will conclude the thesis.

2 LITERATURE REVIEW

With the advancement of computer technology, animals can now enjoy the benefits and convenience of its application. Furthermore, a wide range of research studies are being conducted in this area.

2.1 Domestic cats need more attention and care

2.1.1 The state of cats in Canada

Humans and cats have lived together for an exceptionally long time. Cats are one of the most popular companion animals. According to statistics, there are currently an estimated 8.5 million pet cats in Canada (Canadian Animal Health Institute, 2021) with 63% of them being indoor cats (Foreman-Worsley et al., 2021). It is a better choice for most Canadians to keep their cats indoors because there are some predators of large size in North America, such as bears, eagles, or coyotes, which, of spices, will increase the risk of surviving cats. On the other hand, urbanization is probably another reason to keep indoor-only cats for cat caretakers. The carers who live in a flat or apartment will more probably keep their cats at home; even in northern Europe, most cat owners choose to keep their cats outdoors. Road traffic accidents also encourage them to consider the safety of their furry kids so that their cats commonly stay at home (Foreman-Worsley et al., 2021).

2.1.2 Many caretakers need to go out for work, study or other activities

The arrival of COVID-19 has brought about changes in the pet adoption situation compared to 2019. The adoption rates for cats and dogs have significantly increased from 2019 to 2020. Research conducted by Ho et al.(2021) indicates that the adoption of cats remains particularly popular. This could be attributed to their adaptability to indoor living. However, with the easing of Covid-19 restrictions, caregivers now have to leave their homes for work, study, or other

social activities. This raises concerns that domestic cats may experience a decrease in quality companionship and care compared to the period of the pandemic. The research also points out that the separation anxiety of pets may impact the behaviour and health of pets because their caretaker disappears for a long time per day. And bad behaviour of pets probably makes the inexperienced caretaker become impatient and abandon the pets to return to the shelter.

Even if COVID-19 has passed three years, people still need to go out due to their jobs, and some of them may remain too busy to care for their cats all the time. This can still affect a cat's health if their basic needs are still ignored by their caregivers. In fact, either temporarily or for an extended period, failing to meet the basic needs of a companion animal is mistreated toward the animal, for instance, a person forgets to feed his companion animal because he suddenly needs to take care of other family members; a person goes away on holiday and doesn't care at all if his pet, who is home alone, has access to enough water and food. Whether the carer is intentionally or unconsciously ignoring the needs of their companion animal, the suffering they endure is the same for the companion animal (Levitt et al., 2016). It is therefore necessary to prevent in advance that the cat's basic needs are neglected today.

2.1.3 What are indoor cats' needs?

Even though most cat caretakers choose to keep their cats indoors, they still concern themselves with the welfare of indoor cats, which they probably don't have compared to outdoor cats. For instance, compared with outdoor cats, domestic cats cannot enjoy wide open spaces and natural environments, which may lead to a lack of enough daily exercise (Foreman-Worsley et al., 2021).

Besides, Scherk (2016) argues that domestic cats have a higher risk of obesity than outdoor cats. The reason is that limited indoor activities often result in indoor cats consuming more calories than they burn. Obesity is the primary health threat for indoor cats, as it can also lead to related diseases such as arthritis or diabetes (Zoran & Buffington, 2011). So, it is important to prevent obesity in cats for their health.

In addition, Scherk (2016) also proposes some ways to improve the quality of indoor life for cats. She mentions that cats need a safe place, hunting exercise, and environmental resources:

- A safe space: This refers to where you can let them rest, relax and sleep. She also emphasized the need for a cat to be in an elevated position where it can be observed from above. This also gives the cat a sense of control. The cat also needs a place to hide, which reduces the cat's stress. Because hiding is a necessary coping behaviour for cats, the safe space also needs to have multiple exits to avoid making the cat feel like it will fall into a trap. Also, cats like to explore the tunnel and stay in a narrow space, which is like a den of their wild ancestor (Hattori, 2020; Scherk, 2016).
- Hunting exercise: Cats naturally need to play and hunt. Hunting can be seen as an occupational need. For domestic cats, the occupational needs become pseudo-predatory play and eating behaviours (Hattori, 2020; Lewis & Scheibmayr, 2021; Scherk, 2016).
- Environmental resources: Cats should have access to all key resources, like food, water, toileting areas, etc. Because territory and resources are closely related to cats. Cats have risk-free access to these life resources within their territory, which can reduce stress(Hattori, 2020; Scherk, 2016).

Moreover, people can evaluate the life quality of pet cats from professional suggestions about feline health. According to Griffin's (2021) research, veterinarians must ensure the well-being of both individual cats and cat populations. The paper identifies three components of feline wellness: environmental health, physical health, and behavioural health. Based on these components, it also presents policies and protocols for the health care of cat populations. Although the suggestions are for the population of cats rather than individual cats, the knowledge, policies, and protocols mentioned in the paper are generally applicable to most cats.

The safe space and environmental resources can correspond to environmental health, which Griffin mentioned, and hunting exercise can correspond to behavioural health. The higher risk of obesity can correspond to physical health. Hence, the above information shows it is important to have a space where cats feel safe, play a mimic hunting game and reduce the risk of obesity for domestic cats. In my study, the design idea of the prototype is mainly based on the three dimensions of feline health. A safe space, a hunting game, and the initial obesity prevention programme will be responded to the prototype.

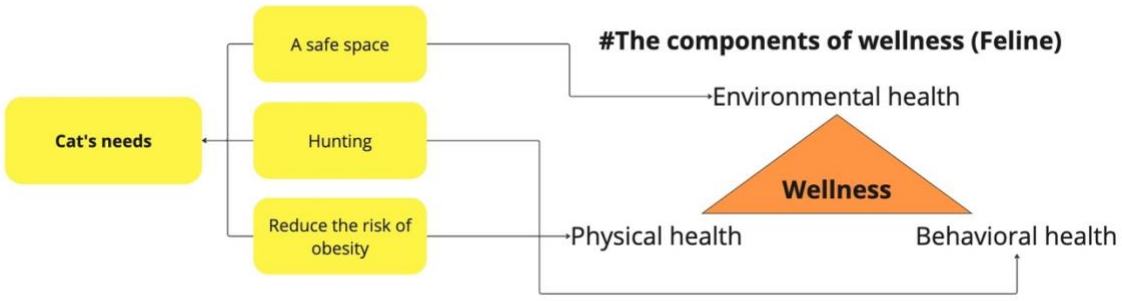


Figure 2. The relationship between the components of wellness of feline and indoor cat's needs is based on Griffin (2021); Hatton (2020); Scherk (2016).

If the caregivers are so busy that it is difficult to provide for the cat's basic needs, it is detrimental to the cat's health. Therefore, we need some methods to accompany and take care of the cat when the caregiver is busy.

2.1.4 Technology can support cats' needs while people aren't at home

To increase the quality of life of domestic cats, they should be cared for and accompanied as much as possible, even when the caretaker is not home.

The Internet of Things (IoT), computer vision, and Arduino technology could efficiently address the needs of indoor cats. Some relevant animal-computer interaction (ACI) research also helps owners care for their pets better. For instance, Chen et al. (2021) use computer vision for remote identification of problematic cat behaviour. Ibrahim et al. (2019) designed an automatic feeder powered by Arduino. Lee et al. (2006) created a wearable computer and mixed reality system for remote communication between people and poultry. Numerous studies utilize these technologies to enhance animal welfare. I will highlight some relevant research studies in the "Related Works" section below.

2.2 The Introduction of Animal-Computer Interaction (ACI)

The concept and theory of Animal-Computer Interaction (ACI) are crucial to my research because they emphasize examining from the perspective of animals, with the goal of using computer technology to enhance the well-being of non-human species. Therefore, ACI has significant guiding

implications for my research. In the prototype design, I will also refer to the methodologies and principles of existing ACI studies.

Animal-Computer Interaction (ACI) is an emerging discipline related to Human-Computer Interaction (HCI) (Mancini et al., 2017). The definition of ACI can be seen as how non-human species communicate and work together with computer science (Hirskyj-Douglas et al., 2018). Its emergence has helped humans better understand and recognize the interaction between natural animal behaviour and modern computer technology. The development of human technology has forced the animals sharing the Earth with humans also to use modern technology. Even without training, people have unexpectedly discovered that certain animals are using human tools (Mancini et al., 2017). This means that ACI has significant implications for the development of human society, the relationship between technology and nature, and sustainability.

2.3 The Brief History of Animal-Computer Interaction (ACI)

In 2011, Clara Mancini proposed the establishment of Animal-Computer Interaction (ACI) as a discipline. This was in response to the growing body of research on the interaction between animals and computers. ACI aims to understand the interaction between non-human species and computation, considering animal behaviour, their environment, and their interactions with humans and other animals. This perspective adds an animal-centric approach to the field of computational interaction.

Mancini (2013) explained that ACI differs from Human-Computer Interaction (HCI), although it is an emerging area related to HCI. The fundamental difference lies in the HCI user-centred design principle, which is dependent on the human user. The design approach must be adjusted accordingly when the users are a completely different group, such as non-human species. Therefore, research on non-human species should not be confined to the same framework as HCI.

After several years of development, an increasing number of ACI studies are emerging in the professional academic field. In 2017, Jukan et al. systematically investigated the related research on intelligent computing technology and sensing technology in the context of household, farming, and

wildlife welfare. They classified ACI in two dimensions. One is applications - which typically refers to the ways and purposes of interaction, such as communication, health, monitoring, and environment. The other is about the animal world - which typically refers to the locations of animal lives, such as domestic, farm, and wild. They also proposed some development suggestions. With the technological advancements of cloud computing, data and system sharing can facilitate the development of ACI.

Additionally, ACI can help promote the development of animal husbandry and improve its productivity. Cross-species and cross-sector research can help us understand our relationship with nature, to establish a sustainable ecological system. Intelligent technology and the Internet of Things can bring us closer to animals. We can create intelligent disaster emergency and response systems, which minimize the impact of disasters on non-human beings as much as possible.

Later, Hirskyj-Douglas et al. (2017) reviewed the research projects ACI from 2011 to 2018 based on the work of Jukan et al. They classified ACI using the framework for technologies in ACI into the following categories: 1) Tangible and Physical. 2) Haptic and Wearable. 3) Olfactory. 4) Screen Technology. 5) Tracking Technology. This classification provides a direct and clear overview of the five main technologies in ACI. They identified the existence of "the gulf of execution" in ACI research, which means that humans cannot accurately understand the thoughts of animals in their interactive behaviour with computers (Hirskyj-Douglas et al., 2018). ACI requires research to understand and explain these "gulfs," which are also related to animal psychology and physiology (Hirskyj-Douglas et al., 2018).

2.4 The Importance of Animal Perspective

It is vital to add the animal perspective for the development of computational interaction. Firstly, it can improve animal's life expectancy and quality (Mancini, 2011). The living behaviours of humans and animals are different. Some designs are fit for humans but not for other species. For instance, the research from Mangat et al. (2019) mentioned in previous parts shows that companion animal cats may have difficulty adapting to the sudden addition of a robot in their home. The reason is the robot was designed for humans, but they did not consider a situation in which humans have companion animals in their home. Similar situations might threaten their pet's health.

Secondly, it can support animals in their legal rights and benefits (Mancini, 2011). The interests of humans and animals often differ. Additionally, there is a power disparity between designers and animals, as animals struggle to express their thoughts and opinions. As a result, human design for animals tends to lean towards human living habits (Lawson et al., 2016). Therefore, in ACI research, it is important to incorporate the perspective of animals as much as possible, minimizing human bias, to ensure better the legitimate rights and well-being of non-human species participants. We should learn as much as we can about the physiology of the animals and their habits, which will help our design not to infringe on the animals. Therefore, for my research project, the needs of indoor cats mentioned earlier will be reflected in the prototyping. In other words, it is the cat's needs that guide the design, not the human's needs.

Thirdly, it can promote the relationship between human beings and animals (Mancini, 2011). Mancini (2013) proposes an opinion of "Thinking outside the (human) box." She believes that the ACI enriches the HCI. And animals and humans share some space on Earth; we are reliant on each other. As technology advances, humans have entered the era of computer technology, and some animals that live alongside humans have also entered this era. It would be unreasonable to abandon them completely. Moreover, humans are one of the kinds of animals, and knowing animals is also a way to learn about ourselves (Mancini, 2013).

2.5 The Principles of ACI

The research object of ACI is usually non-human organisms. The advantages of humans and the difficulties in cross-species communication may inevitably cause discomfort to animals in related research (Hirskyj-Douglas et al., 2018). In response to this, Mancini (2011) proposed ethical principles:

- Researchers should acknowledge, understand, and respect the characteristics of all species participants, and there should be no discrimination.
- Researchers have an obligation to treat human and non-human organisms equally and care for their needs.
- Research should have a positive impact on the species involved.
- Research should avoid and prevent physiological and psychological harm to participants.

- Human and non-human participants should have the right to withdraw from the study at any time and anywhere.
- Human and non-human participants should have the right to be informed about and consent to the content of the research.

As mentioned above, research on ACI (Animal-Computer Interaction) follows the same user-centred principles as HCI (Human-Computer Interaction). However, in ACI, animals are also considered users in interactive research (Mancini & Nannoni, 2022). Thus, Mancini and Nannoni supposed and explained the fundamental principles of animal-centred research - relevance, impartial treatment and welfare prioritization:

- **Relevance**: Animals should only be involved in research procedures if it directly applies to them and benefits them.
- **Impartial treatment**: The ethical framework for researchers supporting research focused on animals should protect all participants regardless of their characteristics (e.g., species, sex, age, provenance) or any attributed abilities. This helps minimize bias toward humans when planning research protocols.
- **Welfare prioritization**: The ethical framework consistently emphasizes the importance of prioritizing participant welfare in animal-centred research. Researchers should avoid procedures that harm animals whenever possible.

In summary, animals are at the heart of ACI, so it is crucial for ACI research to respect and acknowledge their needs and welfare. Although this thesis does not focus on the ethics principles, it does use the three fundamental principles above to evaluate.

2.6 Related Works

The following research projects are some relevant ACI works designed for animal welfare. They are classified by technology and provide some experience and inspiration for my research.

Table 1. The related research papers that utilize computer vision technology, Arduino technology and Internet of Things to design for animals

Technology	Related Paper	Author	Year	Keywords
Computer Vision technology	Monitoring the behaviours of pet cat based on YOLO model and raspberry Pi	Chen et al.	2021	Raspberry Pi, Pattern recognition, YOLO model, Deep learning.
	TAS for Cats: An Artist-led Exploration of Trustworthy Autonomous Systems for Companion Animals	Schneiders et al.	2023	multi-stakeholder, art as research platform, participatory design
Arduino Technology	Pet food autofeeder by using Arduino	Ibrahim wt al.	2019	Arduino, Pet Feeder.
	Geofencing technology implementation for pet tracker using Arduino based on Android	Setiawan et al.	2021	Geofencing, GPS, Arduino Technology
	Reliable Smart Pet Feeding Machine Using Arduino Uno Starter Kit	Suffian et al.	2021	Arduino, Pet Feeder, weight sensor
	Internet of Robotic Cat Toys to Deepen Bond and Elevate Mood	Han and Witzman	2023	human-robot interaction, animal-robot interaction, internet of robotic things, smart pet care system
Internet of Things (IoT)	A mobile pet wearable computer and mixed reality system for human–poultry interaction through the internet	Lee et al.	2004	Multimodal interaction, Mobile computing, Mixed reality, Cybernetics, Haptic interfaces, Wearable devices
	Towards a Smart Toy Ecosystem for Pets	Hof and Hoang	2020	Internet-of-Things (IoT), software architecture, pets, smart systems, pet behavior classification, mobile applications, cloud computing

2.6.1 Computer Vision Model in ACI Designs Involving Cats

Computer vision is a technology that allows computers to see (Ibrahim et al., 2019). Nowadays, Computer vision is already applied in multiple areas, such as optical character recognition (OCR), machine inspection, retail, 3D model building, medical imaging, etc. (Szeliski, 2022). In the field of ACI, Computer Vision is usually applied to object recognition and animal behaviour analysis.

There are some popular computer vision models which can detect various kinds of objects, like COCO and YOLO. COCO is published by researchers at Microsoft and can recognize 91 objects,

such as bicycles, cars, birds, dogs, cats, etc (Lin et al., 2015). In this thesis, the COCO model was utilized in prototype 2 to detect whether a cat is there or not.

1) Monitoring the behaviours of pet cat based on YOLO model and raspberry Pi (R.-C. Chen et al., 2021)

The project used an object detection model, the YOLO model, and Raspberry Pi to design a system that can monitor pet cats and warn caretakers if cats exhibit inappropriate behaviour while they are at home alone. They use a lot of pictures which can show the inappropriate behaviour of cats to train the YOLO model. Let the YOLO model form an object detection model to be a cat's inappropriate behaviour detection model. Then, they attached a camera to Raspberry Pi and ran the trained model Raspberry Pi. They got a Monitor of the behaviours of a pet cat. It could send a message if the Monitor detects any inappropriate behaviour, like jumping up to the counter or rummaging through trash.

This design made me realize that I can use a computer vision model to identify cats and their behaviours. Similarly, I can use a computer vision model to give my prototype design the ability to "see" cats and give the response to the user – cats.

2) TAS for Cats: An Artist-led Exploration of Trustworthy Autonomous Systems for Companion Animals (Schneiders et al., 2023)

This project has created a utopian environment. Interestingly, this utopian environment is for cats. Researchers want to discuss a question: What if the world could satisfy the desires of cats? This project has enabled computer vision technology to give the system the ability to recognize different cats. Also, researchers have used several robotic arms to meet the needs of cats, such as playing with them.

This design envisions a utopia for cats that does not currently exist. However, the researchers applied some technology to meet the cats' needs. This gave me an insight into the possibilities of enriching the lives of cats with computer technology, such as computer vision and robot arms.

2.6.2 Arduino Technology in ACI Designs

Arduino is an open-source platform for microcontroller development. Its integrated development environment allows users to create any control system using any programming language (Blum, 2013). Arduino is often used to create prototype designs.

1) Pet food autofeeder by using Arduino (Ibrahim et al., 2019)

Some owners are so busy that they prepare a large portion of food in advance that exceeds their pet's normal intake to avoid forgetting to feed it. This may cause the pet to become overweight.

In this study, they used Arduino to design an automatic feeder to solve this problem. This feeder can feed pets on time and in quantity. It can also be set to feed different amounts of food, as different pets need different amounts of food.

2) Reliable Smart Pet Feeding Machine Using Arduino Uno Starter Kit (Suffian et al., 2021)

This study is likewise an automatic feeder. The researchers designed it using an Arduino, weight sensors, and a single motor. The weight sensor detects the weight of the remaining dry pet food. Once the weight sensor detects a reading set to detect weights less than 50 grams, the Arduino is turned back on to dispense the food. This ensures that the pet eats the previously dispensed food before another meal is offered. The design uses a 3D printer to make special parts (plywood, aluminum tin, etc.), which are then assembled with parts made from other materials.

Both above designs mentioned that this automatic feeder was designed to solve the problem of carers being too busy to feed. They both use Arduino technology as the smart driver to solve the problem. The above two designs provide the experience of making an automatic feeder using Arduino.

3) Geofencing technology implementation for pet tracker using Arduino based on Android (Setiawan et al., 2021)

This project is a wearable device that can locate a pet's position. In addition to using Arduino, the researchers also used Geofencing technology and the Global Positioning System (GPS). They designed the wearable device into a Pet Tracker collar, with a small box hanging on the

collar containing Arduino and GPS antennas, etc. Arduino serves as the processor for GPS data, and this data can be sent to a mobile phone.

Geofencing technology can be seen as a virtual fence, where a safe range can be set. When a pet wearing the Pet Tracker collar leaves a safe distance, Arduino will send information to the caretaker's mobile phone. This way, the caretaker can know where their pet is, which can reduce the risk of pet loss.

This project uses Arduino and Geofencing technology to track the pet's location. It ensures that the pet is within a safe range and sets up a safe territory for it.

4) Internet of Robotic Cat Toys to Deepen Bond and Elevate Mood (Han & Witzman, 2023)

The project created several smart toys for cats that can be placed in different areas of the home. They explored the idea of internet-connected smart toys for cats. They developed three types of smart toys and connected them to create a smart environment that can keep cats company automatically. This design focuses on interactions between cats and robots, making it more suitable for cats than humans. This research is valuable for my thesis because it provides insights into how we can create smart environments for cats.

This project has provided me with some inspiration. It made me understand that Arduino technology can make a cat toy to accompany a cat. Multiple cat toys can also be set up in different locations in the home, which makes the home like a playground for the cats.

2.6.3 Internet of Things (IoT) in ACI Research for Pet Design

The Internet of Things (IoT) is a network of physical devices embedded with sensors, software, and connectivity that enables them to collect and exchange data. These devices can communicate with each other and with users through the internet, allowing for remote monitoring, control, and automation. IoT has applications in smart homes, healthcare, transportation, agriculture, and more fields (Perera et al., 2014).

As mentioned earlier by Jukan et al. (2017), Internet of Things (IoT) technology can help us establish more comprehensive systems to improve animal welfare. When caretakers go out, they can connect with their pets remotely through the use of IoT technology (Kim, 2016). Besides, IoT

technology can also be used to create a system for caring for pets, such as by connecting smart toys, feeders and wearables together to form a system where they can care for pets and collect data to analyze their behaviour and health based on real-time data from them (Hof & Hoang, 2020; Kim, 2016).

1) A mobile pet wearable computer and mixed reality system for human–poultry interaction through the internet (Lee et al., 2006)

This research focuses on the application of wearable devices and AR technology in remote interaction between humans and animals. Humans can remotely touch a toy chicken, which will send a signal to the farm. The chickens on the farm wear a jacket, and when the jacket receives the signal, it will vibrate in response. This process simulates the experience of humans touching domestic fowl. Through technology, remote physical touch simulation is possible.

2) Towards a Smart Toy Ecosystem for Pets (Hof & Hoang, 2020)

This paper proposed a smart ecosystem for small dogs or cats. The ecosystem consists of a wearable collar, a mobile app, and a cloud data space. The wearable collar can monitor certain health conditions of the cat and collect data, which is then sent to the cloud. The mobile app allows communication with other toys. This system builds an IoT smart system for cats and utilizes the cloud data to train an intelligent model for a better understanding of cats.

This research inspired me to create a smart environment for cats by integrating multiple smart devices with different functions into one system. Each small device can be designed for the cat's specific needs, and then integrated into a system that can meet the cat's multiple needs.

In conclusion, Animal-Computer Interaction (ACI) is an emerging discipline that emphasizes the importance of understanding the animal perspective in interactive system design. ACI specifically focuses on the interaction between non-human species and computer technology, adapting design principles to meet their unique needs. Moreover, domestic cats need to be cared for to keep the environment healthy, behaviour healthy and physically healthy, but some people probably ignore the cat’s needs due to their busy life. To prevent the problem, utilizing computer vision technology, Arduino

technology and IoT can create a better smart environment for companionship and care for cats. Previous works have shown the potential of these technologies in improving animal welfare. Therefore, I will choose the above three techniques (computer vision, Arduino, and IoT) to explore the design of a smart environment that can provide a safe environment for cats, simulate the game of hunting and an option to prevent feline obesity.

3 METHODOLOGY

My research aims to develop interactive smart toys for indoor pet cats and meet their needs for solo play and physiological needs through these smart toys. In this study, I will use various research methods to design and develop a multifunctional smart toy. The methodology of this research project will use the Research Through Design (RtD) approach. The design process will be iterated from elementary prototyping to more advanced designs. In the end, the research will use the informed argument and scenario to evaluate the design.

Currently, this study has not access to real cats to test. According to “relevance” in the fundamental principles proposed by Mancini and Nannoni (2022), animals should only be allowed to participate in an experiment if the study procedure is clearly beneficial to the animal (2022). Therefore, I would not choose to involve cats at this stage. The prototype design can be evaluated by both informed argument and scenario building (Hevner et al., 2004) to assess whether the prototype design can meet the needs of domesticated cats and is beneficial to cats.

If the prototype is shown to benefit the cat's life after evaluation by informed argument and scenario, we can consider involving the cat in its evaluation in future work.

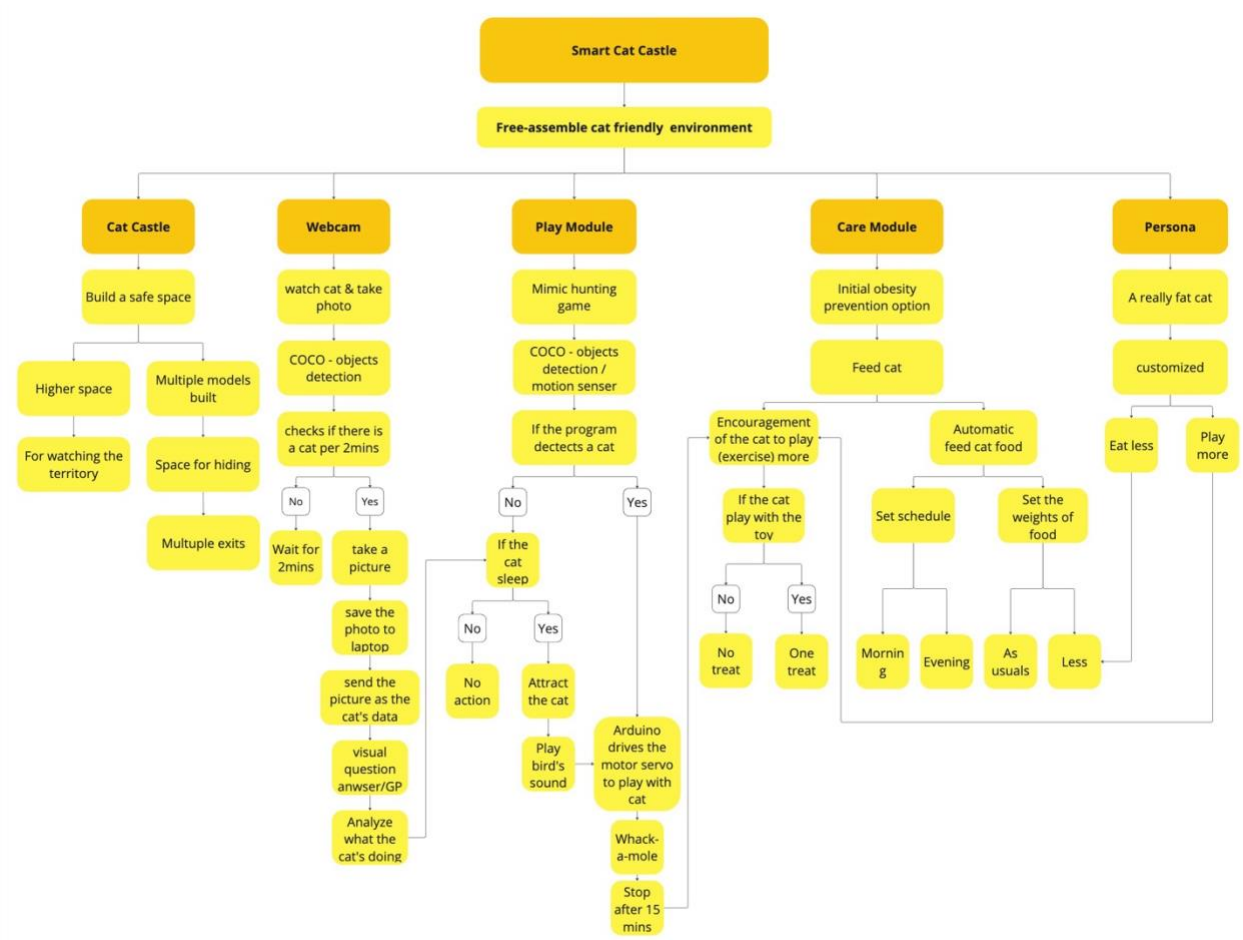


Figure 3. High level overview of what a system could look like to achieve the goal of this thesis. However, only an early design has been implemented currently at this stage.

3.1 Research Through Design

Research Through Design (RtD) approach is an academic research method that combines research and design. Zimmerman and Forlizzi (2014) indicate that "Research through Design (RtD) is an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge." It allows for prototyping and iterative design. This research method is not only applied in the field of HCI but also in the field of ACI. In other words, ACI refers to some research experience from HCI and applies it reasonably in the field of ACI. French et al. (2017) explored the application of RtD in ACI research. They believe

that RtD has advantages in ACI research. Due to the different living environments and habits of different animal species, research needs to address animal needs in a deep and targeted manner. RtD emphasizes providing solutions for research purposes, which means that RtD is a good way to conduct research. French et al. (2017) also mentioned that the process of creating a series of artifacts is a fundamental aspect of RtD (Research through Design) and the basis of its design philosophy. In the maker community, there is a culture of sharing and providing remote assistance to others. RtD practices promote the dissemination of works through various channels since public participation plays a crucial role in evaluating an artwork, particularly when the designer's intention is to generate interest. ACI professionals can adopt this practice to showcase their achievements in different formats. This provides more opportunities for ACI research to be widely disseminated and recognized. In my research and design, I will go from theoretical exploration to prototype design and then to iterative design, creating a smart environment that can accompany and care for cats. This research design will be based on the needs of cats who are home alone to conduct prototype design and explore the possibilities of computer interaction for pet care.

3.2 Informed Argument

The informed argument approach is a part of the descriptive evaluation method in the Design Science methodology (Hevner et al., 2004). It uses existing knowledge and research findings to build a compelling case for the utility and effectiveness of Artifacts (Hevner et al., 2004).

It is crucial to establish the artifact's validity within the existing body of knowledge. This allows the research to connect the innovations with the established theories and previous research experience.

This method will be used in this study to evaluate the research project. I will compare and analyze four relevant past research projects with the current prototype design for this study. This will be used to discuss the usefulness of the prototype design in this research project.

3.3 Scenario

The scenario approach from Hevner (2004), involves creating detailed, hypothetical, or real-life scenarios for applying artifacts. These scenarios aim to illustrate the utility of the artifact, showing how it can operate in a particular context to solve an identified problem or enhance an existing solution. Through narrative descriptions, researchers can vividly demonstrate the functionality of an artifact and its potential impact on users or stakeholders (Hevner et al., 2004).

For this approach, this study will use Persona to simulate a potential user based on research in the context of prior literature knowledge.

3.4 Persona

The Persona method involves creating detailed, fictional personas that represent key user groups for the product. These "personas" are usually abstract and fictional, but they are based on user research and include specific characteristics, goals, needs, preferences, and contexts of use (Miaskiewicz & Kozar, 2011). These personas can be used as prototypes to guide the design and evaluation process by focusing on the user experience from the perspective of these representative users.

For this thesis project, I set up a cat persona based on the background knowledge of cats collected in the literature review before designing the prototype and designing the prototype based on the persona. Besides, for evaluation, combining Scenario and Persona methods offers a powerful approach to evaluating the prototype. This helps to build a richer and more specific picture of the potential environment and user research, which can also better enable the evaluation of prototypes more effectively.

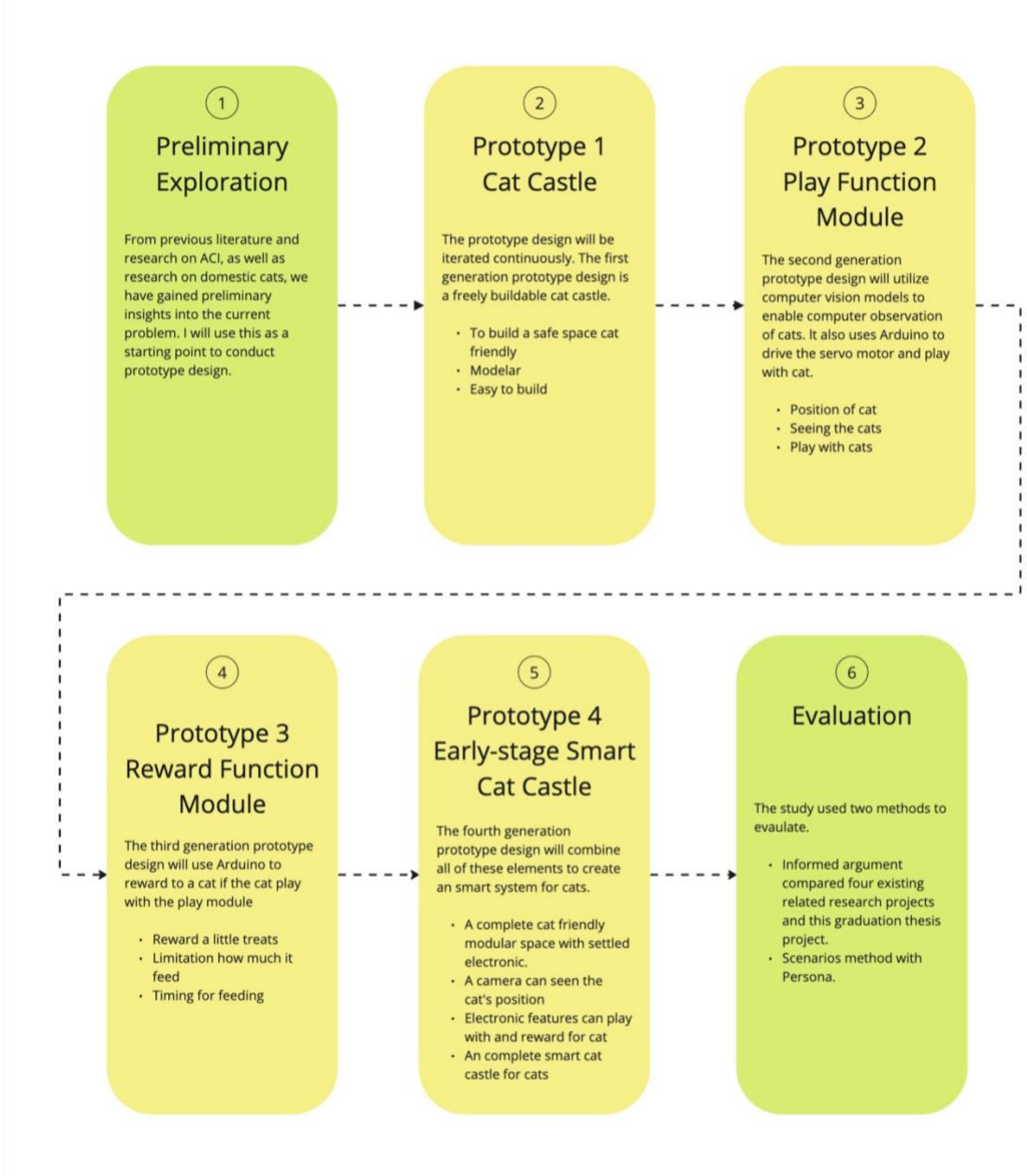


Figure 4. The flow chart of the methodology

The entire design and process will be presented in the next chapter. Additionally, I will attach the design files and code of the thesis project as attachments appendices in the final part (See Appendix).

4 ITERATIVE PROTOTYPING STAGES

This section illustrates four prototypes which are designed to address three basic needs of cats (a safe space, hunting activities and obesity prevention): 1) Cat Castle: it is the basic framework of the whole design, which establishes a safe space for cats, and subsequent prototypes will be based on this framework for extension. 2) Cat's Play Function Module: this is a smart cat teaser stick device. It is a simulated hunting game designed for cats, and the mode of the game is similar to Whack-a-Mole. 3) Reward function module: the prototype is to encourage cats to exercise. this module is similar to an automatic feeder device, but its main purpose is not to feed cats but to give cats a little reward after exercising and to encourage cats to exercise more in a positive incentive way. 4) A fully constructed cat castle with smart functions: This cat castle consists of multiple modules and includes two play modules and one reward module. It provides multiple hiding spaces for cats and has multiple exits. It also encourages the cat to exercise by linking the play module with the reward module which encourages the cat to exercise.

Now, prototype 3 has finished with the fundamental structure, which can be driven by Arduino. The future work will involve the reaction of the reward function module to cats. Prototype 4 is for the Digital Futures Graduation Exhibition. In addition, the smart level in this prototype design is not advanced, and it is only at an early stage. It merely can only identify cats but cannot recognize cat behaviour yet. This design exploration would not involve more advanced cat behaviour analysis at this time due to the lack of relevant data.

4.1 Persona

This persona is a cat named Ginger, who represents the majority of overweight indoor cats. His owner is too busy to spend much time with him and unconsciously neglects the needs of domesticated cats, which can lead to health problems. Therefore, I introduced Ginger's timeline (see figure 5) to depict a cat's daily behaviour. Through this daily timeline, Ginger's indoor life will be shown.

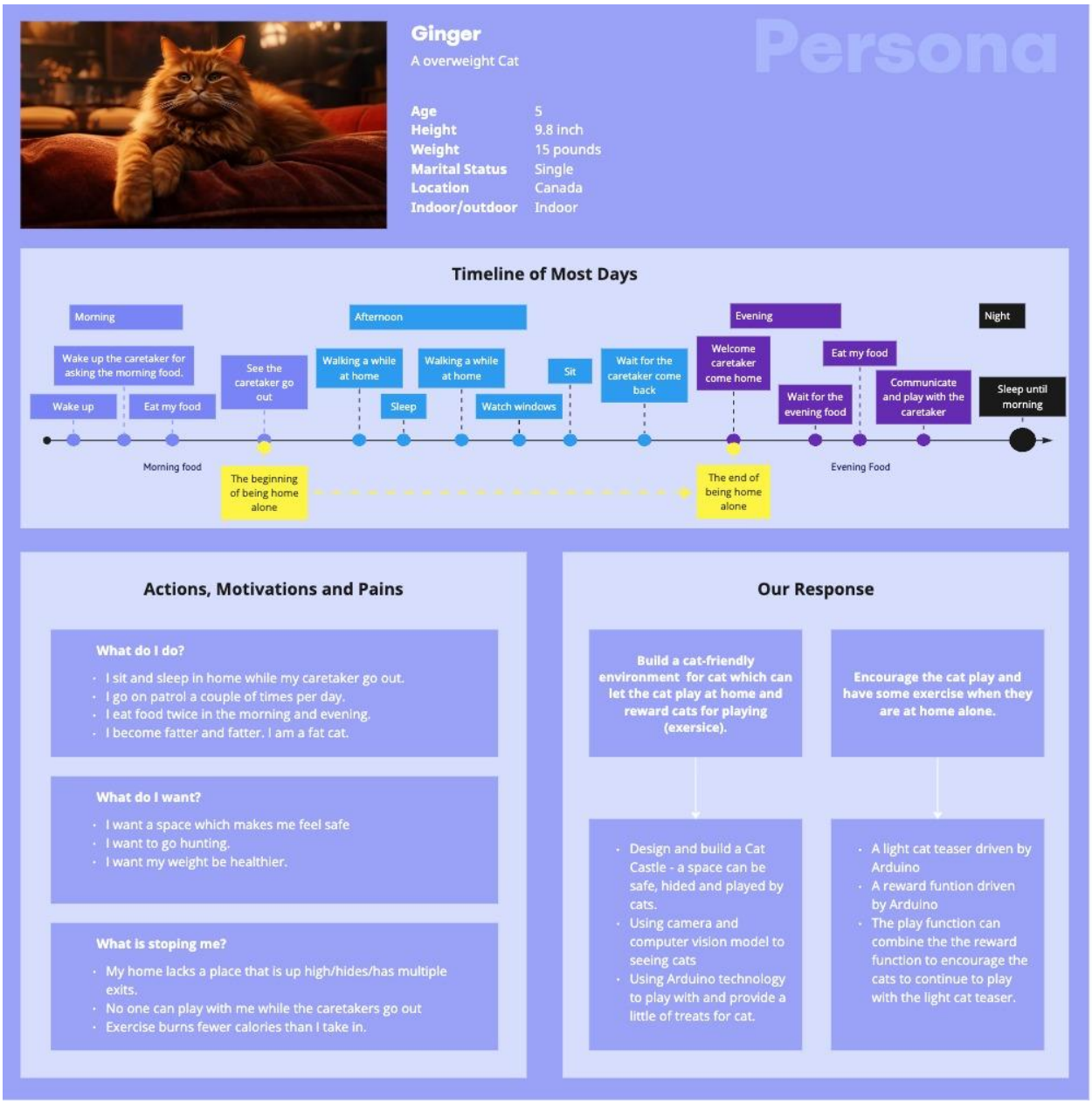


Figure 5 The persona of the overweight cat - Ginger

Ginger's daily indoor life was referred to some books and papers on feline biology (Hattori, 2020; Lewis & Scheibmayr, 2021; Scherk, 2016; Shyan-Norwalt, 2005), for example, some cats wake up in the morning to wake up their owners; indoor cats need to patrol the space in the house because it is their territory; some indoor cats like to look out of the window, etc. The timeline shows that there is currently no information about Ginger's indoor life.

The cat is named Ginger. Aged 5, it is in its prime, and its weight has already exceeded the normal range. This could pose some health risks. Ginger is an indoor cat, and its owner needs to be away for work for extended periods. This results in Ginger spending a lot of time alone at home. After the owner leaves, it would patrol the house a couple of times, then sleep, or just sit and wait for the owner to return. This lifestyle has made it increasingly obese, affecting its health. Therefore, Ginger hopes to get more exercise to improve its health and enrich its time.

As shown by Ginger's timeline (see figure), when its owner leaves the house, Ginger rarely has the opportunity to hunt alone. It is only when the owner comes home at night that Ginger has the opportunity to play and interact with the cat.

Moreover, I have written about Ginger's needs based on the three needs of indoor cats mentioned in the previous literature review(Foreman-Worsley et al., 2021; Hattori, 2020; Lewis & Scheibmayr, 2021; Scherk, 2016):

- I want a space which makes me feel safe.
- I want to go hunting.
- I want my weight to be healthier.

Therefore, the prototypes will be designed according to these three needs of cats (see figure 6).

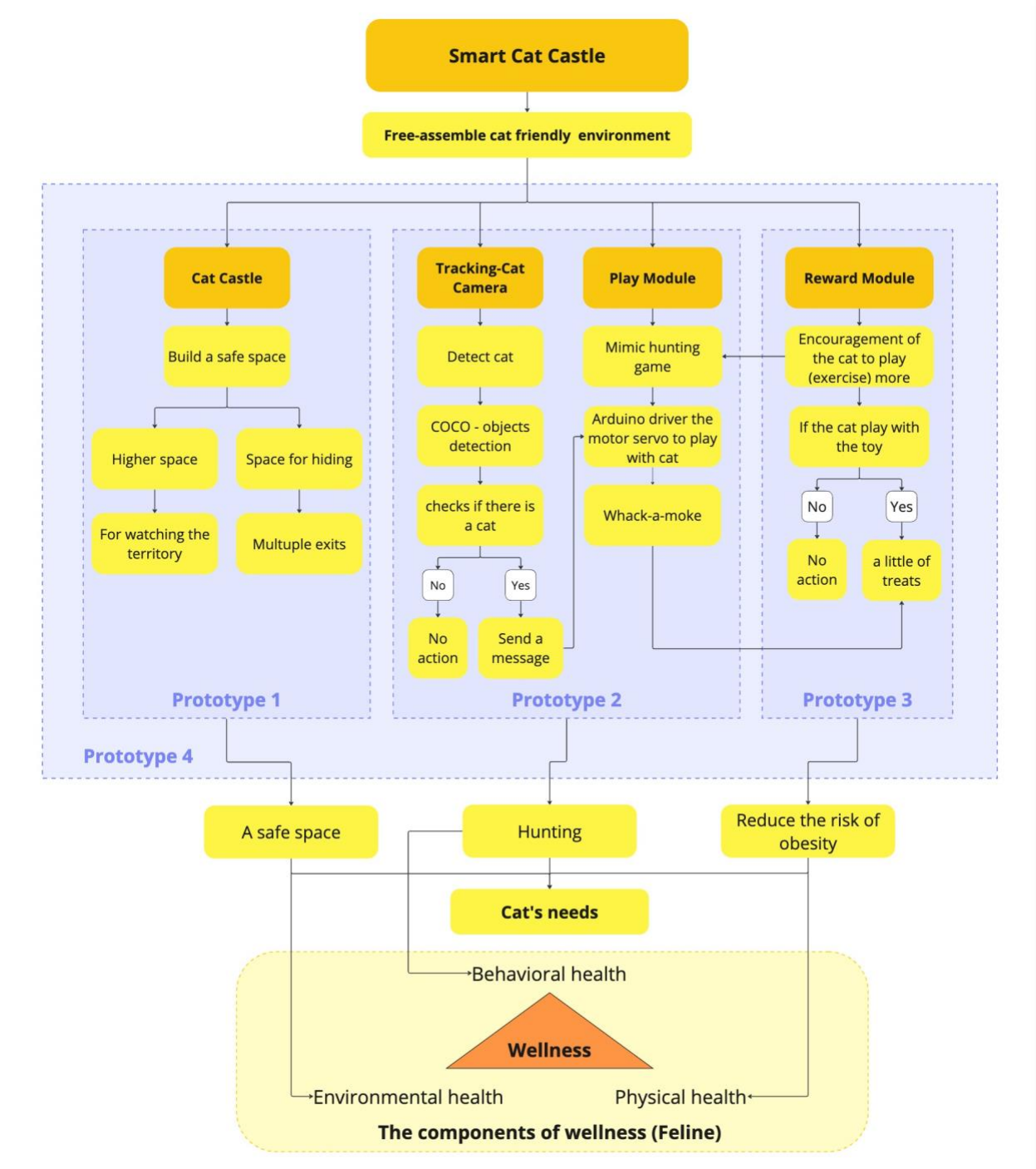


Figure 6. How the prototypes respond to the cat's needs and wellness

However, there are some limitations of the Persona. Although the information used to build the persona came from some preliminary research, the Persona can only be used as an early tool to help with design research, and it cannot fully represent the user's thoughts (Chen & Liu, 2015). In my case, the Persona is a tool to help bring the brainstorm to the project's design. Because animals

can't quite tell humans what they need, human knowledge of animals has been based on studies of their behaviour, physical health data, etc. It does not enough fully understand to real cats' needs.

4.2 Prototype 1: Cat castle

4.2.1 Cat's Tunnel

1) Ideation

Cats like to stay in small spaces, which gives them a sense of security. They also like to explore passages, which is an instinct from their wild ancestors (Hattori, 2020). The design of the cat's tunnel is based on their habits. It is like a maze game for cats. A cat can explore the tunnel and find the exit. Moreover, this prototype design also requires an Arduino and some electronics to be installed in subsequent prototypes.

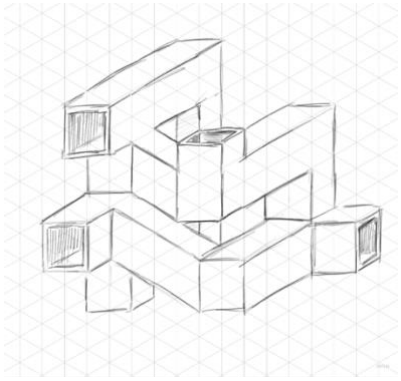


Figure 7. The sketch of the cat's tunnel

2) Motivation

I designed this cat tunnel based on cats' habits to create a safe and secure space that cats love. The tunnel has multiple entrances and exits, which will give the cat a sense of security. Cats also like to sit in a high position, which lets them observe the surroundings clearly (Scherk, 2016). Moreover, the narrow space will make them feel like they are staying in a

nest (Hattori, 2020). Hence, the design should fulfill the requirements: 1) providing the hiding space, 2) having a high position, 3) having multiple exits.

3) Design & Method

I use Autodesk Fusion 360 and follow my design sketch to create a 3D model with a 1 to 10 scale. As you can see, the whole model needs 45 pieces with different shapes. I designed the finger joints to combine them to form a Cat Tunnel.

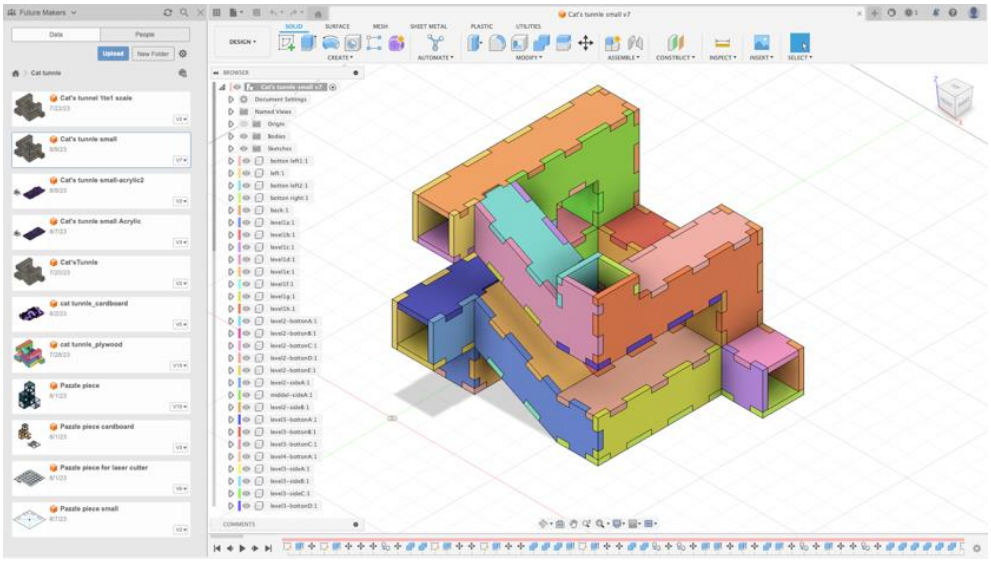


Figure 8. The 3D model of cat's tunnel in Autodesk Fusion 360

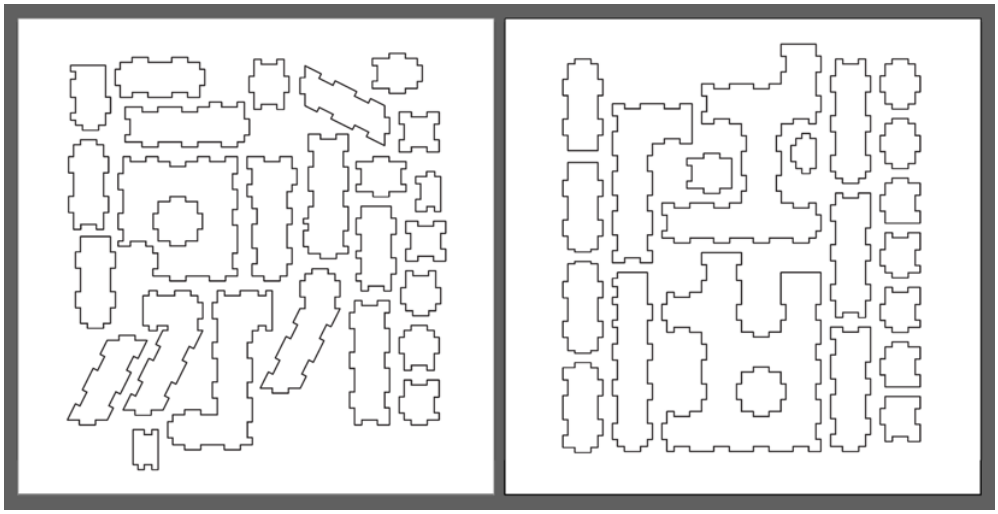


Figure 9. The drawing for laser cutting (1:10 scale)

This small-scale design was made using two types of materials: plywood and acrylic. The manufacturing process utilized laser cutting technology.

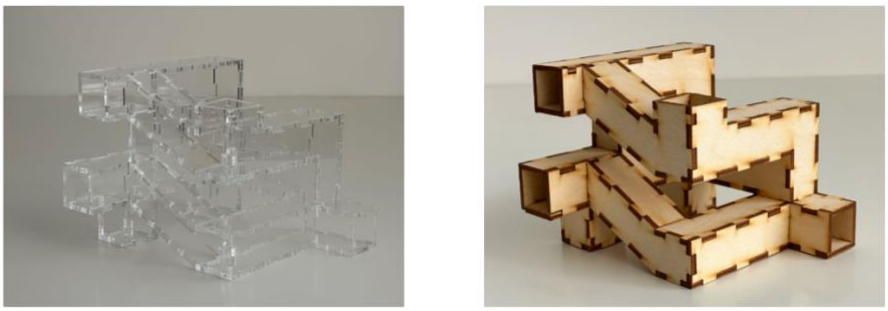


Figure 10. Cat's tunnels are made with plywood and acrylic (1:10 scale)

Due to the characteristics of laser cutting, I offset 0.1mm from the original dimensions when creating the flat file. This is enough for plywood but not enough for acrylic components, which are too loose to fit together without clear glue. If designing something finger-joint with acrylic in the future, I need to offset the dimensions from 0.15mm to 0.2mm to ensure a stable fit without any glue.

Unfortunately, when I built the 1 to 1 scale 3D model and made a 1 to 10 scale model to simulate, I found this cat tunnel hard to build up.

It is also hard to set up the electronic component on it. So, I made another version of Cat Tunnel.

4.2.2 Free-assemble Cat Castle

1) Ideation

This design inspiration comes from the fact that cats love playing with cardboard boxes, and they enjoy staying inside them (Hattori, 2020). Besides, I also need to create a design that is easy to assemble and disassemble. So, I thought of a puzzle game where only a few basic shapes can be assembled into various shapes. I designed the basic shapes of the assembly pieces. They are very easy to assemble, and people can also design different paths for their

cats. At the same time, this structure also makes it easier for me to install electronic components for the following prototypes.

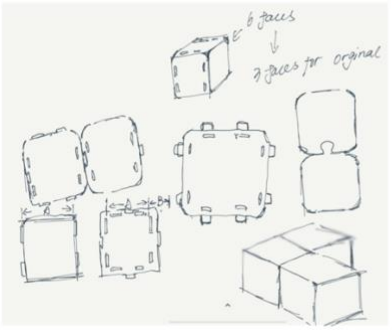
2) Motivation

This version of the design made me realize that ease of use is also important for the project. The cat castle also needs to be built up and dismantled a couple of times to set up the electronic element and installation, so it is necessary to design a new version with an easy-to-use feature. It also needs to be considered to meet the design requirements: 1) providing space that can be hidden, 2) having multiple exits, and 3) having elevated platforms available. The reason is that these requirements are based on the cat's need for a safe space.

3) Design & Method

I drew a sketch of the different pieces that can be assembled into a module. Each module should be able to be composed into a cat's building with multiple paths, entrances, and exits. So some of the pieces have a hole cut in them, which allows the cat to pass through the hole from one module to another. This hole can also be used for the entrance and exit of the cat's castle.

I also designed a window for the cat to look out through.



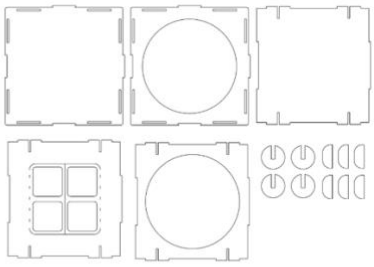


Figure 11. The sketch of the assembly pieces

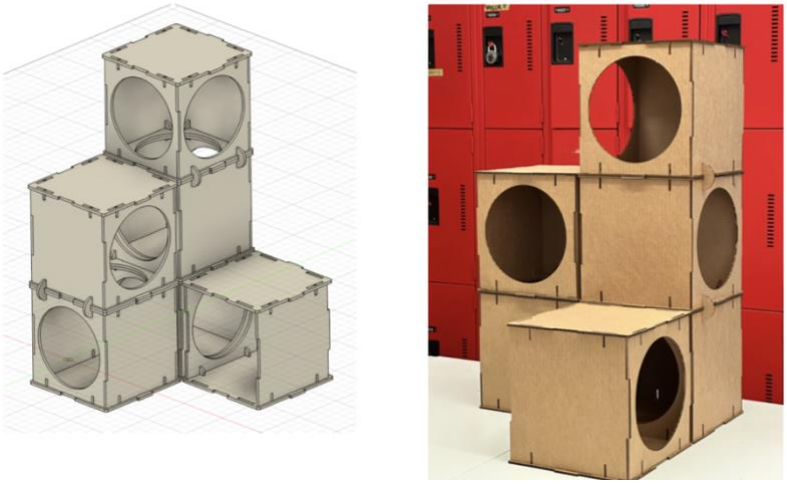


Figure 12. The 3D model of the cat castle in Autodesk Fusion 360 (left)

Figure 13. The assembled cat castle without window (right)

Figure 14. The assembled cat castle with windows

This design is very easy to assemble, and users can also design different paths for their cats. At the same time, this structure also makes it easier for me to install electronic components in the future.

4) Reflection

In this design project, I completed the cat castle through continuous improvement of the design and production.

The initial maze-like design with electronic components proved challenging to construct, leading to the final design inspired by cats' love for cardboard boxes. I found the design process valuable for my thesis research, and the importance of learning from mistakes and understanding the intended user of a product. The value of creativity and innovation in the making process and the importance of improving designs.
This design is designed to create a safe space for cats. It can be built by assembling pieces to create high platforms and spaces that can be hidden, as well as multiple safe exits. Overall this prototype responds to the cat's need for a safe space.

4.3 Prototype 2: Play module

4.3.1 Tracking-cat Camera

1) Ideation

The tracking Cat camera is one of the features of the Cat castle. The camera would be set up opposite the cat castle. It can watch and detect whether a cat is there or not. The prototype uses the COCO object detection model with p5.js to recognize the cat.
COCO is an object detection model that can detect cats (Lin et al., 2015). p5.js is “p5.js is a new interpretation of Processing written in JavaScript that makes it easy to interact with HTML5 objects, including text, input, video, webcam, and sound (McCarthy et al., 2016).”
If the camera detects a cat, it will send a message to the Arduino and let the Arduino drive the cat teaser to play with the cat.

2) Motivation

When the cat is at home, but the human is not, we need a tool to monitor the cat's location. It is an efficient way to use COCO to let the cat castle see if the cat is nearby or not. When the COCO detects a cat, then the system knows there is a cat and lets the Arduino drive the servo motor to react to the cat.

3) Design & Method

I use the P5.js to create a program. I use the P5.js to enable the camera. Then, it loads the coco-ssd model in the program.

Then, I used code to set up the canvas to show the items detected by coco-ssd. I also set it up so that when coco-ssd detects a cat, the canvas will tell us whether it detected a cat or not (see Appendix I). I've also set it up to let the program draw where the cat is. That way we know where the cat is.

The code is references to a tutorial from Daniel Shiffman (2020).

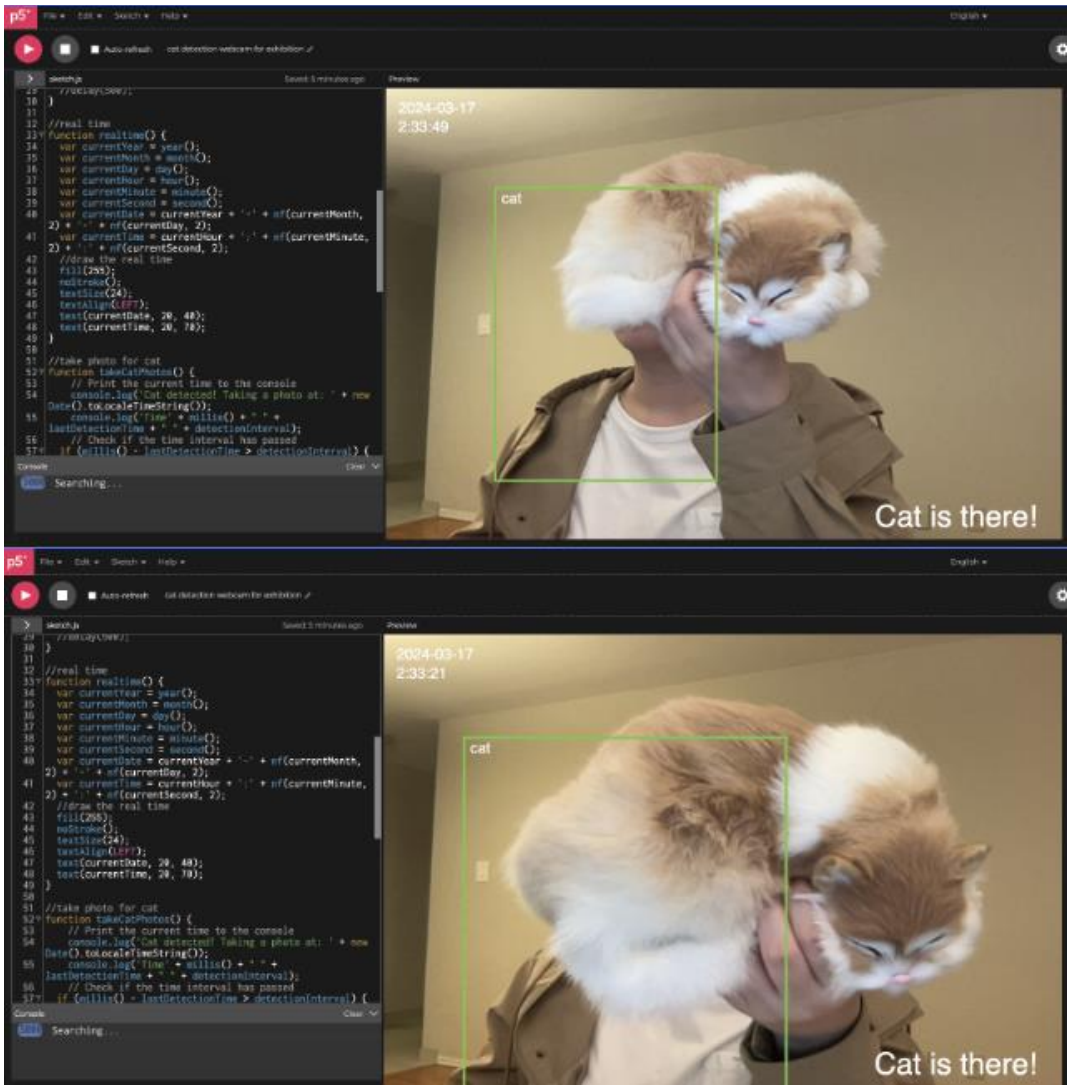


Figure 15. The screenshots of testing the tracking cat camera it shows the program can detect the mimic cat

4) Reflection

I have faced a few challenges while working on my project. As a part of the process, I programmed the Tracking-cat Camera to take a picture whenever it detects a cat. The purpose of taking the photo is to use it as data to train the model to recognize the cat's behaviour. However, the app takes photos all the time because the coco-ssd model is always in the state of detecting. Moreover, when I set a time interval to pause the program, it crashes. I haven't found a solution to this problem yet, so I had to disable the photo-taking function for now.

4.3.2 Smart cat Teaser

5) Introduction

The smart cat teaser is a part of Cat Castle. It would be set up in one model and could be built with another model together to assemble a smart and cat-friendly environment. The smart cat teaser uses light fibre and LED. The Arduino would drive the servo to spin the light fibre to attract the cat’s attention. Then, cats can play with the light fibre like they play with cat teasers.
The smart cat teaser will be set up in a model of the cat castle and become a play function model.

6) Motivation

When the cat is at home alone, they need some exercise to maintain a healthy activity. According to that cats have an occupational need to hunt (Scherk, 2016), I design the smart cat teaser to play with cat, it can attract the cat to catch.

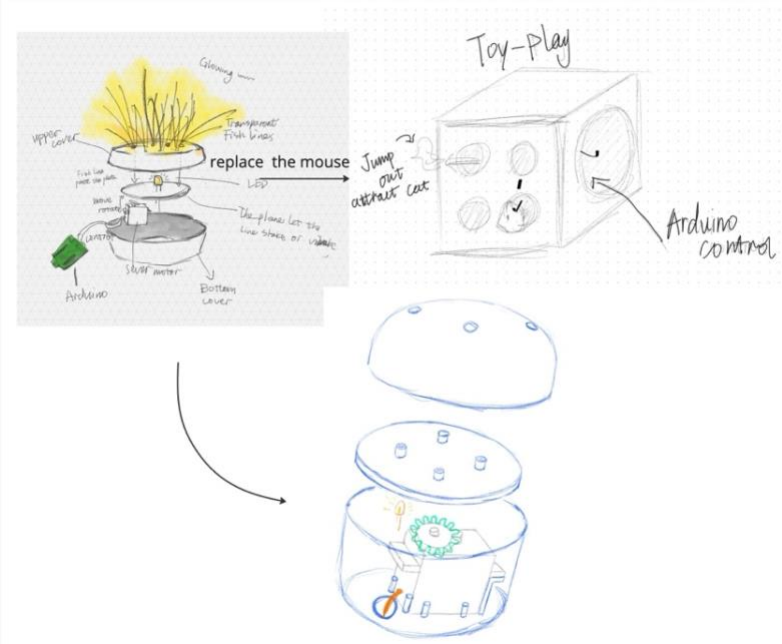


Figure 16. The sketch of the inner sketch of the spinning cat teaser

7) Design & Method

1. Cats are curious creatures with an instinct for hunting and catching potential prey. Compared to humans, they possess heightened senses of sight and hearing. Therefore, I designed a lighting teaser using light fibre and Arduino to attract their attention.
2. The design utilizes 3D printing to create the inner structure of the smart cat teaser. Firstly, I used AUTO Fusion 360 to design the inner component, which allows for easy integration of servo motors, LEDs, and light fibres. I used a 3D printer to bring the design to life.

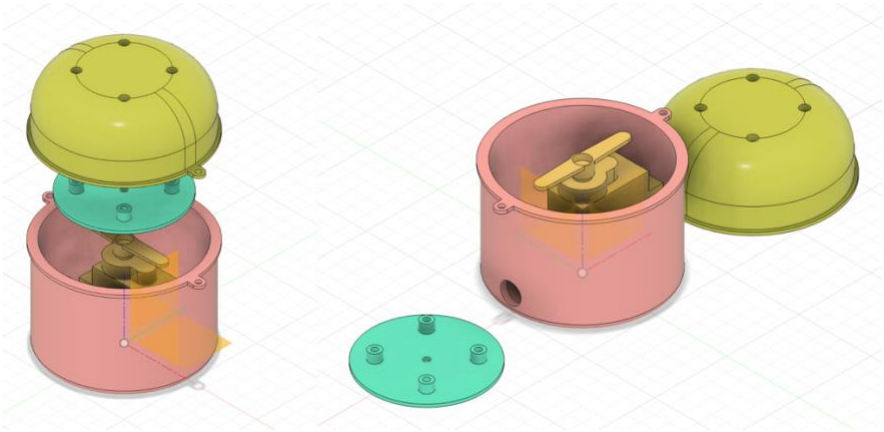


Figure 17. The 3D model of the spinning cat teaser in Autodesk Fusion 360

3. I installed the Arduino and light fibres, connecting them together. Additionally, I attached the Arduino to the model. The smart cat teaser model was modified with minor changes to ensure the stability of the inner components installed in the model (see Appendix II).

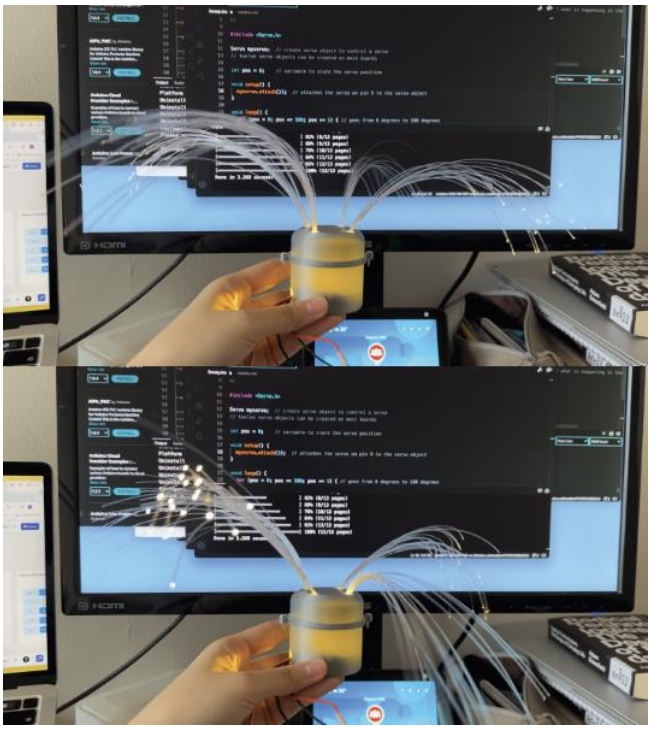


Figure 18. The spinning light fibre is driven by Arduino

4. After printing the internal components of the cat castle using a 3D printer, I modified the assembled pieces. There are assembled pieces inside the model that can support the stably set up smart cat teasers.

8) Reflection

This game mode is like whack-a-mole. Prototype 2 responds to the need of indoor cats for a simulated hunting game, which can fill in the gap where carers are unable to spend long periods of time with their cats' playing games. Future game modes can be added to make it more appealing for cats. This will keep your cat interested in the game and won't get bored easily.

4.4 Prototype 3: Reward function module

1) Ideation

The care feature is a functional model that can feed a little cat a treat to encourage it to get some exercise daily. It also allows the cats to be fed remotely while the caretaker isn't at home.

2) Motivation

The motivation of cat hunting is finding food. So I try to combine hunting and treating together, which means the smart environment attends to building the whole process of hunting. If the cat can play with the cat teaser, which means the cat has some exercise, then the system will give some treats to the cat as an award for cats.

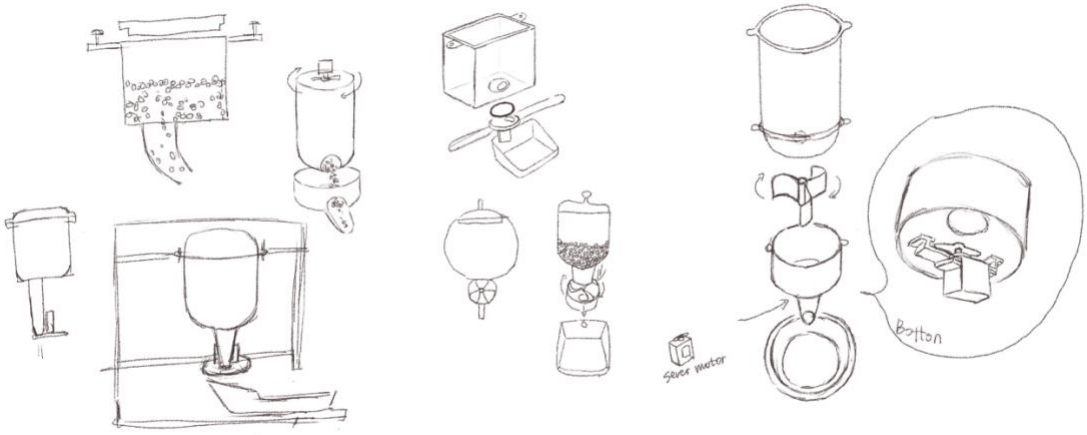


Figure 19. The sketch of the structure of the auto feeder

3) Design & Method

I design an inner structure to support this function. As you can see, the structure is divided into three parts: the upper part, the middle part and the lower part.

The upper part is designed for storing the treat. the caretaker can fill the cat's treats to the upper part. The bottom of the upper part has a little hole that can allow the treats to go to the middle part.

The lower part is designed for cats to eat the treats. It is a bowl for cats. The treat falls down from the middle part and drops into the bowl.

The design method is like the cat teaser. I use the Fusion 360 to build the 3D file of each component for 3D printing. After 3D printing, I can install the Arduino and fill in some treats to test it.

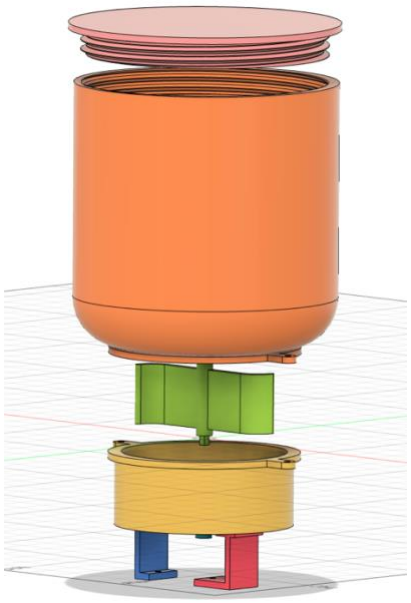


Figure 20. The 3D model of the structure of the auto feeder in Autodesk Fusion 360

After printing the feeder components of the cat castle using a 3D printer, I modified the assembled pieces so that the feeder could be set up in the model. I added a piece inside the model to support the feeder and designed joints to fit together seamlessly.

The design is based on another automatic pet feeder, but it is meant to dispense small cat treats. Since the cat can only eat a limited amount from it, the treat feeder can be seen as a tool to encourage the cat to engage in some physical activity instead of just lounging around or sleeping all day.

4) Reflection

During the use of the 3D printer to print out components, some smaller parts were not printed accurately. As a result, they couldn't fit together properly during installation. These

smaller parts had to be processed manually before they could be installed. Therefore, it is advisable to avoid designing parts that are too detailed when creating a model. If the project requires the printing of finer parts, the designer can design multiple sizes to be printed. This way, it is possible to test out which size can be printed better.

4.5 Prototype 4: Early work Smart Cat Castle

1) Ideation

The final prototype is a combination of the cat castle, a tracking-cat camera, two play functional modules, and a reward function module. The prototype 4 is for the Digital Futures Graduation Exhibition.

2) Motivation

The final prototype aimed to create a smart cat-friendly environment. There are the goals for the prototype 4:

a. Build a cat castle where a cat can feel safe.
b. Provide a mimic hunting game with two play function modules when the tracking-cat camera detects there is a cat.
c. The reward function module can give a small amount of treats to the cat if the system detects that the cat is playing with the play function module.

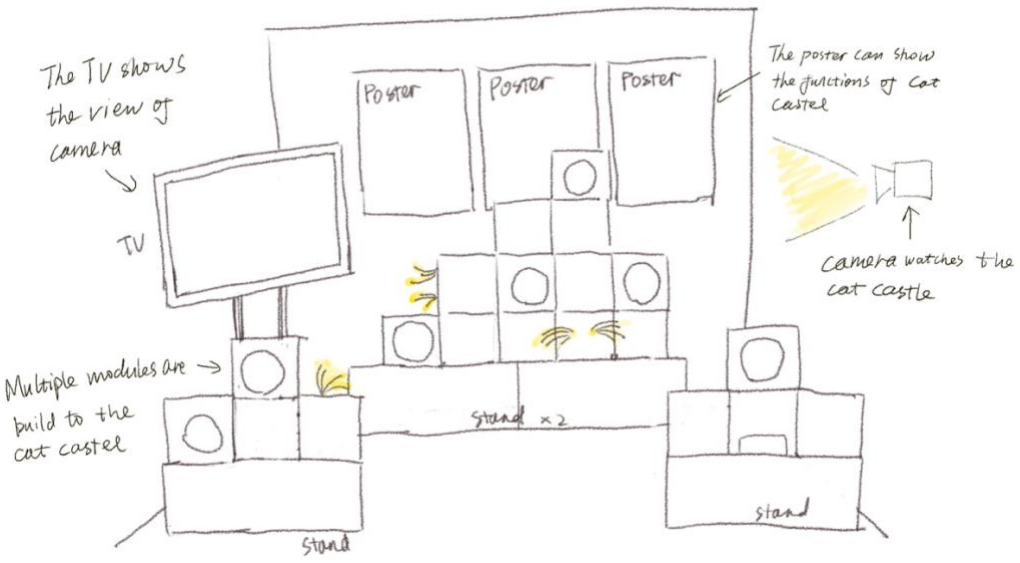


Figure 21. The sketch of the plan to set up the cat castle in the Digital Futures graduation exhibition

3) Design & Method

Assemble the Functional Mod: Install the play and care models. Connect the servo motor to the Arduino with jumpers.

Assemble the complete cat's castle: Install the cat's castle with the assembly pieces. The play functional modules and reward functional modules are built in the cat castle as well. It also needs to assemble multiple exits for cats.

Setting up the Tracking-cat Camera: The tracking-cat Camera should be on the opposite side of the cat castle. Make sure the camera's view range and P5.js's canvas can see all the cat castles.

Setting up WebSocket and Arduino: The Arduino and WebSocket should be set up earlier and checked the network connection.

Prototype 4 will finally be presented at the Digital Futures graduation exhibition. Therefore, there will be more play modules in the exhibition, and a TV set will be set up to show how the camera detects the cats in real-time. I will also install three posters to introduce the

functions of the Cat Castle, which will help the audience understand more quickly that the Cat Castle is designed to solve the needs of cats.

Figure 22 Display of the Cat Castle at the Digital Futures Graduation Exhibition

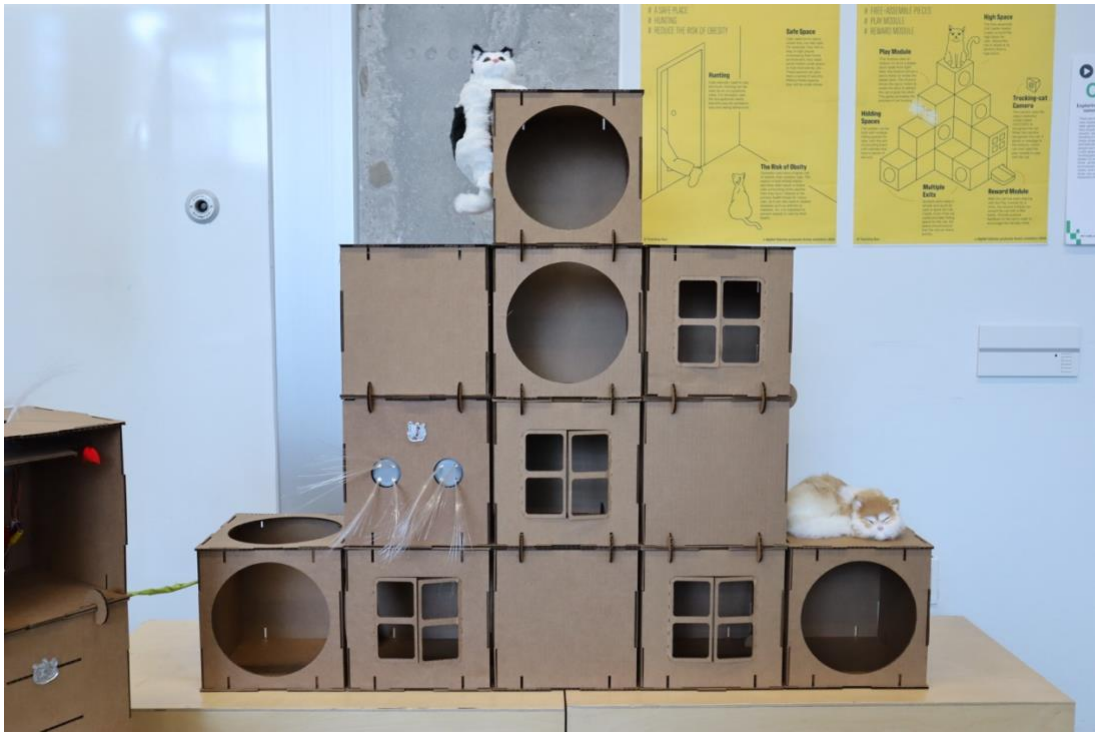


Figure 23 Display of the Cat Castle at the Digital Futures Graduation Exhibition

4) Reflection

When prototype 4 was assembled, it was found that some of the joints were not designed to be very stable. So, at a later stage, the tolerance of the small accessories was increased to make the mods more stable when building. This design should add some weight at the bottom to make the whole cat castle more stable.

5 DISCUSSION & EVALUATION

5.1 Overview

In this study, I did not have access to live cats to test Cat Castle, and this thesis focuses on exploring the prototype design. So, I evaluated the thesis project using two methods: informed argument and Scenarios in the section. Informed argument uses the previous 4 research projects to compare the prototype. Scenarios will speculate on how Ginger the cat's life will be different once she owns the Cat Castle through the Persona prepared earlier.

In the end, I will discuss the impact of the human perspective and animal perspective in ACI research and how to make the balance between the two perspectives in ACI research.

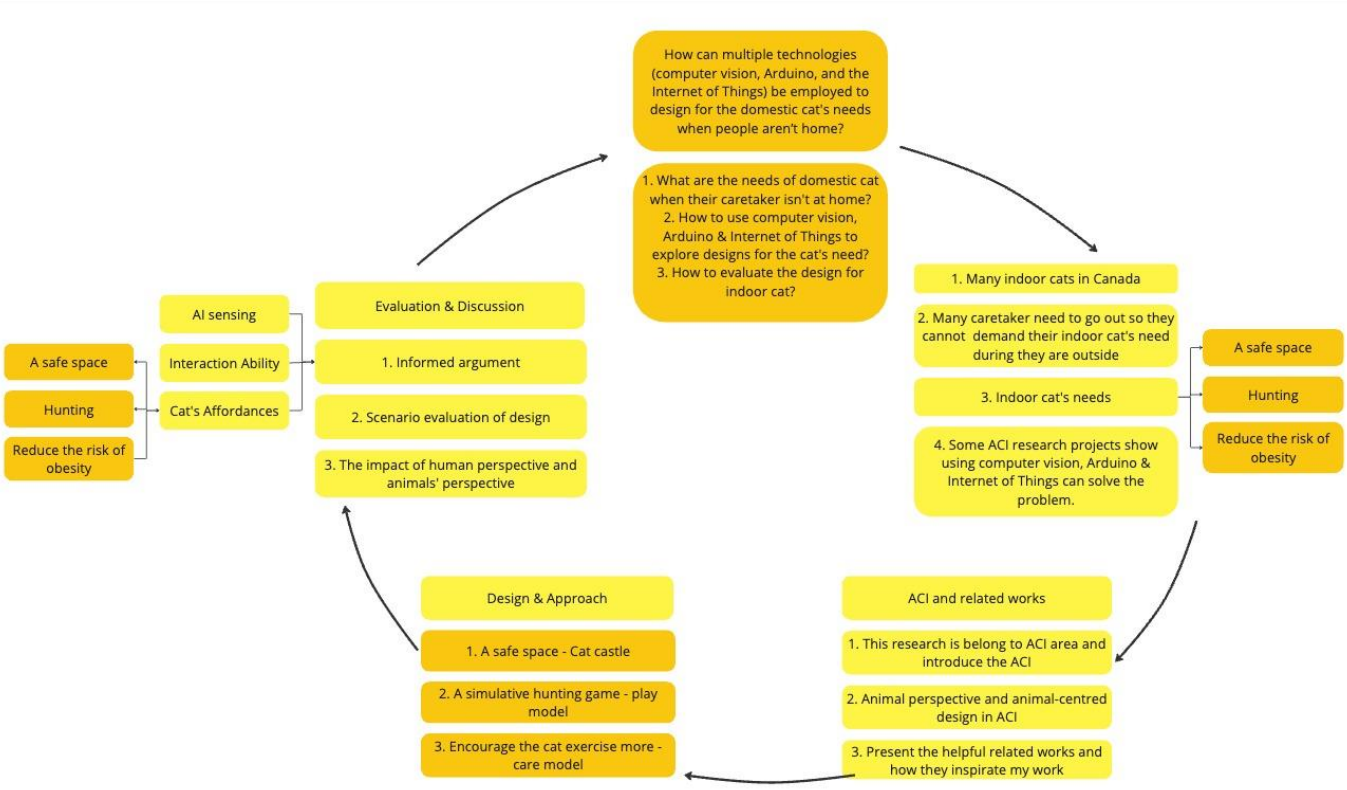


Figure 24. The structure of the thesis

5.2 Evaluation - Informed argument

This section will compare my research project with related research works. I chose these four related works to compare with the prototype of the thesis because all four works are designed for cats and use computer vision, Arduino, and Internet of Things technologies. They also inspired my prototyping to varying degrees. Therefore, they have a high correlation with my prototype design.

This section will be scored from three perspectives: AI Sensing, Interaction Ability and Cat's Affordances. As you can see, the score scale is 0 ~ 2. 0 is a low score, 1 is a medium score, 2 is a high score.

- AI Sensing: This refers to the project's AI sensing ability, including, but not limited to, seeing, hearing, touching, etc. The stronger the project's AI sensing ability, the higher the score.
- Interaction Ability: This perspective means the interaction level of the project. Whether the audience can communicate with the project installation in some form, and whether the project installation can give feedback to the audience. The higher the interaction level of the project, the higher the score.
- Cat's Affordances: This refers to whether the work can meet the cat's needs, such as space, resources, health, etc. The more the works meets the cat's needs, the higher the score. The better the work meets the cat's needs, the higher the score.

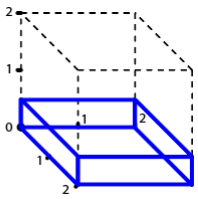
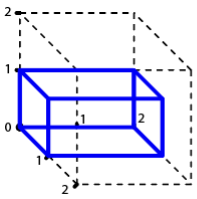
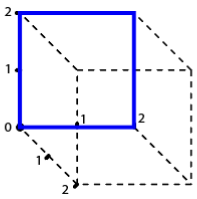
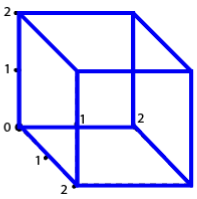
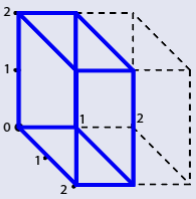
	Existing Research 1 Internat of Robotic Cat Toys Han and Witzman 2023	Existing Research 2 A Smart Toy Ecosystem for Pet Hof and Hoang 2020	Existing Research 3 Monitoring the behaviours of cat Chen, Saravanarajan and Hung 2021	Existing Research 4 TAS for Cats Schneiders et al. 2023	Prototype Early Stage Smart Cat Castle
AI Sensing	0.5	1	2	2	2
Interaction Ability	2	2	2	2	1
Cat's Affordances	2	1	0	2	2
					

Table 2. The table of comparing four related works and prototypes in terms of AI sensing, interaction ability and cat's affordances.

This table shows the different designs but not how usefulness for cats.

Through this research, design and comparative evaluation, there are the following reflections:

a. The five research projects all utilize sensors for detecting pets. The first research project (Han and Witaman, 2023) used a motion sensor to detect the cat. This may cause some mistakes that the system detects a human as a pet. The other four research projects used a computer vision model, which greatly improved their accuracy in the detection of pets.

b. The interactive capability of a project depends on the device's ability to interact with the target users. In these works, their target customers are different. Research 1, Research 4 (Schneiders et al., 2023) and my prototype have the same target audience, which means they are designed for pets, and the project is intended to interact with pets. On the other hand, research 2 (Hof and Hoang, 2020) and research 3 (Chan, Saravanarajan and Hung, 2021) are designed for the caretaker, they aim to help the caretaker to solve some problems but not for pets. At present, their level of interaction with the target users is quite good.

c. The differences in Cat's Affordances scores are due to the different target users. As mentioned in the second point, Research 2 and Research 3 were not designed for cats, so they scored low on cat applicability. The design of Research 2 is to allow caregivers to have a remote control pet smart system, which is difficult for cats to use. The design of Research 3 is to enable caretakers to recognize the cat's bad behavior in time, but the cat cannot use this system. On the other hand, the other three research projects are designed with the cat's needs in focus, and cats can effectively interact with these smart devices.

d. Compared to Research 4 (Schneiders et al., 2023), the thesis prototype can be improved to be smarter. Research 4 has a high score in 3 dimensions. It used robot arms and a computer vision model and explored the possibility of filling the cats' demands as much as possible. My prototype references method research 4 but designed a different environment for cats. Since the prototype is in the early smart stage, it can be developed by a smarter AI model, for example recognize more behavior of cat. It will be described in the conclusion part.

5.3 Evaluation - Scenarios, Storytelling to show usefulness –

Persona is helping to understand some of the possible usefulness for cats. In Chapter 4, I did some user research using the persona method. This helped me understand the cat's needs better and made the goals and process of prototyping clearer. Next, I will use the scenario method to evaluate the prototype based on persona.

In the previous user study, I created a daily timeline of Ginger's activities based on the cat's habits. In this part, I created a new timeline to show how Ginger's life would change if it had a cat castle.

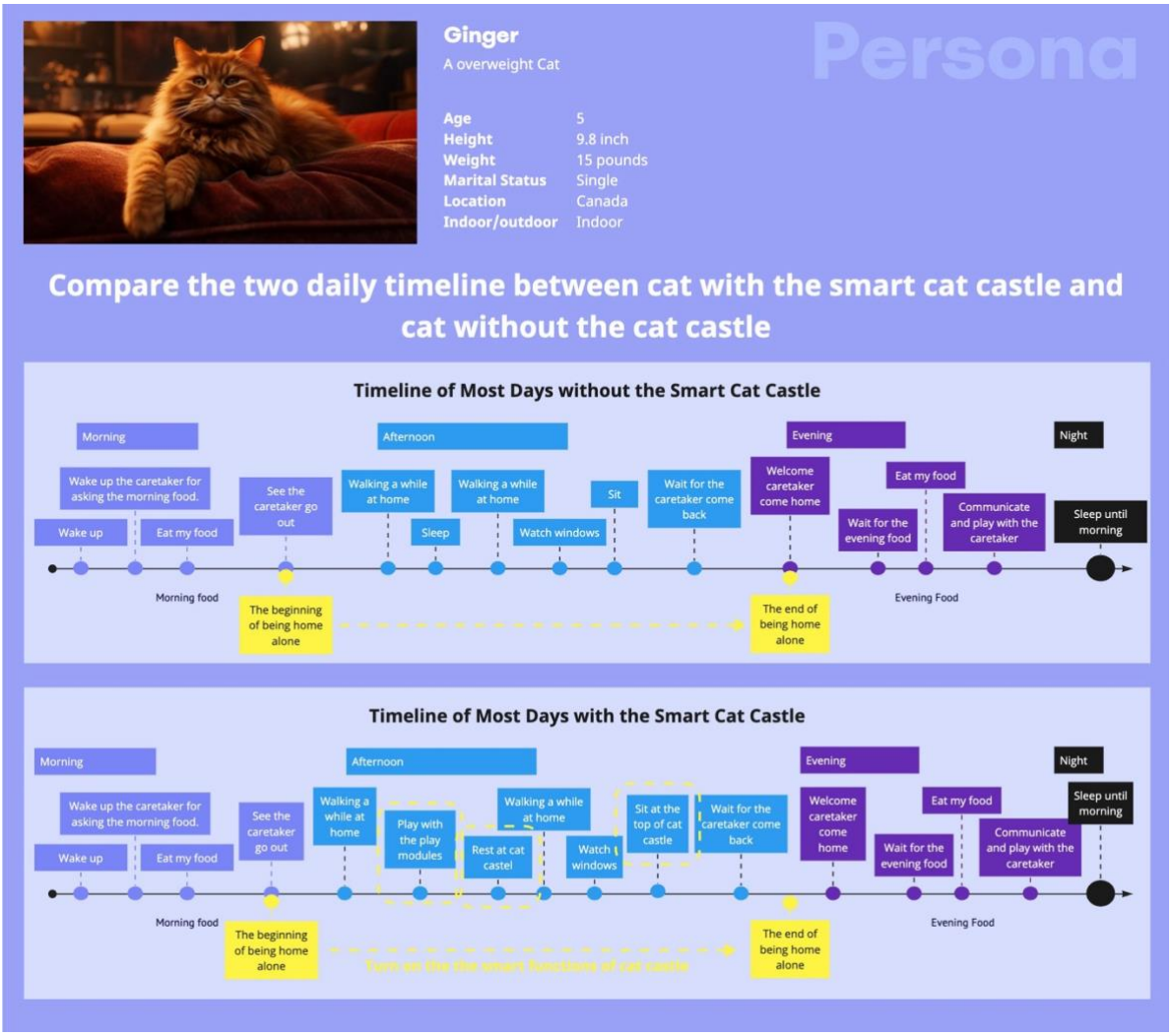


Figure 25. Compare the two daily timelines between the cat with the smart cat castle and cat without the cat castle

Through the exploration of relevant literature, we understand that even though domesticated cats often live longer than stray ones, they also face certain health risks, such as obesity. This is because

the amount of activity indoor cats get is often less than the calories they consume. Therefore, I used the Persona method to construct a target customer that fits this situation.

1. In my research, the Smart Cat Castle provides a new activity environment for cats. Cats love boxes and exploring different passages. The Cat Castle is designed for this. Its easy-to-build modular structure and the passages that can be freely combined into different shapes make it easy for the caregiver to build a cat-friendly device for Ginger.
2. The Smart Cat Castle also comes with an automatic light teaser, powered by Arduino. This will attract and guide the cat to chase it. This process simulates a hunting game for cats. It can run alone at home. This will increase Ginger's activity level and enrich its alone time.
3. The reward function is like an auto feeder but is currently set to dispense small amounts of food. This is also driven by Arduino. When the programme detects the cat has been playing with the light teaser for a while, the feeder will drop a little food as a reward for the cat. It is hoped that this can serve as positive feedback for Ginger, encouraging it to play more simulated hunting games.
4. At present, this design only has a reward food function to motivate the cat to continue playing with the toy. This may lead to the cat getting tired of the toy and not wanting to continue playing. Therefore, the design lacks more plans to continuously stimulate the cat's fun in playing with the cat castle. In the next version, this project can consider adding other plans to motivate the cat to stay in the game for a longer time, in order to increase the cat's amount of exercise.

5.4 The Impact of Human Perspective on ACI

This research project utilizes user-centered design, with domestic cats as the main users. Designing an interactive device from the perspective of a cat will differ from human-centered design.

However, this project has incorporated some human perspectives into the design. In the initial prototype design (Prototype 1), the iterated version 2 actually considered whether the installation process could be simplified to make it easier for the cat caretakers (humans) to build the cat castle.

On the other hand, from the product design perspective, we also need to consider how to make humans willing to buy this cat castle to enrich their cats' daily lives. Adding more decorations to the cat castle can make it more appealing to humans. For example, some caretakers might consider whether certain pet supplies can match their home decor style. They may expect a variety of colours to choose from for pet supplies, but these decorations may be meaningless to cats.

These two aspects made me realize there are differences in rights between humans and animals. Cats or other animals cannot express their needs and opinions through language, and the needs of humans and animals might be completely different, which could make the research a struggle between animals and humans in ACI research.

Nevertheless, properly incorporating the human perspective into the design of ACI research projects can improve the cooperative relationship between humans and animals and human efficiency. This is because interactive systems designed for animals often require humans for assembly and operation.

Noz and An (2011) designed a "mouse-catching" iPad game for cats and their caregivers. They took into consideration that cats are colour-blind and can only see blue and green, not red. Therefore, they designed the game primarily using blue and green colours. The caregiver can participate in the game by controlling the mouse. This cross-species game design strengthens the bond between the caretaker and the cat. The project provides an example to enhance the relationship between caretakers and cats through playing the Touch game together, but such design needs to follow the principles of ACI research and cannot affect the interests of the animals themselves.

5.5 Overall lessons learn

In this study, I used two methods, Informed argument and scenarios, for evaluation. The informed argument compared four existing related research projects and the thesis project. It was found that the results derived from animal-centric design and human-centric design are not the same, even if the same computer vision technology is used.

In the Scenarios method, we used the classic method of user research, Persona. By simulating a target user - a very fat cat's daily life, pain points and needs, our research project provides solutions

to these problems. At present, the research project can meet the needs of the cats. However, the project does not offer more options to lengthen the cat's playtime with the toy. Therefore, consideration should be given to whether the toy can be made more interesting for the cat, providing more plan options.

After evaluating the prototype, this design can meet three needs of cats: 1) The Cat Castle establishes a safe space for cats, which can satisfy the needs of cats to rest, hide, and observe their territories. 2) The Play Module provides a simulation of a hunting game, which allows cats to exercise hunting even when their owners are not at home. 3) The Reward Module provides positive feedback to the cat. The Reward Module drops a little cat treats when the cat completes the hunting game.

In addition, this project also considered the ease of human beings in building the cat castle. The design of each part is for the caretakers to build this smart environment for the cat more easily. Designers can make some convenient designs for humans without affecting the interests of animals when designing for animals. This can promote the cooperative relationship between humans and animals and also improve efficiency.

6 CONCLUSION

6.1 Overview of the thesis goals

This thesis discusses the possible needs of a cat to be accompanied and cared for when it is home alone, and how a cat-friendly environment can be designed and put together and utilize AI technology and Arduino technology to meet these needs.

6.2 Outcome and Contribution

I have been exploring, studying, and designing for the previous period, and we have got some outcomes so far:

- Designed and built a cat-centred environment. I designed a cat-friendly cat castle. The design takes into consideration the cat's natural tendency to burrow into boxes and explore tunnels, as well as the simplicity of building the castle, which means that it is quick and easy for cat carers to assemble the toy for their cats.
- This project uses computer vision models of AI to recognize cats. It completed a preliminary stage of the Tracking-cat camera, where I applied a COCO object detection model into the P5.js editor, allowing the Tracking-cat camera application to recognize cats and kittens and the Cat Castle's play module to have the potential to respond accordingly to the presence or absence of cats in the nearby.
- A design of a play functional module, which is a spinning cat teaser. I used some structural design with an Arduino driver to build a Play model, which functions by spinning light fibres. By rotating these light fibres, we can attract cats to play the game of catching.
- A design of a reward functional module. Its aim is to reward cats if they play the hunting game with the play module. It is like a simple automatic feeder which is also powered by an Arduino.
- Combine the cat castle, tracking-cat camera, play module and reward module to build a cat-friendly system with a rudimentary level of AI that meets the needs of cats for companionship and care.

6.3 Limitation

This paper project has achieved some results to a certain extent, but there are some limitations that need to be acknowledged.

- **Lack of AI training data**

  Current smart systems are merely early-stage AI. The artificial intelligence model lacks training data. The system can identify whether there is a cat here, but it cannot analyze the behaviour of the cat.
- **No live cat testing**

The Cat Castle has not yet been tested with real, living cats. Since cats have different personalities, the design may be biased toward the cat's preferences.

- **Limited Game Modes**

  The play model only has one game model. This may make the cat easily bored with the play model, making it difficult to keep the cat interested in it for a long time.

- **Non-customizable Care Plan**

  This design does not yet allow for making exercise and diet plans for cats according to each cat's health condition.

6.4 Direction for future research

In the future, the Cat Castle can be developed into a smarter application. It could include an advanced cat tracking camera to analyze cat behaviors, more strategic game plans to engage cats in play, and additional caring functions for cats.

- **Share with DIY/Maker community**

  Because Smart Cat Castles allows caretakers and interested researchers to customize their own cat castles, the drawings and code for this project can be shared with the DIY/Maker communities, such as Github.com. This will allow people who are interested in the project to participate in it together. They may come from different backgrounds, so they can contribute different ideas to the project. They can also contribute together to the well-being of indoor cats.

- **Smarter cat tracking camera**

  The thesis project can train the AI model using more data so that the smart system can analyze cat behaviours. This will allow the system to have more interaction modes with different cat behaviours. The Tracking-cat Camera can check what a cat is doing right now and give some responses to cats, like turning on the spinning light teaser to wake up the cat if it has been sleeping too long.

- **More strategy game plans**

  Currently, the play model only has one game mode for cats. After prolonged play, cats may become bored. To maintain their interest, it would be beneficial to introduce a variety of game plans. For example, we could add several play modes to the castle system.

Additionally, we could position multiple play models around and use Arduino to drive them with various strategic game plans. This approach will help to keep the cat's attention.

- **Customized care plan**

  Can the Cat Castle system create a customized exercise plan for a heavier cat like Ginger? In future developments, the system could offer various exercise plans based on a cat's health status. For overweight cats, the system could encourage longer play (exercise) sessions and reduced food intake. Conversely, for cats of normal weight, the system could balance the play (exercise) time with a moderate cat food portion.

6.5 Final statement

This study uses computer vision technology, Arduino technology, and Internet of Thing technology to provide a safe space for cats, simulate hunting games, and plan to encourage cats to exercise more. This project is a cat-centered design of a cat castle. It is an initial smart solution for the health of cats. Currently, the level of smart of the cat castle is in the early stages. Its level of smart is not high enough, which can be optimized in the future. However, this project is an exploration of the companion animal smart environment design centered on cats. I hope that this research project can provide some experience for future related research.

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APPENDICES

Appendix A: The code of the tracking-cat camera

```
let video;
let videoWidth = 1920;
let videoHeight = 1440;
let detector;
let detections = [];

//web serial
let port;
let connectBtn;



function preload() {
 detector = ml5.objectDetector('cocossd');
}

function gotDetections(error, results) {
 if (error) {
  console.error(error);
 }
 detections = results;
 detector.detect(video, gotDetections);
}

//real time
function realtime() {
```

```
  var currentYear = year();
  var currentMonth = month();
  var currentDay = day();
  var currentHour = hour();
  var currentMinute = minute();
  var currentSecond = second();
  var currentDate = currentYear + '-' + nf(currentMonth, 2) + '-' + nf(currentDay, 2);
  var currentTime = currentHour + ':' + nf(currentMinute, 2) + ':' + nf(currentSecond, 2);
  //draw the real time
  fill(255);
  noStroke();
  textSize(24);
  textAlign(LEFT);
  text(currentDate, 20, 40);
  text(currentTime, 20, 70);
}


function connectBtnClick() {
  if (!port.opened()) {
    port.open('Arduino', 9600);
  } else {
    port.close();
  }
}

function sendBtnClick() {
  port.write("Hello from p5.js\n");
}

function sendBtnClick() {
  port.write("Hello from p5.js\n");
```

```
}

function setup() {
  createCanvas(1920, 1080);
  video = createCapture(VIDEO);
  video.size(videoWidth, videoHeight);
  video.hide();
  detector.detect(video, gotDetections);

  // web serial
  port = createSerial();
  // in setup, we can open ports we have used previously
  // without user interaction
  let usedPorts = usedSerialPorts();
  if (usedPorts.length > 0) {
    port.open(usedPorts[0], 9600);
  }

  // any other ports can be opened via a dialog after
  // user interaction (see connectBtnClick below)
  // the button for connecting to Arduino
  connectBtn = createButton('Connect to Arduino');
  connectBtn.position(200, 20);
  connectBtn.mousePressed(connectBtnClick);
  //the button for click to sent message to Arduino
  // let sendBtn = createButton('Send hello');
  // sendBtn.position(440, 20);
  // sendBtn.mousePressed(sendBtnClick);
}

function draw() {
  image(video, 0, 0, videoWidth, videoHeight);
```

```
realtime();
// this makes received text scroll up
copy(0, 0, width, height, 0, -1, width, height);

// reads in complete lines and prints them at the
// bottom of the canvas
let str = port.readUntil("\n");
if (str.length > 0) {
  text(str, 10, height-20);
}

// changes button label based on connection status
if (!port.opened()) {
  connectBtn.html('Connect to Arduino');
} else {
  connectBtn.html('Disconnect');
}

//COCOSSD detection
for (let i = 0; i < detections.length; i++) {
  let object = detections[i];
  console.log(object.label);
  // if COCO detect a cat
  if (object.label == 'cat') {
    //to draw the position of cat
    stroke(255, 255, 0);
    strokeWeight(4);
    noFill();
    rect(object.x, object.y, object.width, object.height);
    noStroke();
    fill(255);
    textSize(32);
```

```
    text(object.label, object.x + 10, object.y + 24);
    //to text the cat is there.
    textAlign(RIGHT);
    textSize(88);
    text("Cat is there!", width-40, height-20);
    port.write("cat");
    console.log("Sending data: " + object.label);
  }
  // if COCO detect a person
  if (object.label == 'person') {
    //to draw the position of cat
    stroke(255, 255, 0);
    strokeWeight(4);
    noFill();
    rect(object.x, object.y, object.width, object.height);
    noStroke();
    fill(255);
    textSize(44);
    text("Big cat!", object.x + 10, object.y + 38);
    //to text the cat is there.
    textAlign(RIGHT);
    textSize(88);
    text("Seeing the big cat! ", width-40, height-100);
    port.write("big cat");
    console.log("Sending data: " + object.label );
  } else {
    console.log("Searching...");
    textAlign(LEFT);
    textSize(24);
    text("Searching...", 20, height-20);
  }
}
```

```
}
```

Appendix B: The code of the spinning cat teaser

```
#include <Servo.h>
//Declare and initialize LED pin variables
int LED_1 = 8;
int LED_2 = 9;
int LED_3 = 10;
int LED_4 = 11;

Servo myservo;//setting up the servos and their names
Servo myservo1;
Servo myservo2;
Servo myservo3;

//This variable will hold a random number generated by the random
long randomNumber;

//Set up - this is where you get the thing "set-up". It will only run once.
void setup() {
  myservo.attach(3); //attaches the servo named "myservo" to pin 3
  myservo.write(0); //sets the starting angel to 0
  myservo1.attach(5);
  myservo1.write(0);
  myservo2.attach(6);
  myservo2.write(0);
  myservo3.attach(7);
  myservo3.write(0);

  //setup serial communications through the USB
  Serial.begin(9600);
  //This will allow your readers and users of your code to understand what is happening in the
serial monitor.
  Serial.println("Starting new Random Number Sequence");

  //Set the LED pins as outputs
  pinMode(LED_1, OUTPUT);
  pinMode(LED_2, OUTPUT);
  pinMode(LED_3, OUTPUT);
  pinMode(LED_4, OUTPUT);
  //Make it more random.
  //This will read the background noise of the A0 pin allowing a true randomizer
  //rander than the consisent generation of the rand() command.
  randomSeed(analogRead(A0));
}

void loop() {
```

```
  randomNumber = random(8, 12);

  //display the random number on the serial monitor
  Serial.print("The Random Number is = ");
  delay(500);
  Serial.println(randomNumber);

  digitalWrite(randomNumber, HIGH);

  delay(1500);

  digitalWrite(randomNumber, LOW);

  if (randomNumber == 8) { //if the randomly show the number 8
    myservo.write(90); // rotate the myservo 90 degrees
    delay(500); //wait 500 milliseconds
    myservo.write(0); //return the servo to the starting point
  } else if (randomNumber == 9) {
    myservo1.write(90);
    delay(500);
    myservo1.write(0);
  } else if (randomNumber == 10) {
    myservo2.write(90);
    delay(500);
    myservo2.write(0);
  } else if (randomNumber == 11) {
    myservo3.write(90);
    delay(500);
    myservo3.write(0);
  }
}
```