RoboCatsitter: A Proposed Design for Pet-Robot Interaction

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Abstract

This paper explores the relatively new area of animal-computer interaction through the lens of constructing the RoboCatsitter: a robot that performs feline care without human supervision. A research review is conducted in the realms of current advancements in animal-robot interaction and techniques in artificial mechanical intelligence that could help advance the field. Techniques explored include the conduction of artificial sensory tasks, indoor locomotion, and the design of a machine's mechanical "presence" (its appearance and volume) to maximize pet comfort. These techniques will be discussed and investigated for their fit for use in our proposed design. Based on this discussion, a blueprint of the possible design of the RoboCatsitter is constructed.

1 Introduction

1.1 Animal-Computer interaction

Animal-robot interaction (ARI) and animal-robot interactive technologies are a still relatively novel concept in the world of robotics. By definition, ARI is the interaction between robots and animals without the need for human intervention [7]. The field is essentially a multidisciplinary view of biology and technology, with the field including bio-inspired engineering design and biological investigations. A majority of work in ARI can be classified under two categories: bio-hybrid organisms and animal-robot mixed societies. In animal–robot mixed societies, robots are placed in animal societies, and designed to imitate the surrounding species' appearance and behaviors [15].

A niche subset of the field of animal-robot interaction focuses on ARI in the context of pet care. The type of ARI pet care we want to focus on typically falls under the animal-robot mixed societies umbrella. Although the robot in this case usually is not created to replicate an actor of the same species as the pet subject, the robot is created to replicate the role of the human caretaker - the pet in this scenario is acclimated to this form of society/relationship.

ARI for pet care can be related to HRI (human-robot interaction) in a variety of ways - mainly because of the human element involved in both fields. In HRI, the robot usually carries out a task for a human at the human's request. In ARI, the robot carries out a task (that would have been performed by the human owner) for the animal/pet, but the pet is unable to directly ask for the service to be provided by the bot (without labor-some training of the pet). ARI pet care arose from an increasingly busy world with owners having traveling duties, long work hours, childcare commitments, school commitments, etc., resulting in pet owners being unable to watch and care for their pets as often as they want to. Most domesticated animals are bred to need attention from humans and rely on them for care, so this can be detrimental to their health.

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Figure 1: The LitterRobot 3, a self-cleaning cat litter robot. It needs no human supervision to operate - it just needs to be emptied on a bi-weekly basis. [2]

Some popular examples of animal-robot interactive technology include the commercial Litter Robot, which is a machine that cleans cat excretion using a sensor and a timer. The robot is composed of two cylinders with one that rotates, cleaning the machine by rotating out the dirty litter once a set amount of time passes after the cat leaves the robot. The sensor senses the presence of the cat within the robot, and thus senses when the cat is no longer in the machine. The robot is fairly popular amongst cat owners, but many have reported issues with the sound and appearance scaring their cats [2].

1.2 Motivation

Current modes of pet monitoring still need a decent amount of room for improvement. The two most common methods for pet monitoring are utilizing baby monitors and hand-controlled mobile pet monitors. Both of these methods are subpar for many reasons. Baby monitors are perfect for babies, which are relatively slow-moving and non-agile, but not for smaller pets that can move quickly and slip and hide into nooks and crannies not visible from a high shelf. They limit what you can see in your household by level and their field of view. They can also be knocked over by excited pets, leaving you with no way to view them. Hand-controlled mobile pet monitors can help solve this issue, for they are on the ground and due to their mobility they can look around the apartment. However, they still require the pet owner to be fully hands-on with the locomotive control of the machine. This causes issues in the case where the pet owner is busy with other duties but still wants updates on their pets or in the case where the pet owner is not fully able-bodied (f.e. fine motor control difficulties) , making it difficult to use the small controls to navigate the bot.

This is where a self-piloting bot that can respond to cat (or other pet) actions and seek and find the animal on its own would be very valuable for the task of pet care. The machine would be able to have a mind of its own to monitor the pet, just as a human would naturally when observing pets in the home.

2 Related Work

Others have attempted to tackle intelligent robotic pet care in research. Three main works provided us with a lot of guidance into how we needed to tackle our design. The first paper dives into the topic of how human-likeness fares in dog-robot interactions. Both of the latter articles present a design for a pet care robot, with the first one being immobile and designed for cats, and the second one being mobile and designed for dogs. Although ours is initially geared towards cats, we feel as though our work and design will be expandable to multiple species of roaming household pets.

2.1 Morovitz et al.: Animal–robot interaction: The role of human likeness on the success of dog–robot interactions

Although our paper is geared towards the care of cats, we foresee our design being transferable into the care of other household animals as well. Both dogs and cats experience a phenomenon called social referencing - where they look to their human owners for environmental reassurance [12]. This shows that both dogs and cats look to external actors for care. Based on this, we believe that we can make a reasonable assumption that we can anticipate the behavior of cats in response to certain appearances and behaviors of robots taking the place of their human caretaker. This paper describes the behaviours of dogs in response to different machines with increasing amounts of similarities to humans. The different robots that were presented had varying levels of human-like appearance and were either vocal or non-vocal, with the vocal robots saying short phrases like "Good dog" or "Come here, buddy".

Morovitz et al. found that dogs actually responded more fearfully in response to human-like robots. According to the authors, based on their results, "it can be concluded that dogs more frequently displayed negative behaviors towards human-like robots and more frequently displayed neutral and positive behaviors towards nonhuman-like robots". For our design, we are not planning to add a vocalization component (for now), but we believe that this paper helps us orient our focus more toward functionality than the appearance of the robot. Animals do not care for human-like robots, especially ones that move, but they should be relatively unbothered by a robot that is not "pretending" to be a human [12].

2.2 Kim, J, et al.: Animal-robot interaction for pet caring.

In [7], the authors describe the design of a pet care robot for the care and entertainment of cats. The robot consisted of a vision system that contained a UNIQ vision UC -685CL digital camera that had a PANTAX 6.5mm C$-$mount lens. The main body of the robot was the X$-$bot of Yujin Robotics Co., which is a robot platform for education. It had bumper sensors and infrared sensors to detect the barrier around it. One of the main things we learned from this paper is their description of the importance of a robot's presence in maximizing the comfort of the cat. This relates to [12], which also described a few similar characteristics of robots that were ideal for their interaction with domesticated animals. The paper highlights the fact of whether or not a robot for pet care needs to resemble humans in order to be effective, while this one defines the criteria for a robot made to be used with animals.

According to [7] the development any robot that is designed to interact with animals needs to have the following characteristics:

- The developer should have a full knowledge of the animal's behaviors and emotions to make the robot understand the animals needs well for natural interaction with the animal.
- The robot should know the state of the animal and provide the service to the animal by itself, as most of animals do not know how to request a service from a robot.
- The animal may have a fear of the robot because the robot is a noisy creature that has never been seen before. The shape and texture of the robot need to be familiar with animals to reduce the fear.
- The smell of the robot should be also considered because most animals are sensitive to the smell.
- The noise of the robot may astonish animals and it would be a great difficulty for the robot to be familiar with animals.
- As the sudden movement of the robot may also scare pets, robot behaviors should be well designed considering animal ethology.

2.3 Deng et al.: Design of Home Service Robot for pet caring

As we mentioned before in the description of the Morowitz paper, our design is geared toward cats, but we can still learn valuable lessons from ARI research geared toward the care of dogs. In [3], they propose the design of a pet care robot for dogs that is composed of a feeding system, serve system, grasp system, driving system, and real-time monitoring system. The driving system was composed of a chassis, Mecanum wheel, servo motor, three-stage decelerator, battery system, and battery pack. Each wheel had its own independent servo motor, and each motor was connected to a three-stage reducer. The monitoring system included eternal equipment, sensor equipment, and a control circuit. The sensing component contained an infrared sensor, which detected obstacles and pet locations. The control circuit system used a STM32 CPU as the core processor, which provided a high-performance hardware platform for robot control.

Drawing from this paper, we hope to also construct a mobile monitoring system. However, there are aspects of this paper that do not pertain to our purposes, and there are issues that we find with this paper. First of all, with an infrared sensor, it will be hard for the monitoring system to tell the difference between each cat in a multi-cat household by body heat alone. For our machine, we need a "standard" camera that is able to see the differences in each cat. Secondly, at the end of the paper, they mention that this system could also be composed using a microprocessor as the main control device, allowing for more control over the device's hardware. As suggested by the authors, we will implement a similar robot while using a microprocessor as the main control unit. Using a microprocessor will also allow us to implement a computer vision algorithm for the purposes of cat/object recognition.

3 Requirements

In this section of the paper, we will go over the behavioral requirements for an intelligent robot that can perform unsupervised pet care.

3.1 Monitoring Capabilities

Our machine's primary purpose is monitoring pets, and therefore, needs the components to allow the monitoring to happen. In the lens of a human monitoring an animal's state and status of well-being includes noting how the animal sounds (whether it's a bark, meow, etc), how the animal looks (dirty, injured, etc.), and how the animal feels (identifying lumps, ticks, etc.). We want to focus on the first two - the last item is more so important if the robot was in control of long-term unsupervised pet care. The robot we design will ideally be used on a pet left alone for 24-48 hours, which is the amount of time a pet is usually left alone with a baby monitor.

So, in our case, the robot needs the ability to hear, and, more importantly, needs to be able to distinguish a cat's meow from other sounds that may appear in an indoor setting. The robot also needs the ability to see, and, again, more importantly, needs to be able to distinguish a pet from other objects in the environment, or, in some households, one pet from another (as two different animals usually have two different sets of needs.

3.2 Locomotion

As mentioned in the motivation, we need to construct a machine that is mobile, so that it is able to move and find the pet, unlike a stationary baby monitor. Therefore, the machine needs to have a means of locomotion, and the means of locomotion have to be able to adapt to different forms of indoor flooring, including carpet, hardwood, etc.

However, more importantly, this locomotion has to be done by the robot alone. It has to be able to pilot itself in an indoor space without the instruction or control of a human. It has to adjust to different indoor terrains on its own and be able to navigate a constantly changing environment. Those who have cared for young pets know that they can cause objects to be constantly knocked over, spilled, broken, etc. If the robot is to be used in a setting without human intervention, it has to be able to identify these hazards and obstacles and be able to avoid them or move through them effectively.

4 Artificial Sensory Memory

Based on the requirements for this machine, it makes sense to frame these tasks in the context of sensory memory. All the tasks the robot will need to accomplish can be directly tied to sensory-memory-related tasks that can be carried out by a human caretaker. However, it is known to be difficult to come up to create a multi-modal sensory input system – doing so in traditional von Neumann architecture requires costing considerable computational resources [17].

Haptic The tasks of the feeling of touch in relation to obstacles, walls/barriers, and the cats themselves all relate to the phenomenon of haptic memory. In humans, haptic memory can translate into us learning how to hold a fragile object after previous failed attempts and knowing the amount of force needed to strum a guitar. The quick sensation and response to haptic sensing is haptic sensory memory, like quickly turning when sensing an obstacle near, which is what behavior we want our robot to mimic. An example of a previous attempt to tackle artificial haptic memory includes combining a resistive pressure sensor and a resistive memory switching device, [16].

Echoic The task of hearing the cats relates to the phenomenon of echoic sensation. The quick sensation and response to echoic sensing is echoic sensory memory, like quickly looking in the direction of a cat's meow when hearing it. In the context of humans, they store the information of a cat meow where the short-term memory assigns it context (for example: "My cat meowed - he needs something"). Common approaches for replicating echoic sensing in robotics include the use of triboelectric auditory sensors [6].

Iconic The robot's tasks of visually recognizing the cats and seeing obstacles in its path both relate to the phenomenon of visual sensation. In humans, iconic memory occurs in the act of processing visual information, including an object's surface in terms of the size, shape, color, and brightness of objects, distance, and location sensation, smoothness, roughness, etc. In robots, this can appear as the quick recognition of something furry, which it should focus on, versus something more rigid, rough, plastic, etc., and sensing it as an obstacle to avoid. Previous approaches to implementing artificial iconic memory include a system composed of an image sensor, a memristor, and a resistive memory-switching device [16]. Other approaches also propose the use of a photo sensor [17].

A lot of the approaches for each of these forms of sensory memory are perfectly capable of accomplishing the tasks we want to accomplish with this machine. However, as mentioned before, the inclusion of all of these different forms of technology and systems in one machine can quickly increase the amount of computing power needed just for the robot to function. This is why we need to use a material and/or component that can cover multiple of the required senses, thus, reducing the amount of computing power necessary. This is where ferroelectret nanogenerators can come in.

4.1 Ferroelectret Nanogenerators

Ferroelectret nanogenerators (FENGs) are flexible energy harvesting devices that have bidirectional capabilities in the electrical and mechanical energy domains [4]. FENGs are composed of foam-like configurations with multiple microscopic voids and behave in a similar fashion as piezoelectric polymers or piezocomposites, but with a different micro structural formation [10]. FENGs have a thin, flexible film-like structure while still having the capability of high piezoelectricity. FENGs are non-polar, require a high-voltage polarization process (some are self-polarized), and have a low Young's modulus. FENGs demonstrate positive and negative piezoelectric effects with comparable efficiency. [9].

According to [17], when external mechanical perturbations are applied to the FENGs surface from a perpendicular direction, the perturbations induce a change of internal dipole moments in the FENG, altering the electrical field distribution within the film and producing free charges at the surface electrodes, which eventually give rise to the output electrical signals needed to register a stimulus.

Unfortunately, ferroelectret nanogenerator's possible visual capabilities are moreso proposed in a stationary context: the images they detect are still, and the FENGs are still. We want the FENGs to be on a mobile machine detecting mobile objects and entities. They will not be useful for the navigation of our system or the identification of cats and obstacles. However, we were able to find literature on an iconic-memory-based system, which we detail below.

Artificial Haptic Memory Ferroelectret nanogenerators are able to generate pulsed electrical signals in response to tactile stimuli, which closely mimics the biological sensing mechanism of tactile sensation - a key component in haptic memory. In order to reproduce tactile sensation, one side of the FENG needs to be supported by a rigid substrate and operate in a "blocked" mode.

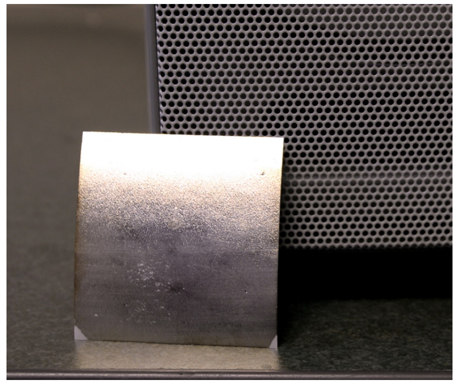

Figure 2: An example of the sheet-like properties of ferroelectret nanogenerators. The sheets have been used to turn flags and clothing into loudspeakers. I believe that it could be used as the outer layer of the machine.

By "blocked", we mean that the FENG needs one side blocked and held in place to provide the "backbone" of the sensor, allowing tactile pressure to be registered in a way that is not overwhelming to the sensor or could damage it [17]. In our design of the robot, the rigid substrate can be an underlying exoskeleton produced through 3D, or, even more simply, a hand-constructed outer-shell protecting the microprocessor.

Artificial Echoic Memory Ferroelectret nanogenerators are able to generate pulsed electrical signals in response to auditory stimuli, which closely resembles the biological sensing mechanism of auditory sensation - a key component of echoic memory. Because the stimulus pressure from an audio signal is much lower than that from a tactile stimulus, the FENG tasked with tracking audio stimuli needs to have a larger effective area than that of the FENG tasked with tracking tactile stimuli. This would allow for transduction and the amplification of auditory stimuli. In addition to this, there should be no surface or material that the FENG is attached to in a parallel manner. Unlike in the tactile scenario, the FENGs need to be freestanding to allow for them to vibrate back and forth and thus send electrical signals [17].

4.1.1 Artificial Iconic Memory

As mentioned before, papers that propose multi-modal systems usually propose the use of photosensors, which is insufficient for the tasks we want our robot to carry out. Fortunately, there is work out there that provides the type of iconic memory-based functions we want to implement.

Omnidirectional Iconic-Memory Based Navigation In [18], Yagi et. al proposes an iconic memory-based approach for autonomous navigation. They point out that previous approaches "basically select the image that corresponds to an input image from discretely memorized images. This means the precision of position and orientation of the mobile robot depends on the spatial sampling density of a moving space". This makes it difficult for the robot to estimate its position and orientation if it were to deviate widely from a memorized path.

The method they propose utilizes an omnidirectional image sensor to continuously capture an image sequence of a horizontal part of an omnidirectional image, which they call the omnidirectional route panorama (ORP), as it moves along its route. Using an ACM (active contour model), they search for an image pattern on the ORP that corresponds to an input. They actually use two ACMs in their study: corresponding control points placed on each of the ACMs are coupled and have a gravitational force. The ACMs then converge from both sides of a desired position (from the ORP) where the image pattern is the same as the input.

When testing their approach, they found that the robot was able to adapt to a changing environment where obstacles were removed, added, or moved around, which is ideal for our implementation. According to the authors, "the omnidirectional route panorama can save iconic-memory, and thus the method does not have great memory requirement even if the robot memorizes a long distance and

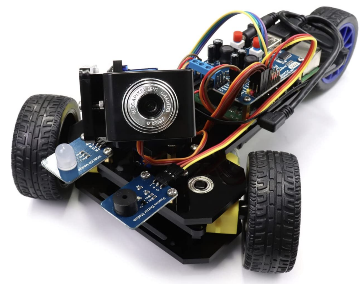

Figure 3: The FREENOVE Three-Wheeled Smart Car Kit for Raspberry Pi 4 B 3 B+ B A+, which was purchased on Amazon to provide locomotion to the RoboCatsitter. The kit came with a starter code that helps control the camera and the wheels of the vehicle.

over a long time period". The processing time was 200ms/frame, which is ideal for indoor navigation, but may be too slow for outdoor navigation [18].

Computer Vision There is previous work that has pointed out the successful identification of cats' faces using state-of-the-art computer vision algorithms. In [8], they propose a cat face recognition system using Siamese and VGG16. The Siamese algorithm served as the main artificial neural network while VGG16 was the feature extraction algorithm. The Siamese network (which is conveniently named) is an artificial neural network that uses the same configuration but with the same parameters and weights [1]. They trained their model on a data set from *Kaggle* that consisted of 13106 images in total that belonged to 509 different cats with each cat having a range of 6-170 photos of them in the data set. They were able to achieve 79.21 % accuracy.

They attributed the low accuracy to the presence of a background in the original data set, which is considered in the training process of the model. They recommend that in future work (which we will do in our implementation), to have the features of the cat's face from the data in the data set extracted and then trained in the image using the Siamese network [8].

5 Conclusion and future work

5.1 In Progress Prototype

This project originally started out as a personal project for me. Based on a personal need, which is described in the motivation of this paper, I began to construct this design. My main goals are to construct the prototype without spending an egregious amount of money. In this section, I describe my thought process as I introduce possible solutions to design components and their benefits and downsides.

The main body of the robot will be constructed of a remote-control car with a camera kit from Amazon that is compatible with a Raspberry Pi. We already had access to a Raspberry Pi 4 Model B (4 GB RAM version), which has a quad-core 64-bit processor. These microcomputers can run as low as a very affordable $35 [13]. According to [3], a wheeled locomotive smart robot would benefit from using a microprocessor to allow more control over the device's hardware, something I care deeply about.

Omnidirectional Camera The benefit of the iconic memory-based navigation method proposed in [18] is that it requires a low amount of memory, which will, hopefully, not prove to be too powerful for the Raspberry Pi 4. The original smart kart kit comes with a standard camera, which is not omnidirectional, so we will need to purchase an external component that has 1. 360° capabilities, 2. is compatible with the raspberry PI, and 3. has a similar definition to the camera used in the study. The original paper uses a lab-manufactured omnidirectional camera, which consisted of a CCD and a hyperboloidal mirror. To save time and not suffer the common resolution loss when using a mirror, I can just purchase a 360 camera, which provides images of the same effect.

Table 1: Comparison of Omnidirectional Raspberry Pi Compatible Cameras

Camera Name	Commercial Price	Resolution	Frame Rate	Sensor Model
2005 CCD Camera (Paper)	$40-$500	5 MP[1]	24fps-30fps[2]	Unkown
PICAM360-4KHDR	$150	4KHDR	Up to 2048X1536 @30fps	Sony IMX214 (1/3.2inch)
PICAM360-CAMPT8MP	$75	8MP	Up to 1024X768 @30fps	Sony IMX179 (1/3.2inch)
PICAM360-CAMTWDR	$100	3.1MP	Up to 1024X768 @30fps	Aptina AR0331 (1/3.0inch)

[1]Most popular commercial resolution for CCDs in 2005 [19].
[2]Commercial frame rate in 2005 [5].

I was able to find a couple of Raspberry Pi 4-compatible omnidirectional cameras all of which are made specifically for Raspberry Pi integration. In Table 1, I provide a comparison between these cameras and an estimation of the camera used in the Yagi et al. study. Most importantly, I must choose a camera with a higher resolution than the one used in the original study, as their approach is most likely not as effective with a camera with a lower image quality. Unfortunately, they did not provide the tech specifications of their camera, so I did a bit of research on resolution, pricing, frame rates, and sensors of popular commercial products on the market in 2005, the year Yagi et al. paper was published.

Based on the comparison chart, the closest camera to the possible CCD in [18] is the PICAM360-CAMPT8MP. It has a higher frame rate than the 2005 industry-standard 5MP and has the logstanding going frame rate standard [5]. It is also, conveniently, the cheapest option of the PiCams. However, other much-higher resolution options are available that still are not extremely expensive.

The PICAM360-CAMPT8MP has a vertical angle of view of 220°, and all of its frame rate options are 3264X2448@15fps, 2048X1536@20fps, and 1024X768@30fps. It comes with a USB 2.0 interface and allows for lightweight livestreaming [13].

The main issue we will come across is testing whether a singular omnidirectional camera will be able to be used for navigation and for cat identification for our prototype. We foresee two possible obstacles with this design: 1. the raspberry pi may not be able to handle running both tasks and/or 2. the navigation system will be unable to be integrated with the VGG16 and Siamese process, resulting in the need for two cameras, one for navigation and one for identification.

5.2 Future Work

As mentioned a few times throughout this paper, we can imagine that this specific design of an intelligent cat care machine can be transferable to the care of other household animals as well, but only with specific tweaks. In the care of dogs, this robot could be utilized as short-term pet-care assistance. Cats can handle being alone much longer and are recommended to be purely indoor animals, requiring them to be inside 100% of the time. We can imagine, as dogs are normally well-traveled on a daily basis, will need more functionalities for a machine to handle their care without the interference of a human.

We foresee this type of design to also be expanded to robots with different types of locomotion. For example, there is work on replicating motor memory in robotics for bipedal and quadrupedal robotics using central pattern generators [14]. This expansion would be useful for animals requiring transitions to the outdoors or multi-story households. Even outside the lens of pet care, this type of robot can be used in facilitating automated conditioning in animal-robot mixed societies, providing an ethical route to animal research that prevents extreme disruption of ecosystems [11].

In addition to this, the topic of embodied multi-modal sensory memory can be a fascinating field to expand on. There can be a vast amount of potential uses for it, whether it's expanding the strength and

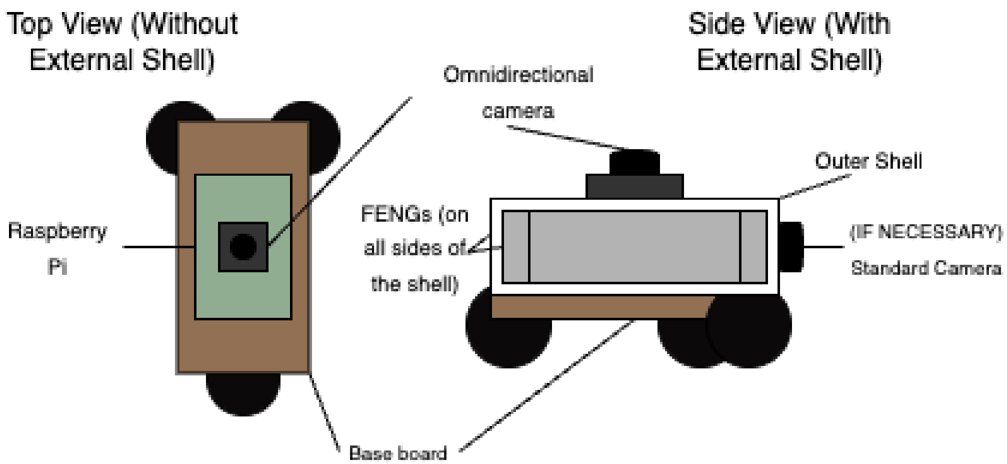

Figure 4: A blueprint of the prototype based on the technologies and techniques discussed in this paper. The items not labeled are the wheels of the vehicle. Not pictured: The FREENOVE smart car shield, servo motor, and other minute components to allow the car to move.

capabilities of home monitoring systems, learning more about the human brain through attempting to replicate it and challenging the notions of intelligence in the first place.

5.3 Conclusion

With this paper, we have proposed a design for the RoboCatsitter, an intelligent machine that can perform, without human supervision, the caring of domesticated cats. With an artificial sensory memory based approach, we believe we have made a feasible blueprint for the implementation of a cat-sitting robot. With the use of FENGs as the outer layer of the machine and the omnidirectional camera, our robot will be capable of replicating echoic and haptic memory. With an external omnidirectional camera, our robot will be able to navigate indoor spaces and be able to quickly respond to newly appearing obstacles. Based on previous literature, all of these are able to be implemented in the first iteration of the prototype through the simple FreeNove smart car kit and a Raspberry Pi 4. We believe that, upon the successful building of the robot, it can be iterated upon and even potentially used and distributed to aid cat owners who do not have enough of themselves to go around.

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