Automated Pet Door with LED Collar

University of Central Florida

Senior Design I

Initial Project Document - Divide and Conquer

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1.0 Executive Summary

In a study done by Nottingham Trent University on the indoor-outdoor lifestyles of pet cats, indoor-outdoor cats make up almost 59% of the population of pet cats (n = 5129). It is important to allow our pet cats a safe place to return home to even when we are not home. If the owner works a typical 9-5 job, they may not be home for up to eight hours. Or if the owner is forced to stay at work later, then there is no chance they will be home in time to let their furry friend inside. Even worse, if it happens to be raining while the owner is out, then there is no way for the pet to get back inside to stay dry. This is where an automated cat door is a necessity for our indoor-outdoor friends.

There are many products already on the market that allow for microchipped pets to re-enter their home even when their owner is not home or not available to let them in. But that does come with a prerequisite, the cats have to be microchipped. And that can cost upwards to $50 per cat without an insurance plan. On top of the price for microchipping, the automated cat doors will cost owners from $100 to $200 alone. Totaling upwards to $250 to have an automated door for an indoor-outdoor cat.

Our design will implement the use of an LED collar weighing no more than 100 grams. This will act as a key for the cat to open the cat door once it has been detected by the passive infrared motion sensor that will turn the system on. An IR receiver diode attached to the cat door will detect the light emitted at 940 nm from the IR LEDs on the cat collar that will notify the system to open the cat door. A set of IR LEDs will shine across the cat door onto some photodiodes that will act as a way to confirm if the cat has passed through the door or not. When the cat passes through the door, the change in voltage across the photodiodes will notify the system to set off a timer to close the cat door after the cat passes. If the cat decides not to enter, the system will default to a timer that will close the cat door after a set amount of time. This prevents the cat door from remaining open due to the unpredictability of cats. Then, the system will return to an idle state where just the motion sensor is supplied with enough power to operate. Now if the cat decides to return at a later time, the automated cat door is ready just as before.

The automated cat door will be easy to install, only requiring the consumer to cut a small rectangular shaped hole in their front or back door, or in some cases the door frame. Due to its size, it will be easier to install than a glass panel on their door.

If households can implement our design into their lives, they will have the peace of mind that their pets can return home safely at any time while giving their pets the freedom they love. Even if the pet owners are home, they will not be forced to stay attentive waiting for their pets to return home. Instead, they are able to

continue working on chores or even stay in their beds. Our design is for cat owners, made by cat owners.

2.0 Project Description

The Automated Cat Door with LED Collar utilizes optics and electronics to automatically let in pet cats without the need of the owner present. Allowing owners the peace of mind that their furry friends can come home safe whenever the owner is asleep or away from home.
This section includes:

- Background of the design
- Motivation for the design based off the members' previous struggles and complaints
- Goals and objectives the design will strive to accomplish
- Existing Products
- List of engineering requirements and specifications with 3 demonstrable specifications
- Prototype illustration
- Functionality of design
- House of quality, block diagram of hardware

2.1 Project Background

Many pet owners are not always home due to work or school; thus, their furry friends are sometimes left bored at home or worse, stuck outside. Our feline friends are forced to unfortunately wait until their owner returns home from work or school after upwards of eight hours. We live in Florida where it happens to rain quite often, which can be a bigger problem for the cats trying to find a safe place to escape from the rain. From experience, cats are forced to hide under nearby parked cars to stay out of the rain, which is not the best option to say the least. Sometimes, our pet cat is stuck outside simply because we fell asleep before our furry friend has returned from their outdoor adventures. This problem can be solved with an automated cat door.

There are some solutions using a microchip and a RFID reader on an automated cat door, but not all owners are able to afford microchipping their pet cat without an insurance plan. Without an insurance plan, microchipping and the cost of a microchip automated door can cost the owner upwards to $250 combined.

Our design will help owners find the solutions to help their pets a chance to return home at any time while keeping the cost of the product down to a minimum. Instead of the need to microchip their pets, our product will utilize optics in the form of a collar equipped with an IR LED that an IR receiver will scan for. Paired with a motion sensor in front of the door, this two-step verification process will act as the cat's key to open the cat door. Then, IR LEDs paired with photodiodes will pass across the entrance of the cat door that will act as a confirmation that their feline friend has re-entered the building. After confirmation, the cat door will automatically close and lock after a certain amount of time has passed. Otherwise, the cat door will still close automatically after a certain amount of time if the cat decides not to pass through the door, whichever comes first.

Although the motion sensor is expected to detect any type of movement, the LED collar is necessary to prevent raccoons, other rodents, and other animals from gaining access into the home. If the cat were to lose said collar, a backup solution will be necessary such as a remote button the owner can press from their computer or phone.

Without the need to get up to open their door, the owner will have the peace of mind that their pet cat has returned home safely while remaining comfortable in their bed. With further development, this design can be accessed through a phone application where the cat door can be opened remotely even when the owner is not home; thus, giving the owner a greater peace of mind if the cat were to lose the collar.

2.2 Motivation

The majority of our group members have experienced situations when they are forced to get out of the comfort of their beds to let their pet cats back into the house. We wait around for our feline friend to come home after hours of adventuring outdoors; then, as if they somehow knew we were comfortable in our beds, they come home meowing at our bedroom windows. Our design is meant to help give our pet cats a way inside while simultaneously allowing the owner to stay comfortable in bed. There have also been times after we get home from work on a rainy day to be greeted by our poor friend soaked because they had no way to get back inside.

2.3 Goals

Our design is to implement optics and electronics to automate a cat door, allowing pets to reenter the home without needing the owner to be home to open a door; while not allowing rodents, such as racoons, or intruders to easily enter through the door.

2.3.1 Basic Goals

The basic goals set are what we expect for our design to accomplish. First, we need an initial step that will turn on our system. This will avoid wasting battery on our automated cat door.

To avoid allowing in random rodents, we want a collar to function as a key for the pet so the door will only operate for our pets wearing the collar. Since the motion sensor will detect anything that comes in front of it, there will be many false positives in the initial step. Thus, a collar to act as a key should function as the second verification step.

If the cat door unexpectedly closes, it may injure our pet while they are trying to pass through the door or if they decide to stand inside the door for cat reasons. We will need a way to verify that the cat has passed through the door and to detect if the cat is still in the doorway.

2.3.2 Advance Goals

An improvement to the motion sensor will increase the detection accuracy for our system. Since motion sensors have a common issue of detecting something even when nothing is in front of it, we want to make sure this improvement will prevent false positives; thus, will prevent randomly turning on our system and wasting energy on our batteries.

2.3.3 Stretch Goals

In addition to the main goals of the Automated Cat Door, there are a few additional goals that are not strictly required for the core functionalities of the cat door, but would provide additional benefits to the user. These goals would incur additional costs and complexity to the project for what they add, so at the moment they are only being considered.

One such stretch goal is the addition of a security feature for the owner. We want to incorporate a method for the owner to view the entrance of the cat door like a live security camera. This will also allow the owner to see if their pet is stuck outside because of a system failure or if the pet has lost their collar.

2.4 Objectives

To accomplish our goals, the Automated Cat Door will utilize IR LEDs, lenses, microcontrollers, batteries, and solar panels to compete with existing automated pet doors on the market.

2.4.1 Basic Objectives

To accomplish our first goal of having an initial step to turn on our system, we will utilize IR LED motion sensors. The IR LED and photodetector will detect our pet in front of the door, then turn the system on.

Our collar will utilize IR LEDs to aid in functioning as a key for the pets. This will shine into a photodetector at the cat door that only operates at 940 nm. Once the photodetector detects the light from the IR LEDs on the collar, the system will then open the cat door to allow the pet in. Otherwise, the cat door will not open since whatever set off the motion sensor does not have the “key” to unlock the system.

For the cat door opening, we will be using IR LEDs and photodetectors to verify that our pet has either passed through the door or is still within the door frame. When the photodetectors are blocked from the light coming from the IR LEDs shining across the door, the system will know that a cat is still within the door frame. Once the pet passes through the door, the photodetectors will detect the IR light coming from the IR LEDs once again and the system will initiate a timer to close the cat door.

2.4.2 Advance Objectives

A passive IR motion sensor relies solely on the naturally emitted radiation to detect an object in front of it. Meanwhile, using an active IR motion sensor can improve the detection accuracy since it will detect the presence of an object from its reflection of radiation from the emitter.

2.4.3 Stretch Objectives

To add a security feature for our cat door, a camera attached to the door that can be viewed on the computer or app on their phone will be beneficial. This would allow the user to see exactly what is at the door, and allow the Automated Cat Door to also function as a home security camera. Incorporating a live camera feed into the system would however bring several challenges to the project, and would incur additional costs. Video processing requires a lot of processing power which our microcontroller alone cannot provide, so we would need to use an additional processor just for video processing. Additionally, in order to send the video to the computer, we would need a wireless transmitter with enough bandwidth to transmit a live video feed. These additional components would consume additional power, which would then require additional solar panels and batteries in order to meet energy demands. Achieving this goal would incur additional costs of at least $60, even for a low quality video feed.

2.5 Existing Products

As mentioned before there are automated cat doors already on the market, but they require the user's cat to already have a microchip implanted into them. This can cost the owner an additional $50 without an insurance plan. SureFlap is a company with various automated cat door designs that range from $100 to $500, depending on features and accessories.

One of the many SureFlap products already on the market.

With over 4,000 ratings and an average rating of 4.0 stars, we can see that the product is doing very well even at this price point. But not everyone can afford such amenities or anything automated for their pets. A major con with these products is the necessity of microchipping their pets or buying a collar with an RFID chip separately, ultimately costing the owners even more money they cannot afford to spend. With our product we envision giving the owners the guarantee their purchase will include everything they need to set up their automated cat door, excluding the tools necessary for installation.

Because we cannot include the tools necessary, our design will be compact enough to give the owners the freedom to install the cat door wherever they desire. Whether they install it directly onto their doors or beside the door frame, we will make sure our design will not cause too much of a headache for the owners to install due to its compact size and durable frame at a budget friendly price point.

2.6 Comparisons to Past Projects

When browsing other senior design projects, we saw that a few groups also made a cat door for their project, so we decided to look at the similarities and differences between our project and past senior design projects.

The first project we noticed was similar to ours was Pet Connect, a project from 2020. This project has a similar goal to ours, to reduce the stress of pet owners who are either not home or not able to monitor the door for their pets which like to go outside. The Pet Connect project uses a system to open a normal sliding glass door, allowing the pet to come inside or outside as they please. It focuses more on dogs, and their need to go outside to relieve themselves, as opposed to our project which focuses on pet owners with indoor/outdoor cats. They also use a camera and audio interface, as well as a mobile app to allow the user to remotely control the door. The advantages of their project is that it is easier for a user to set up, as they can install the system without having to cut a hole in their door, and they have an advanced system which allows the user to monitor what is at the door, and set it to be locked or open, etc. The disadvantages are firstly the cost, as the Pet Connect ended up costing about $370, with an initial budget of $450, while our project budget is $150. This comes from the expenses of the camera system, the advanced sensors they use, as well as the system to automatically open a sliding glass door. This system also requires the user to have a sliding glass door, so it has a more limited customer base. Our project aims to reduce the cost by using a simpler and more cost-effective system, using infrared communication through our collar, and is more accessible as a user can install our system on most front doors.

The next project we noticed was similar was the IoT Smart Doggy Door. This project also focuses on dogs like Pet Connect, but works in a completely different way. This project uses collars like ours does, except they use RFID instead of infrared communication. The IoT Smart Doggy Door focuses on incorporating IoT into the project, as the name says. The features this allows is that the user can be sent pictures of the outside of the door when something is there, and they can set custom permissions for each pet based on the collars which are registered to the system. Being an IoT project, it allows much more remote control than our project. Another advantage of their project is that the collar they use does not require a battery, since it uses a passive RFID tag instead of an infrared communication system like ours, which requires a battery. However, all of this customization and remote control comes at a cost, as their project ended up costing them around $600. A large part of this cost comes from the RFID technology, as the reader and antenna cost them around $350. Our project is different in that we aim to provide a solution for pet owners that is lower cost, around $150 if possible. Still, the IoT Smart Doggy Door is a good project for us to draw inspiration from.

2.7 Engineering Requirements and Specifications

We have a few expectations for our product to ensure it will compare to other products on the market. To start, the product is expected to open and close. With our product, we'd like our product to close its door after a set time after the pet has passed through the door. Since we are using an IR motion sensor, we expect our system to detect our pet within a certain distance and with reasonable reliability.

2.7.1 System Specifications

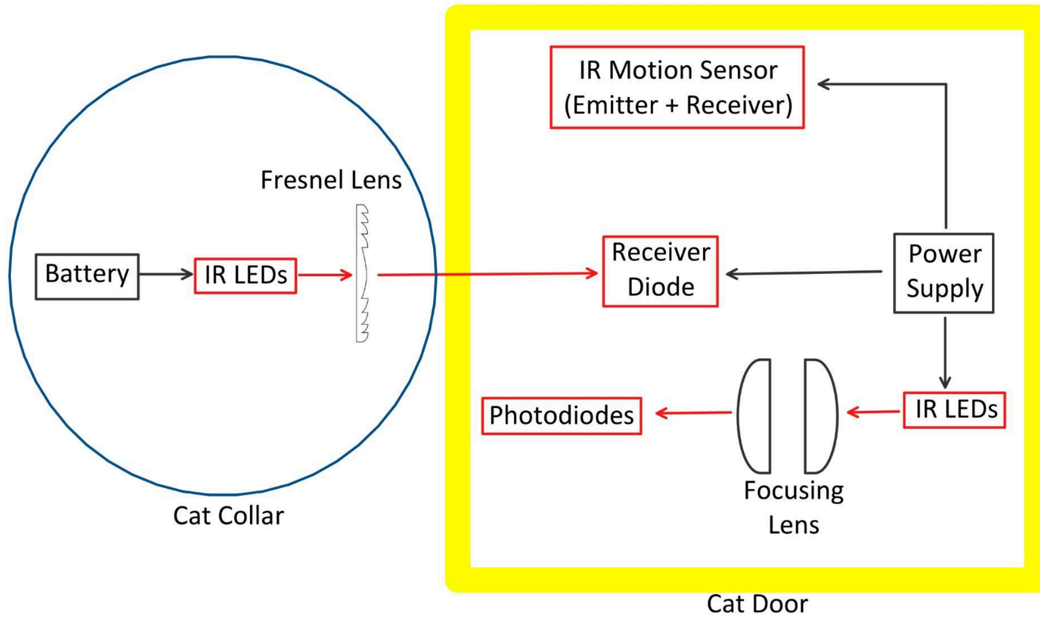
Subsystem	Parameter	Specification
Motion Sensor	**Maximum Response Time**	< 3 ms
	Range	0 < x ≤ 3 meters
	Detection Reliability	~ 90%
Power Supply	**Maximum power usage while offline**	< 100 milliwatts
	Maximum power usage while online	< 10 watts
Microcontroller	**Time Before Door Closes(Cat Enters)**	10 Seconds
	Time Before Door Closes(Cat Leaves)	60 seconds
IR LEDs	**Collar Weight**	< 100 grams
Collar Battery	**Battery Life**	~ 8 hours

2.7.2 Component Specifications

Component	Parameter	Specification
IR LED	Voltage	1.2 V < V < 3 V
IR Photodiode	Detection Range	0 < x < 1 m
Fresnel Lens	Focal Length	0 < f < 50 mm
Solar Panels	Power Generated Under Ideal Conditions	500mW < p < 1500mW
DC Motor	Power Draw	1W < P < 2W
Main Microcontroller	Operating Voltage	3 V < V < 3.6 V
Collar Microcontroller	Operating Voltage	2.7 V < V < 5.5 V
Door battery	Capacity	~12Wh
Collar Battery	Capacity	~0.9Wh

2.8 Prototype Illustration

A motion sensor will be the initial step to turn on the entire system, rather than using a RFID reader that will require more power to operate than a simple motion sensor. Without the need of a RFID tag and reader, the cat's collar will be lighter and our design will require less electronics; thus, lowering the cost.
In our design, an LED is attached to a cat's collar along with a fresnel lens. An IR LED at 940 nm is used because it will prevent misbehaving neighbors from tampering with the cat door. A simple IR receiver is used to detect the IR LED, as shown in Figure 2.



Prototype Illustration of optical components.

A camera with a live feed will be a stretch goal to provide the owner safety and clarity in case it is not their cat setting off the motion sensor. With the live feed, the owner can see if their pet cat has lost its collar so the owner can manually activate the system's backup to open the door with a press of a button.

At the cat door, IR LEDs along with photodiodes will be used as a confirmation step that the cat has passed through the door, as shown in Figure 2.

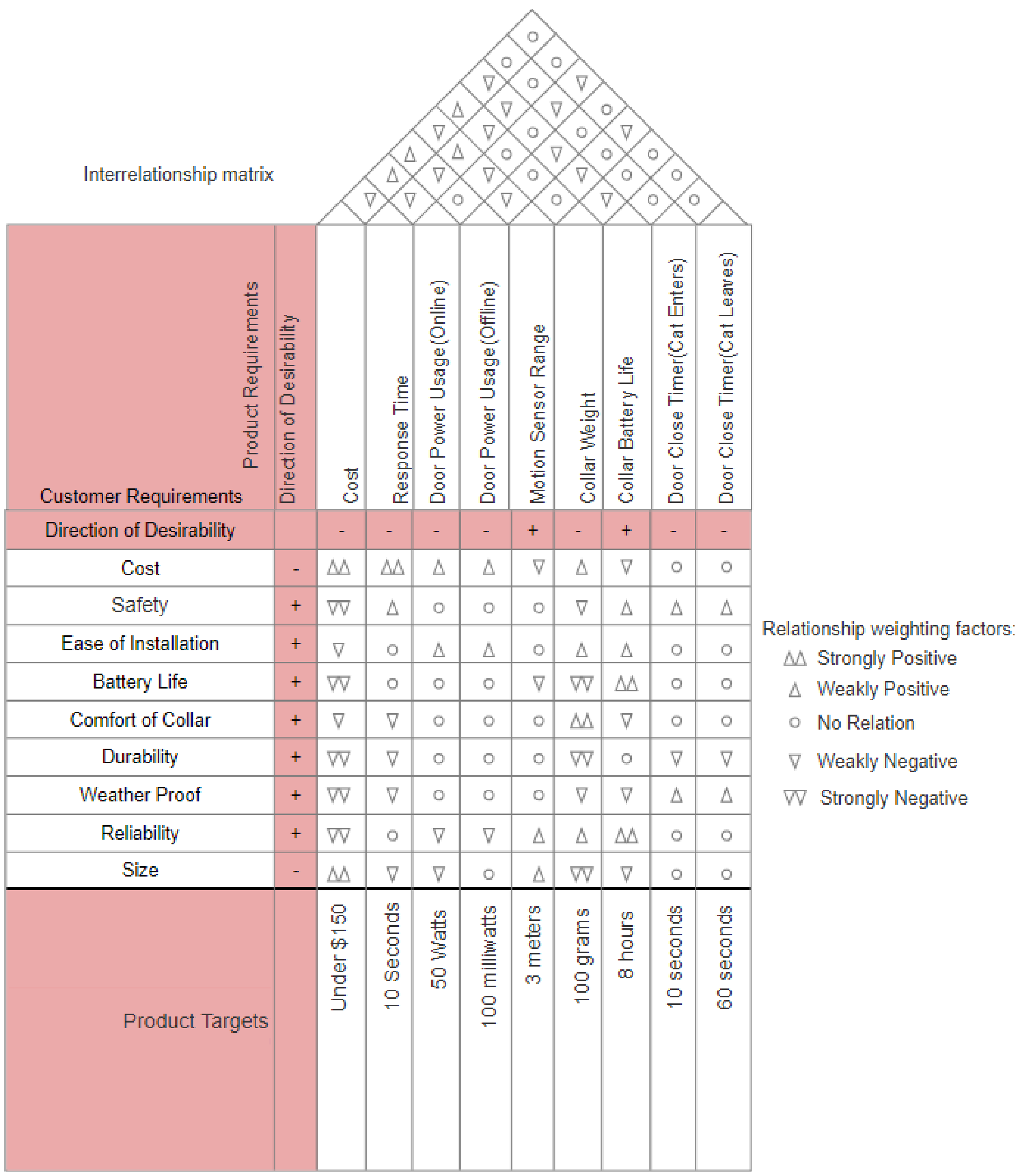
2.9 Functionality of Design

Initially, the majority of the system is off and the only component powered will be the motion sensor. Once something has passed the motion sensor, the system will turn on and a shutter will open, revealing the IR receiver to detect the light coming from the IR LED on the cat's collar. When the IR receiver has reached a certain threshold voltage, the cat door will open and the IR LEDs will turn on and another shutter will open to reveal the photodiodes used to detect the IR LEDs to begin the verification step of the cat passing through the cat door.

If the cat enters through the cat door, all the photodiodes will be blocked and the voltage will drop; thus, indicating to the system that the cat has passed through the door. After the cat has passed through the cat door, the photodiodes will not be blocked anymore and will detect a certain voltage again, indicating that there is no cat blocking the doorway. This will then set off a timer in the system to close and lock the cat door after the time has expired.

Or if there is no voltage drop from the photodiodes because the cat decides not to pass through the cat door, then a predetermined timer will notify the system to close and lock the cat door. To ensure the cat door does not remain open forever, the cat door will close whichever event occurs first.

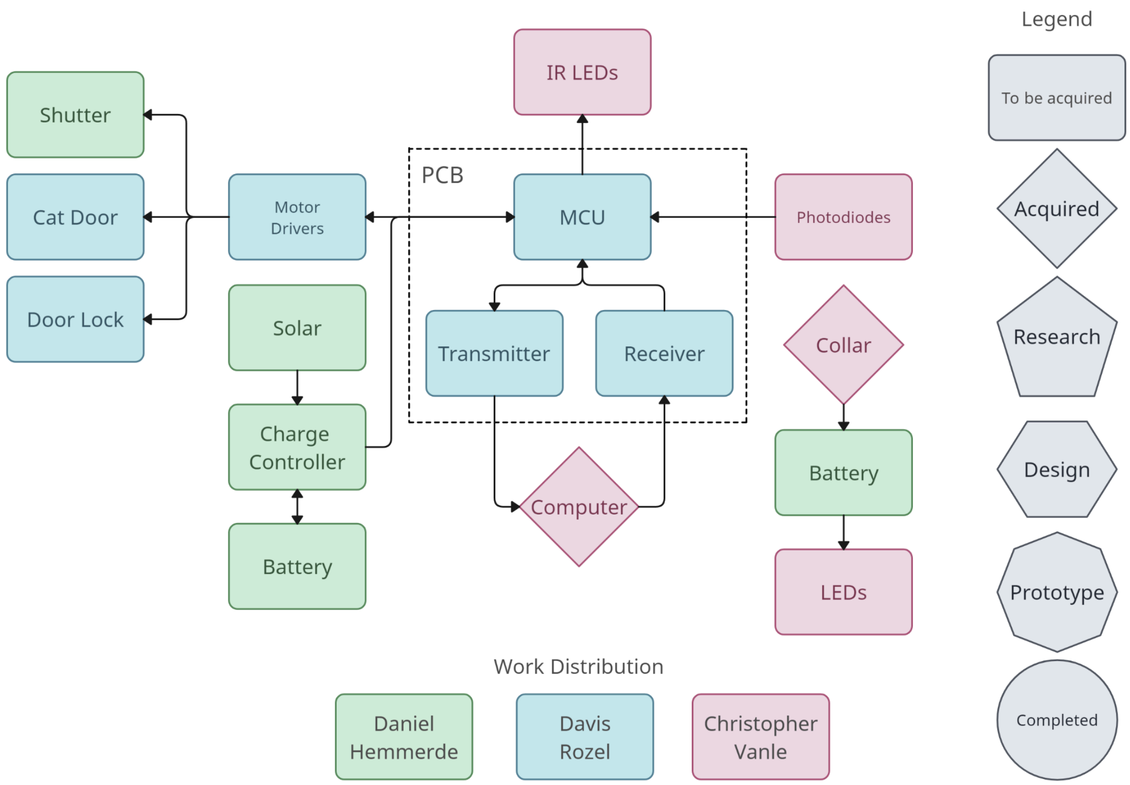
2.10 Marketing and Engineering Requirements (House of Quality)



House of Quality diagram.

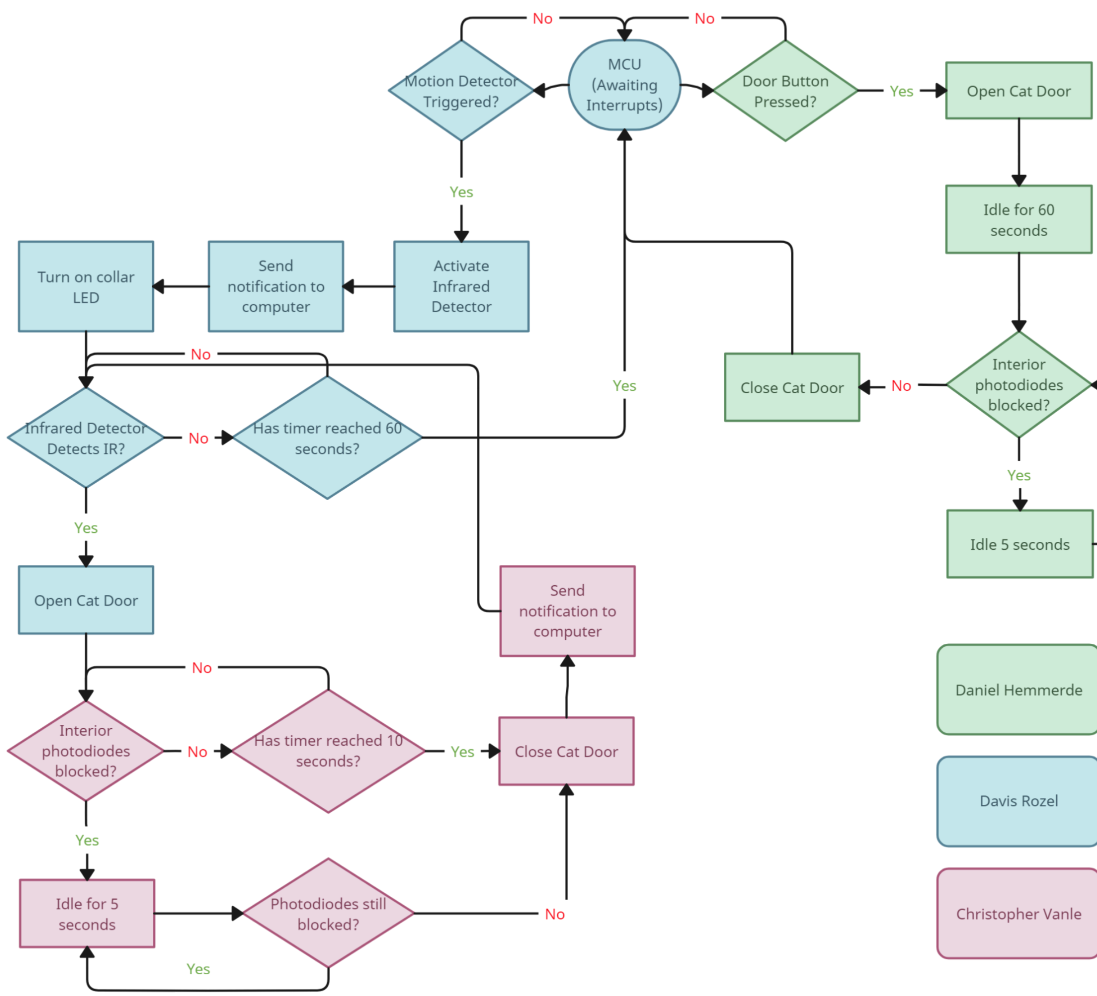
2.11 Hardware Block Diagram

Since our group is made up of one PSE and two ECE students, the electronic requirements are split between the two ECE students while the PSE student handles the optic components. There are various blocks which the group members already own, such as cat collars and computers to program our MCUs.



Hardware block diagram with work distributions and progress.

2.12 Software Block Diagram



Software block diagram with work distributions.

3.0 Research and Investigation

The idea is simple, a pet door that will automatically open without the direct assistance of the owner while keeping out unwanted rodents. To do such, there are many options that will help accomplish our goals that will compare to other products already on the market.

3.1 Technology Comparison and Selection

Our design requires similar technology as the products on the market, such as motors and a way to power the device. To add to ours, we have unique technology such as motion sensors, solar panels, and a way to communicate between the door and pet collar.

3.1.1 Communication Technology

Our project will require two way communication from the door and the collar. Therefore it is important that we choose the right communication technology to meet these needs, as well as fulfilling our requirements specifications.

Infrared Communication

In order for the door system and the collar to communicate, we have chosen to utilize infrared communication. This communication system utilizes an infrared LED pulsing on and off quickly, in order to communicate data to an infrared receiver. Typically the LED is pulsed at the IR signal's carrier frequency; 38 kHz. Different communication protocols can also operate at 36 kHz, but generally as long as the communication is close to the carrier frequency the communication will work. We chose to use IR communication because it is a cheap form of communication, needing only an infrared LED and a detector to communicate. It is also quite power efficient, being that the LED just needs to flash on and off to communicate.

A flaw of using IR communication is the lack of security that IR communication has. Without any additional security measures, anyone with a device that transmits IR data using the same communication protocol as us could communicate with our door, which is a potential security risk. Therefore in order for only the collar and the door to be able to communicate through IR, we did some research on ways to improve the security of IR. We found a paper called "Eavesdropping Vulnerability and Countermeasure in Infrared Communication for IoT Devices", by Minchul Kim and Taeweon Suh, discussing security issues with IR communication. We will be adapting the method they used to improve the security of IR communication to our own project, as it is one of the simplest and most effective methods we have found.

The way we will improve IR security is by using an encryption key, which will be generated based on the count of the timer on our collar microcontroller. In addition to the encryption key, we will have a counter counting up by 1 every time a command is transmitted. By adding the encryption key with the counter count, and then doing an XOR operation with the key + counter and the command, we create an encrypted packet. This packet is then transmitted from the collar to the door, and is decrypted using the same method in reverse. By using this method, our system will be more impervious to foreign control, and should allow only the collar and the door to communicate.

3.1.2 Power Source Technology

Our project will include several electronic components that will need a consistent power source to keep everything running properly. Our project will be broken up into long periods of low power usage that is occasionally broken by short bursts of higher power usage. For this reason, we must consider several factors for the power source. These factors include quantity of power supplied, reliability, cost, and convenience.

Outlet

The first potential solution for the power source for our project is to include a cable to plug the door into the wall. This solution would be fairly straightforward and simple to install, and would likely be one of the cheapest options up front. This option would also be fairly reliable as it would not lose power as long as the customer's house still had power. This option is not without faults however. Most outlets provide very high voltages, and due to our project being very low power, we would need to step down the voltage by a very large margin. This would require a voltage regulator to disperse the majority of the power provided by the outlet, resulting in a great loss in efficiency. This can either result in some safety risks, or the use of complicated machinery that would be much more difficult to implement. In addition to this, the door would also need to be placed near an outlet, which would limit the options for the customer. If the consumer is willing to have the door placed near an outlet then this would become the most reliable power source for keeping the batteries charged. For this reason we will be providing the option to plug the door into an outlet if desired but not limiting them to only this option.

Disposable Batteries

The next option for the power source is the use of disposable batteries. This option is also very straightforward and would likely be much easier to implement than either of the other two options. Alongside the ease of implementation, the disposable battery approach would also be very convenient as it would not be limited at all in terms of location, and disposable batteries are very easy to find in stores. These batteries would also be fairly reliable as they are unaffected by external issues and are only affected by their own lifespan. Therein lies the main issue though, as due to the consistent power drain of our project, it is likely that the batteries would need to be replaced fairly consistently. This would add a considerable amount to the post-purchase cost of using our project, and would likely cause reliability issues as the battery may die at a time when it would not be feasible to replace it.

Solar

The final option we considered was the use of a solar panel to charge the device. This option synergizes the best with the power use profile of our project as the constant charge it provides would be able to refuel the battery in the long down times between full activity. This reasoning makes using a solar panel fairly reliable. It would also be very convenient to implement this approach as the location is only somewhat limited as it would not be very effective in a darker or shaded area. However, this limitation is somewhat made up for by the lack of maintenance needed for this option. This sparse maintenance would mostly be limited to cleaning the solar panel on occasion, and replacing the battery after a very long period of use. Like the other solutions to the power source problem, this approach has a glaring flaw. This flaw is the significantly higher base cost of the solar charge structure. Despite this issue, we believe that this higher base cost will be made up for by the near total elimination of the post-purchase price. For these reasons, we have decided to use this approach to power our system.

Source	**Outlet**	**Disposable Battery**	**Solar**
Location Convenience	Medium	Highest	High
Initial Cost	Lowest	Low	High
Post-Purchase cost	Low	Medium	Lowest
Charge Rate	High	N/A	Low
Maintenance Required	Lowest	High	Low
Efficiency	Low	High	High

3.1.3 Door Opening Mechanisms

Of course one of the most important parts of the automatic cat door is the door, so we have to make sure we choose a design that meets our needs. There are a few factors to consider, including the cost of our solution, the amount of time the door takes to open, safety, and size of the door mechanism.

Flap

The flap design is one of the simplest and cheapest solutions we could come up with, being just a flat sheet attached to the top of the frame with hinges. This design would not require any motors to be opened, and would be opened by physically pushing on the door. It is also self-stabilizing, returning to its center point due to gravity, but may also take more time to stabilize depending on the force the door was opened with. It also takes the least amount of space out of these designs to install. The flap design is also very safe, since the door is opened by the pet, and the way the door moves poses little risk of the cat getting stuck or crushed by the door. The benefits of this design are why many automatic cat doors use it, however it does come with several drawbacks. Since the door has to be pushed open by the pet, it does not give a clear indication of when it is locked or unlocked, so the pet may be confused and now know when the door can be opened. This type of door design is also much more difficult to make automatically open than other designs, so it is limited to manual operation. The locking mechanism for this type of door could also be more complex due to the irregular nature of its motion, taking different amounts of time to fully settle.

Vertical Sliding

The vertical sliding door design is another option we have considered. This design consists of a flat door opening and closing by sliding up and down the door frame. It would be moved by a motor driving a belt and a pulley, which would lift and raise the door along a track which will keep the door in place and allow it to slide smoothly. The advantages that this design provides are one, it is automatic unlike the flap door, so the pet knows more clearly when the door is open. It also allows us to precisely control the speed at which the door opens and closes, based on the speed we drive the motor at. A disadvantage of the design is that it takes up a lot of space, since the door needs to move up when opened. This design is also less safe than the flap design, since a cat in the door could potentially be injured if the door closes while the cat is entering. Our system to detect if something is in the door helps to counteract this safety risk, but if that system fails we would also like to have another safety measure if using this design. After considering our options, we decided to go with this design since it is less prone to mechanical failure than the shutter design, is automatic unlike the flap design, and also is less noisy than the shutter design.

Rolling Shutter

Finally, the rolling shutter door design is a design that has a door made of interlocking horizontal plates, allowing the door to be rolled up when opened. It is driven by a motor which would rotate a roller, rolling up the shutter when opening the door, and rolling out the shutter when closing the door. This design is also automatic like the sliding door, and it also allows us to precisely control the speed at which the door opens and closes. The shutter design still takes more space than the flap design would, but it is smaller than the sliding door, since the door rolls into a more compact form, though this design would take up more horizontal space than the sliding door. This design shares some of the disadvantages of the sliding door, like the safety risk, but also has a higher risk of mechanical failure than the sliding door due to the more complex rolling motion, there is a chance that the shutters could get stuck or not fold properly. Another disadvantage of the shutter design is the additional noise caused by the rolling of the shutters, which could scare off the cat.

Door Design	**Flap**	**Vertical Sliding**	**Rolling Shutter**
Ease of Use	Hardest	Easiest	Middle
Simplicity	Simplest	Middle	Most Complex
Cost	Cheapest	Middle	Most Expensive
Noise	Least	Middle	Loudest
Space	Least	Largest	Middle
Is Automatic?	No	Yes	Yes
Security	Least	Most	Middle

3.1.4 Door Materials

We need to choose a suitable material for our door to be made out of to meet requirements including weatherproofing, withstanding moderate physical force, and being as lightweight as possible. The lighter our door weighs, the less power we will need from the motor to lift the door, so we want to reach a balance between strength and weight.

Plywood

Plywood is an obvious first choice for a door material. It is quite cheap, being a composite material of small pieces of wood, and is durable enough to withstand moderate force, but not as strong as the plastics on this list. Plywood is commonly used as a material in doors due to these properties. It is also the least dense material out of these options, making it require less power to lift than our other options. Additionally, plywood can withstand a wide range of temperatures, and is strengthened in cold environments. However, plywood degrades when exposed to rain and moisture for extended periods of time, since the glue will weaken, and the wood fibers can rot and be damaged by moisture. There are of course methods to make plywood more weather resistant, such as using marine plywood which uses waterproof glue to withstand wet conditions, as well as using sealants to protect the wood.

PVC

PVC is a less obvious but still decent choice for a door material. It has a lower cost than acrylic or polycarbonate, and is a decently strong material for its price, with a high impact strength. Its density is greater than that of plywood, and similar to the other plastics on this list. PVC is very resistant to chemicals, fire-resistant, and has a low permeability to most gasses. Additionally, PVC has been shown to be resistant to UV radiation, with its tensile strength and elasticity remaining unchanged after prolonged exposure; however the impact strength can degrade from UV radiation, and PVC is prone to yellowing after long sun exposure. However, one of the biggest flaws of PVC is its low resistance to cold temperatures, as it gets brittle in temperatures below freezing. Here in Florida this may not be a big issue, but in parts of the world that experience below freezing temperatures, PVC would not make a good door choice. It also is vulnerable to temperatures above 60° C, where it starts to decompose, and it melts at 71.1° C.

Acrylic

Acrylic, also known as plexiglass, is a good choice for a door material, especially a cat door. It has good tensile strength and impact strength, with its tensile strength being stronger than PVC but its impact strength weaker than PVC. It has a similar density to the other plastics on this list, being around 1.19 g/cm3. Acrylic is resistant to chemicals like PVC, and has good insulative properties. This material is also very resistant to weather, with it being waterproof and very resistant to UV radiation, not yellowing from long exposure like PVC or polycarbonate. It is also more temperature resistant than PVC, being able to withstand much colder temperatures which allows it to be used in many more parts of the world, but still not in extremely cold climates. Acrylic is also transparent, which is not necessary but still is a good benefit to be able to see through the door. These properties are why it is often used in the place of glass. A downside of acrylic is that it is vulnerable to fire, while difficult to ignite, if it does manage to catch fire it will burn vigorously, but for our application this is not a major issue. Out of these options, acrylic is the best option for our application, due to its high weather resistance, UV resistance, and strength. Therefore we have chosen to use acrylic as our door material.

Polycarbonate

Polycarbonate is similar to acrylic, being another type of clear plastic, but has different properties. For one the impact strength of polycarbonate is much higher than that of acrylic, being roughly 15-25 times stronger than acrylic. Polycarbonate is also slightly more dense than acrylic, but not by that much. It is harder to crack that acrylic, but also more prone to scratching as well as denting. Polycarbonate is also less transparent than acrylic, being more translucent. Polycarbonate additionally has a higher chemical resistance than acrylic, so is generally more durable. Additionally polycarbonate can handle a slightly higher temperature range than acrylic. A big downside of this material however is that it is susceptible to yellowing due to UV radiation, so it is not as good for prolonged sun exposure. Polycarbonate is also generally about 35% more expensive than acrylic. Overall polycarbonate provides much more strength and durability than acrylic, but for our purposes this extra strength is not needed.

Properties	Plywood	PVC (extruded)	Acrylic (extruded)	Polycarbonate (extruded)
Tensile Strength (Yield) (MPa)	N/A	14.8 – 57.4 (average 42.4)	44.9 – 86.0 (average 68.9)	39.0 – 120 (average 65.9)
Tensile Strength (Ultimate) (MPa)	27.6 – 34.5	0.00123 – 60.8 (average 23.9)	29.0 – 75.0 (average 57.7)	28.0 – 75.0 (average 65.9)
Density (g/cm^3)	0.4 – 0.75	1.13 – 1.85	0.942 – 1.19	1.03 – 1.26
Temperature Range	-184° C - 93° C	0° C – 60° C	-34.4° C – 82.2° C	-40° C – 137.8° C
Continuous Weather Exposure	No	Yes but not in cold	Yes	Yes but susceptible to yellowing due to UV exposure
Cost Comparison	Lowest	Low	High	Highest

3.1.5 Motor Technologies

In order to operate our automatic door we will need a suitable motor. Since there are many kinds of motors, we must look at a few types of motors and choose the type that is best for our application.

DC Motors

DC motors are powered by DC current. The two main types of DC motors are brushed and brushless. Brushed DC motors send current through a commutator and carbon brushes connected to the rotor, generating a magnetic field. The commutator reverses the current between the motor and power source, producing a steady torque. Brushless DC motors instead use a permanent magnet as the rotor, and a sequence of coils as the stator. The coils are switched electronically at the correct rotor positions, and use sensors to determine when to switch the current. Brushed DC motors are cheaper than brushless, but have less lifespan due to the brushes which wear down and need to be replaced after a lot of use, whereas brushless motors are more costly, they have a much longer lifespan and require less maintenance. Since brushless motors do not lose energy to friction from brushes, they are more energy efficient than brushed. Controlling the speed of a DC motor is done by changing the voltage applied to the armature, one way to do this is with a pulse-width modulated signal.

DC motors have high power efficiency, and are good for applications where the load is constant, and where precise speed control is desired. Since our application does not require a very powerful motor, and our load being the door is constant, we have decided that a DC motor would be the best choice of motor for our application. Since the motor will only be in use when opening/closing the door, it will only be active for short periods of time, making a brushed motor viable since the brushes will not be worn so fast from infrequent use. The advantages a brushless motor offers are just not worth the additional cost in our application, so a brushed motor makes more sense.

AC Motors

AC motors are driven by AC current. These motors work by supplying AC current to coils wound around the slots of the stator, producing a rotating magnetic field. A rotor attached to the output shaft produces a second rotating magnetic field, which can be produced by different sources depending on the motor, such as permanent magnets or additional current conducting windings. Two common types of AC motors are induction motors and synchronous motors. Induction motors use slip, a small difference between the speed of the rotor and the rotating magnetic field produced by the stator to induce current in the AC winding of the rotor. A synchronous motor instead uses permanent magnets or independently excited rotor windings. The speed of an AC motor is determined by the frequency of the AC supply and will not change speed even if the load changes. To adjust the speed, a variable frequency drive must be used which converts the AC to DC back and forth at a different frequency.

AC motors are generally less power efficient than brushed DC motors, due to the different methods of generating torque. They are best for applications where the motor runs at a slower speed, with a changing load, and are mainly used for heavy-duty industrial applications. AC motors are generally used for high power operations in heavy machinery, so they are not the best choice for our project.

Motor Type	**DC Motor (Brushed)**	**DC Motor (Brushless)**	**AC Motor**
Power Efficiency	Middle	Highest	Lowest
Variable Load	Lowest	Lowest	Highest
Control Circuitry	Simplest	Complex	Complex
Heat Dissipation	Middle	Best	Worst
Average Lifespan	Lowest	Highest	Highest
Required Maintenance	Medium	Low	Medium
Speed Control	Middle	Best	Worst
Cost	Middle	Highest	Lowest

3.1.6 Programming Language

For our application we need to choose a programming language that is capable of meeting the constraints of our project. We want a language that is not power or performance intensive, and ideally we would like to work with a language that we are already familiar with.

C/C++

Many microcontrollers run on C or C++, or on C with some features of C++, it is a very widely supported programming language. It is a high-level language, but it compiles closer to machine code than many other high-level programming languages, which uses less processing, which makes the code run faster and reduces the power consumption. C/C++ is supported by integrated development environments such as the AVR IDE or the Arduino IDE, which gives us options besides doing bare C/C++ code.

We have chosen to use C/C++ as our programming language of choice, particularly using the Arduino IDE, since it fits much better with our goals than Python. Our group is much more experienced with C/C++ than with Python, since a lot of our coursework like embedded systems focuses on C/C++. Using Arduino IDE allows us access to many public libraries which are widely supported, but still allows us to use bare C/C++ if we wish.

Python

Python is another option that is becoming more popular for use in microcontroller programming. It is generally easier to learn and use than C++ because it has easier to read code and a simpler syntax. However, since Python is interpreted rather than compiled, it has more steps in translating to machine code and therefore runs slower than C/C++ and uses more power. Python is much better for applications like data analysis and machine learning, but since our project will not involve much of these, Python is not the best choice for our project.

Programming Language	**C/C++**	**Python**
Use in Embedded Systems	More common	Less common
Processing Speed	Faster	Slower
Power Consumption	Less	More
Complexity	More	Less
Use of IDEs	Yes	No

3.2 Part Comparison and Selection

With the many options available on the market we must consider their pros and cons, such as cost, effectiveness, and efficiency.

3.2.1 Microcontrollers

The microcontroller (aka MCU) is one of the most important components of this project. It will be responsible for the logical operation of the system, controlling when and what actions are taken by the system. The microcontroller will be interfaced with all of the sensors and actuators of the system, and will be reading sensor data to determine when to open the cat door, what to communicate to the collar and the computer, as well as all of the other control elements of the system. Therefore it is vitally important that we choose a microcontroller that is able to meet all of the specifications and requirements of the components of the system. There are many factors to consider when choosing a microcontroller, including clock speed, memory, pin count, supported software, programming languages, power consumption/efficiency, and more. For our project, we will need at least two microcontrollers, one for the main system on the cat door which will control the main system operations, as well as a smaller one for the collar which will control the functionalities of the collar.

The pin count is very important, since pins are needed to connect the microcontroller to external elements like sensors. The microcontroller needs to at least have enough pins to connect all the components needed for the project, plus having some extra would allow us flexibility in the implementation of our project. Having more pins is useful, but we also do not want an excess of pins, as this comes with disadvantages such as increased space usage, an increase in power consumption as well as an increase in cost.

Clock speed is another essential aspect of the microcontroller to consider, as a faster clock speed generally means faster processing. Having a higher clock speed allows the microcontroller to execute instructions faster, which would lead to a faster response time. A faster clock speed also increases power consumption, which is important to consider.

Storage is also an important part of the microcontroller. Storage comes in multiple forms, including flash, which is a nonvolatile memory used to store and load programs, RAM which is volatile memory that is used for temporary storage during operation, ROM which is nonvolatile memory used to store instructions, and EEPROM, which is also nonvolatile memory and usually used to store configuration settings. Both the size of storage and rate of data transfer must be considered as we need enough storage space to handle the size of our code, and the data must be transferred as quickly as possible to improve response time.

The microcontroller we choose should also support the communication protocols we decide to use. Most MCUs available support the common communication protocols like UART, I2C, and SPI, but if we want to use a different communication protocol we need to make sure the MCU supports it. The architecture and programming languages that the MCU supports is also important, ideally we would want one that supports the Arduino IDE, or the Code Composer Studio (CCS) IDE, as these IDEs are familiar to us, but other MCUs are still worth considering if they provide worthwhile benefits.

We could also consider using a microprocessor like the Raspberry Pi instead of a microcontroller, or using both for different tasks. A microprocessor would provide us with much more processing power than a microcontroller, and allow us to compute more complex tasks than a microcontroller, but there are also many downsides to this approach. A microprocessor uses more power than a microcontroller, and often lacks a low power mode, where most microcontrollers have multiple low power modes which can be switched between for different applications. A microprocessor requires more additional components like external RAM/ROM, I/O ports, etc, which adds to the size and cost, and would require a larger and therefore more expensive PCB. For our application, the benefits of a microprocessor are not really needed, and the drawbacks are too great, so we will most likely not be using one.

3.2.1.1 Main Microcontroller

The main microcontroller for this project will be installed on the cat door itself, and it will be responsible for most of the major operations of the system. Therefore the microcontroller we select must be capable of handling multiple peripherals and tasks, so we must make sure it has good enough specs for this. Additionally, the microcontroller we choose should not have many more pins than is necessary, as this will increase its footprint on the PCB and therefore increase costs.

Atmel ATmega328

Atmel is a very popular microcontroller manufacturer, whose chips have been used for many projects. The ATmega328 is one of their most common chips, being used in Arduino development boards like the Arduino UNO. It is an 8-bit RISC based microcontroller, featuring a clock speed of 20 MHz, as well as 32 KB of ISP Flash memory, 1 KB of EEPROM memory, and 2 KB of SRAM memory. It has 23 GPIO ports, a 6 channel 10-bit A/D converter, and supports UART, I2C, and SPI communication protocols. The ATmega328 is quite power efficient and offers a low power consumption, with 5 different low power modes. It is also inexpensive considering what it offers, and is overall a decent microcontroller, and it has extensive documentation available given its popularity, so it is easier to work with. For our application this MCU could be enough, but being a beginner chip it may not be able to provide all the capabilities we need. The pin count is especially an issue, with all of the components of our system this MCU may not have enough pins.

Microchip ATxmega64A4U

The ATxmega64A4U is an 8/16-bit AVR microcontroller, with 64 KB self-programming flash memory, a 4 KB boot code section, 4 KB of SRAM, 2 KB of EEPROM, and has a 32 MIPS throughput at 32 MHz. This MCU has 44 GPIO ports, a 12 channel 12-bit A/D converter, a two-channel, 12-bit D/A converter, and supports common protocols like I2C and SPI. The capabilities of this MCU are enough to support all of the needs of our project, and the pin count is high enough to support all of the peripherals we plan to use in our system. The active mode power consumption is higher than other chips like the ATmega328, which is a drawback to consider.

Microchip ATxmega128A4U

The ATxmega128A4U is in the same family as the ATxmega64A4U, but it is a slightly more powerful chip. It features 128 KB of self-programming flash memory, as well as 8 KB of SRAM. Therefore this chip has higher capabilities than the ATxmega64A4U, but it also comes at the cost of slightly increased power consumption. For this application, we likely do not need the extra performance that this chip offers, but it is worth considering.

The issue with this chip as well as the ATxmega64A4U is that programming them is very difficult. We would need a specific programming tool which can cost anywhere from $150 - $250, which for our project is just not worth the cost. Additionally, many senior design 2 students were reported to have issues with ATmega chips, with them being very sensitive when soldering. For these reasons, it is very unlikely that we will use these chips.

Microchip PIC24FJ128GA006

Another MCU by Microchip, the PIC24FJ128GA006 has a key difference from the rest of the microcontrollers considered so far, being that it is a purely 16-bit MCU instead of 8-bit or 8/16-bit. It has a 16 MHz clock speed, 128 KB flash memory, and 64 GPIO ports. This MCU has a 16 channel 10-bit A/D converter, and supports common communication protocols like UART, I2C, and SPI. This chip has good specs at a fairly low cost, however it consumes quite a bit more power than the other options. It also has the most pins out of all of the other options here, and its specs make it worth considering, however the extra power consumption may not be worth it.

ESP-WROOM-32D

The ESP32 is our final choice for a microcontroller. It is much more powerful than the other microcontrollers on this list, boasting a max clock speed of 240 MHz, 4 MB of flash memory, and 520 KB of SRAM. The pin count is less than some other options at 34, but this is still enough to interface all of the peripherals in our system. A big feature of the ESP32 is its integrated 2.4 GHz WiFi and Bluetooth module, which makes it possible for us to use these forms of communication in our design. Furthermore the ESP32 can be purchased with a development board, which makes it much easier to program, and we can simply move the chip from the development board to our custom PCB.

Despite the higher specs on this microcontroller, the power consumption is not much higher compared to the rest of the list. With the RF modules disabled, the power consumption of the ESP32 is around 25 mA running at 80 MHz. In low power mode, the power consumption can range from 5 µA to 800 µA, depending on which power saving mode we use. We have decided to use the ESP32 as our microcontroller, mainly because it is a well-documented and well-supported microcontroller which has more than enough capability for our project.

Table of Options

MCU	**ATmega328**	**ATxmega64A4U**	**ATxmega128A4U**	**PIC24FJ128GA006**	**ESP-WROOM-32D**
Max Clock Speed	20 MHz	32 MHz	32 MHz	16 MHz	240 MHz
Flash Memory	32 KB	64 KB	128 KB	128 KB	4 MB
RAM	2 KB	4 KB	8 KB	8 KB	520 KB
EEPROM	1 KB	2 KB	2 KB	N/A	N/A
Pin Count	23	44	44	64	34
Bit Size	8-bit	8/16-bit	8/16-bit	16-bit	32-bit
Recommended Operation Voltage	1.8V - 5.5V	1.6V - 3.6V	1.6V - 3.6V	2.5V - 3.6V	3.0V - 3.6V
Low Power Mode Current	0.9 µA @ 3V	1.4 µA @ 3V	1.4 µA @ 3V	27 µA @ 3.3V	5 µA - 150 µA
Active Mode Power Consumpti	5.2 mA @ 8 MHz	8.2 mA @ 32 MHz	9.5 mA @ 32 MHz	32 mA @ 16 MHz & 3.3V	20 mA - 31 mA @ 80 MHz with RF

on					disabled
Availability of Programming Tool	Limited	Limited	Limited	Middle	High
Cost	$2.63	$5.13	$6.18	$4.80	$9.99

3.2.1.2 Collar Microcontroller

An additional microcontroller is required to be mounted on the cat collar, to control the few operations on the collar. It must be capable of communicating to and from the cat door, by using an infrared LED and detector. It just has to receive the code from the door, and then flash the LED to communicate that code back to the door. Since it will be mounted on the collar, we want to minimize the size and weight it takes up, so we want a microcontroller that is just able to handle these simple requirements, while being as small and having as little power consumption as possible.

Microchip ATtiny85

The ATtiny85 is our first choice for the collar microcontroller, being that it has a small pin count at 8 pins with 6 GPIO pins. It features an 8 KB flash memory, 512 B EEPROM, 512 B SRAM, two timers, one 4-channel 10-bit A/D converter, and operates on 8-bits. This chip has more than enough to support the few peripherals we need it to, and the specs are more than enough to complete all of the processes we need this microcontroller to do. The drawback of this chip is that since it has higher specs than some other microcontrollers on this list, it may draw more power than the other chips. Despite this drawback we have chosen to use this microcontroller for our project, since the extra specs gives us more flexibility in how we use it, and the extra power consumption is not that large.

Microchip ATtiny212

The ATtiny212 is another microcontroller by Microchip, and it uses an 8-bit AVR processor. It can run up to 16 MHz, though for our application we do not need it to run anywhere near that fast. This microcontroller can run at 32.768 kHz on an ultra-low power oscillator, which we would use to consume as little power as possible. It is equipped with 2 KB of flash memory, 128 B of SRAM, and 64 B of EEPROM. It has 8 pins, and a 6-channel, 10 bit A/D converter. This microcontroller has very small memory sizes, but this is okay given that the functionality we require it to have is very limited. Given its low power consumption and size, this microcontroller is a good option to consider.

Microchip ATtiny402

The ATtiny402 is yet another microcontroller by Microchip, and features slightly better specs than the ATtiny212. It uses an 8-bit AVR processor, able to run at speeds of up to 20 MHz. It has 4 KB of flash memory, 256 B of SRAM, and 128 B of EEPROM. This microcontroller also has an 8-pin package like the ATtiny212, and has a 12-channel 10-bit A/D converter. This microcontroller like the ATtiny212 can also be run at 32.768 kHz on an ultra-low power oscillator, which will be very useful for saving power. Considering that this microcontroller is essentially an upgraded ATtiny212, we may consider using the ATtiny402 if the ATtiny212 is not enough to meet our needs.

Texas Instruments MSP430G2230-EP

The MSP430G2230 is an ultra-low power microcontroller by Texas Instruments, using a 16-bit RISC processor. Its max clock speed is 16 MHz, and it has 2 KB of flash memory, and 128 B of RAM. This microcontroller is also equipped with a 4 channel, 10-bit SAR A/D converter and has 4 GPIO pins. The pin count of this microcontroller is smaller than the other microcontrollers in this list, and the cost is greater than the ATtiny212 and ATtiny402 which have similar specs, but the MSP430G2230-EP has advanced features that make up for this. Firstly, this microcontroller has multiple clocks including the master clock, a 32 kHz crystal, and a very-low-power low-frequency oscillator. It also has four low power modes, which the other microcontrollers lack, which allows it to consume much less power when not in use than the others in this list.

MCU	**ATtiny85**	**ATtiny212**	**ATtiny402**	**MSP430G2230-EP**
Max Clock Speed	20 MHz	16 MHz	20 MHz	16 MHz
Flash Memory	8 KB	2 KB	4 KB	2 KB
RAM	512 B	128 B	256 B	128 B
EEPROM	512 B	64 B	128 B	N/A
Pin Count	8	8	8	4
Bit Size	8-bit	8-bit	8-bit	16-bit
Recommende				

d Operation Voltage	2.7V - 5.5V	2.7V - 5.5V	1.8V - 5.5V	2.2V - 3.6V
Idle Current	0.1 µA (power down mode, no clocks running)	4 µA @ 32.768 kHz & 3V	4 µA @ 32.768 kHz	0.5 µA in LPM3 (only ACLK clock enabled) & 2.2V
Active Mode Power Consumption	300 µA @ 1 MHz, 1.8 V	11 µA @ 32.768 kHz & 3V	10 µA @ 32.768 kHz & 3V	300 µA @ 1 MHz & 3V
Cost	$1.66	$0.55	$0.54	$1.95

3.2.3 LEDs

Light Source	**Power Consumption**	**Weight**	**Cost**	**Example**
IR LED	70 mW	9 grams	< $1	Gikfun 5mm 940nm LEDs IR Emitter and Receiver EK844
Laser Diode	100 mW	14 grams	< $1	HiLetgo 10pcs 5V 650nm 5mW Red Dot Laser Head

We chose LEDs instead of other components that can produce more light due to its cost and small size. Although laser diodes are just as small, laser diodes consume more power and are more expensive, especially infrared. LEDs are cheap and can be purchased in a pack, which will help if any LEDs go bad or break; making it easier to maintain the design as well as reduce stress if a replacement is needed. Since LEDs do not require a lot of power to operate, the battery and power supply requirements are not as taxing. This keeps the cost of the design to a minimum while also accomplishing our basic goals of using a cat collar as a key for the cat door.

For the sake of the cat collar, LEDs weigh less than laser diodes and consume less power. This is important because we will need to install multiple sources of light onto the collar just in case the cat has somehow twisted or flipped the collar around. Laser diodes can consume upwards to 100 mW per diode. Laser diodes also weigh upwards of 14 grams compared to the 9 grams of a single IR LED. Also, more photodiodes are necessary to pair with the laser diodes if we want to accomplish the same goal as the IR LED emitter and receivers.

3.2.3.1 IR LEDs

With our Automated Cat Door with LED Collar, the use of IR LEDs for the cat collar to communicate with the cat door is a cheap alternative to RFID chips and a way to implement optics into the design. We initially went with colored LEDs so that a camera can distinguish the different color codes for multiple collars for multiple pets, allowing the owner to be notified which of their pets have returned home. But since we do not have a computer engineering major on our team, we decided to rely on IR LED emitters and receivers that will not bother the animal with bright lights, nor will it allow anyone to tamper with the cat door by shining a laser into our receiver diode at the cat door. This method does not require a camera for the detection portion of the design and will lessen the overall cost. Here we discuss a couple of options for the IR LED emitters and receivers from various suppliers.

Gikfun 5mm 940nm LEDs IR Emitter and Receiver EK844 from Amazon

The Gikfun IR LED is a cheap option available from Amazon. One major advantage of this option is that they come as an emitter and receiver pair. This saves a significant amount towards the cost while also being significantly light in weight. The IR LED works at a peak wavelength of 940 nm, allowing for an unlikely chance of someone tampering with the communication of the collar and cat door. From Amazon, we can purchase a pack of 10-pairs at $0.62 per pair, which is almost 10-50% of the price of some others which we will discuss further. Due to the size and cost restrictions set for the collar, this LED will be a viable option as it weighs in just under half a gram per LED. The battery needed for the collar will be limited to its size and weight as well. Along with its lightweight, this LED only requires a forward voltage of 1.4 V while consuming a maximum of 70 mW. This allows us to consider small button batteries for the collar. Most bulb shaped LEDs are similar in dimensions, with the bulb measuring at 8.6 mm x 5 mm. With the terminals, the Gikfun IR LEDs measure a total of 53.3 mm x 5 mm. The emitter and receiver pair allows the collar to communicate to the cat door at a maximum range of 8 m, but further testing has proved that adding a lens to focus the light to the receiver will benefit our system since the LED’s light transmitting and receiving half-angle is as wide as 40 degrees. With that wide of a transmitting angle, a lot of the light is diffused; thus, a lens to collect the light in between the emitter and receiver is necessary to ensure communication, as mentioned before.

LED940E – 940 nm Epoxy-Encased LED from Thorlabs

Optical components from more commonly known suppliers, such as Thorlabs, provide LEDs that are almost ten times more expensive than ones found on Amazon. Thorlabs offers more variety in terms of specific wavelengths the consumers, us, are looking for in our design. The LED940E provides the same peak wavelength as the one found on Amazon at 940 nm but cost $2.73 per emitter. The bigger issue is that only an emitter LED is provided, rather than an emitter and receiver pair. Thus, purchasing additional components, such as a photodiode or phototransistor, will be necessary to pair with the IR LED. The advantages and disadvantages of a photodiode is discussed later and will bring the total close to $20 per emitter and receiver pair. Since the LED will be used on the collar, power consumption and weight are the next biggest factors. Like the Gikfun IR LED from Amazon, the forward voltage is about the same at 1.45 V. Meanwhile, the power consumption of the IR LED from Thorlabs consumes at maximum 140 mW of power, double the power consumption of the Amazon IR LED. According to Thorlabs, the weight of each LED is about 2.72 g, which is a little over six times heavier than the Amazon counterpart. We will have to purchase one to confirm these numbers since LEDs should not be so different in size and weight, but the weight difference can be due to the epoxy encasing the LED. On the other hand, the LED940E from Thorlabs provides a better transmitting half-angle, allowing us to direct more light to the photodiode. However, this will give us other problems since the LED940E will require us to point the LED directly towards the photodiode rather than relying on an LED's diffused light. To compensate for that problem, we will need a lens in front of the photodiode to collect the incoming light from the IR LED and require us to install more LEDs around the collar since the light will be diffused a lot less than the Gikfun IR LED. As mentioned earlier, the dimensions of LEDs do not differ much or at all. The bulb size is the same as the Gikfun IR LED at 8.6 mm x 5 mm. Including the terminal pins, the full dimensions of the LED940E is 35 mm x 5 mm. This will not change the overall installation of the LEDs onto the collar since the terminals will be soldered into the cat collar design; thus, the bulb size is all that matters for our IR LEDs.

Super-bright 5mm IR LED – 940 nm from Adafruit

Like the LED940E from Thorlabs, the Super-bright from Adafruit is only the emitter LED rather than the emitter and receiver pair that Gikfun from Amazon offers. Like the others previously mentioned, this IR LED emits at a peak wavelength of 940 nm. It is only about double the price of the Gikfun emitter LED at $0.75 per emitter but goes down in price the more we buy. For our design, we would need about 10 IR LEDs, so then we'd be buying the IR LEDs at $0.68 per emitter. As mentioned, we would require buying a receiver that will pair with the

Super-bright IR LEDs and will increase the price of each pair to about $2.44 per emitter and receiver pair. In comparison to the LED940E and photodiode pair from Thorlabs, the Super-bright IR LED and receiver pair is about 10% of the price but almost 400% of the price of the Gikfun IR LED emitter and receiver pair. Like the previous models mentioned above, the forward voltage is 1.4 V, but the power consumption is slightly higher than the previous models with a maximum power consumption of 150 mW. This is more than double the power consumption of the Gikfun IR LEDs which can be an issue when installing more than four for the cat collar. Unfortunately, the weight of a Super-bright IR LEDs was not found on the datasheet nor on Adafruit, but we can assume it is in the range of the other two IR LEDs from Amazon and Thorlabs. Like the LED940E from Thorlabs, the transmitting half-angle is 10 degrees; thus, would require a lens to collect the incident light onto the receiver that will be placed on the cat door. As mentioned before, this will aid in the communication of the IR LED emitter and receiver. Putting multiple LEDs on the cat collar will help to mitigate this problem, but the small transmitting angle would prevent the receiver from collecting the incident light from the emitter unless the emitter was pointed directly at it. The bulb size is the same as the previous two at 8.6 mm x 5 mm, and the total dimension with the terminal pins is the same as the LED940E at 35 mm x 5 mm. But the bulb size is all we are worried about since they will be soldered for the cat collar.

IR LED Emitter Design Options

IR LEDs (Emitter)			
	Amazon **Gikfun 5mm 940nm LEDs IR Emitter and Receiver EK844**	**Thorlabs** **LED940E – 940 nm Epoxy-Encased LED**	**Adafruit** **Super-bright 5mm IR LED – 940nm**
Cost (per)	**$0.31 per emit.**	**$2.73 per emit.**	**1-9 $0.75** **10-99 $0.68** **per emit.**
Power Consumption	**Max 70 mW**	**Max 140 mW**	**Max 150 mW**
Forward Voltage	**1.4 V**	**1.45 V**	**1.4 V**
Transmitting Angle	**40 degrees**	**10 degrees**	**10 degrees**

(Half-Angle)			
Transmitting/Receiving Distance	7-8 m	-	-
Item Weight	8.96 g	13.61 g	-
Dimensions	53.3 mm L x 5 mm W 5mm diameter	35 mm L x 5 mm W 5 mm diameter	35 mm L x 5 mm W 5 mm diameter

3.2.4 Photodiodes and Photodetectors

Photodiodes were considered because they are relatively cheap and do not require a large output light to operate. Similar to LEDs, photodiodes can be purchased in packs and are easy to replace if they were to go bad or break. For that reason, phototransistors are not an option. Photoresistors are a viable option in place of photodiodes, but further testing must be done to see which of the two are a better option. Although, using either photoresistors or photodiodes should be capable of accomplishing our goal of having a confirmation step across the cat door.

FDS100 – Si Photodiode, 350 – 1100 nm from Thorlabs

Since the LED940E from Thorlabs is just the emitter diode, we need to purchase a receiver or photodiode to pair with it to accomplish our design. For this, we have the FDS100 Si Photodiode from Thorlabs. This would be positioned at the cat door to communicate with the IR LED. This photodiode has a short rise time of 10 ns and can collect light in the range of 350 – 1100 nm with a peak wavelength at 980 nm. Of course, we will require a filter to only allow light at 940 nm before the photodiode so that stray and ambient light will not interfere with our design, which will set off false positives, thus, randomly opening the cat door. If this route is taken, the FDS100 photodiode will cost us $16.40 per photodiode. As mentioned before, the total cost of the pair from Thorlabs will come out to be $19.13 for the IR LED and photodiode pair. Since the photodiode will be connected to the power supply of the cat door, the power consumption is not too much of an issue. Fortunately, the photodiode has a moderate power consumption at maximum 125 mW while the maximum reverse voltage of the photodiode is 25 V, giving us a high tolerance to avoid burning out the photodiode. Since the photodiode will be installed on the cat door, the weight of the photodiode is another factor we are not worried about. But the photodiode is very light, weighing in at only 4.54 g. A factor that we do have to consider is the size of the photodiode. From the top view, the photodiode has a maximum diameter of 10.2 mm at the notch with an active area of 9.36 mm^2. This is important since we must consider installing a lens in front of the photodiode and making an indentation for the photodiode to protect it rain. Due to the price of an individual photodiode, we are less inclined to go with this component and will consider changing the photodiodes at the cat door as well.

TSOP38238 IR Receiver Sensor from Adafruit

Like our emitter and photodiode pair from Thorlabs, we need to buy a receiver to go along with our Super-bright IR LED emitter from Adafruit since they do not come in pairs. The TSOP38238 IR receiver sensor only collects light at 940 nm, so a filter is not needed unlike the photodiode. Alone, this IR receiver sensor will cost $1.95 each unless we buy more, bringing the price down to $1.76 each. Paired with the Super-bright IR LED emitter, we will be spending $2.44 per emitter and receiver pair when purchasing 10 or more of each emitter and receiver from Adafruit. According to the datasheet, the receiver sensor has a very low power consumption of a maximum 10 mW. On the other hand, the forward voltage of the TSOP38238 receiver sensor is 2.5 V. Although not much, this will play a factor when putting together a power supply that will be sufficient for our cat door. This IR receiver has a receiving half-angle of 30 degrees, giving us a bigger margin for the light coming from the IR LED emitter. We will still have a lens to collect the light from the emitter to ensure enough light is incident onto the receiver sensor. One huge improvement to this IR receiver in comparison to the Gikfun receiver is that the advertised receiving distance is up to 45 m. Although we don’t need that huge of a range, it should guarantee the distance between the IR emitter and receiver should not be an issue especially after including a lens to collect the light. Since the IR receiver will be installed at the cat door, weight is not a factor in our design but it’s good to know that this receiver sensor is very light, weighing in at only 0.43 g at a size of 6.95 mm x 5 mm for the sensor itself and 30.5 mm x 5 mm when including the terminal pins.

Receiver Design Options

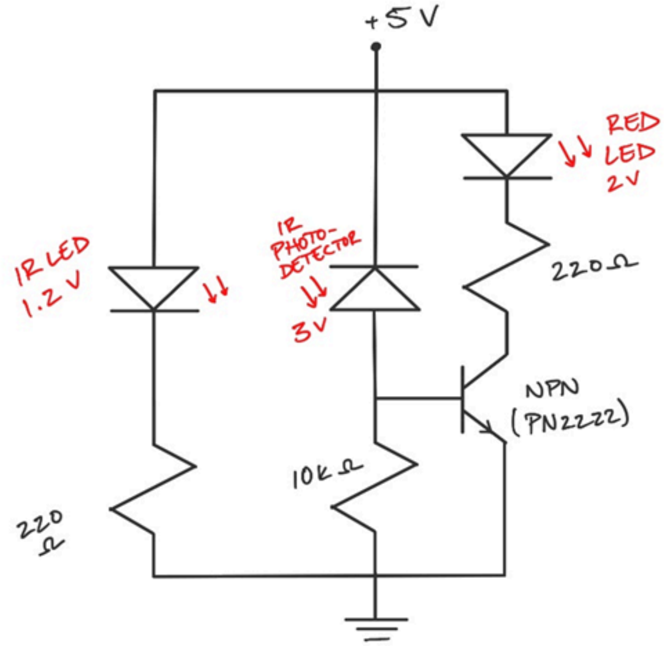
Receiver			
	Amazon **Gikfun 5mm 940nm Photodetector EK844**	**Thorlabs** **FDS100 – Si Photodiode, 10 ns Rise Time, 350 – 1100 nm**	**Adafruit** **IR Photodetector Sensor – TSOP38238**
Wavelength	940 nm	350 – 1100 nm 980 nm peak	940 nm
Cost (per)	$0.31 per receiv.	$16.40 per	1-9 $1.95 10-49 $1.76 per receiv.
Power Consumption	Max 70 mW	Max 125 mW	10 mW
Forward Voltage	1.4 V	(Max Reverse) 25 V	2.5 V
Receiving Angle (Half-Angle)	40 degrees	-	30 degrees
Transmitting/Receiving Distance	7-8 m	-	45 m
Item Weight	8.96 g	4.54 g	0.43 g
Dimensions	53.3 mm L x 5 mm W 5mm diameter	41.6 mm L x 8.3 mm W Active Area 9.36 mm^2	30.5 mm L x 5 mm W 5mm thick

3.2.5 Motion Sensor

Sensor	Detection Method	Distance	Cost	Example
Infrared	Light Waves	< 8 m	< $1	Gikfun 5mm 940nm LEDs IR Emitter and Receiver EK8443
LiDar	Light Waves	< 8 m	$25	MakerFocus LiDar Range Finder Sensor
Ultrasonic	Ultrasonic Waves	< 5 m	< $2	Smraza Ultrasonic Module HC-SR04
Radar	Radio Waves	< 7 m	$3.50	Radar Sensor RCWL-9196

Similar to the cat collar and cat door, we decided to use infrared for our choice of motion sensor. As shown above there were quite a few options, including LiDar, ultrasonic, and radar. For our design, infrared LEDs will be the cheapest option because we are capable of buying a pack of 20 emitter and receiver pairs for about 62 cents each pair. There is also an advantage in terms of power consumption, as IR LEDs take less than 70 mW to power. Weight and size is a huge factor for our design, as each LED weighs less than 9 grams and about two inches in length; thus, there will be no issue when installing onto the cat door. Infrared motion sensors are commonly used in automated lights and doors, so there are other products and designs we can reference with our design. LiDar options are available to satisfy the optics portion of the design, but a single LiDar kit costs at least $25; thus, replacements if it were to break will quickly add to the overall cost of the design. LiDar kits also consume upwards to 350 mW of power. Although not a lot, keeping our power consumption at a minimum is a necessity.

For the IR motion sensor circuit, we require a 5 V source. The idea of the IR motion sensor is to have the light from the IR LED to bounce off an object that the photodetector will pick up and then light up a red LED. Since the photodetector is connected to the base terminal of the NPN transistor of our circuit and has received some light, the current through the red LED at the collector terminal is allowed to flow through the transistor to the emitter terminal. Below is a drawing of our IR motion sensor schematic.



Simple IR motion sensor circuit schematic.

Testing of the detection range of our motion sensor will be discussed in a later section of the document.

3.2.6 Focusing Lens

For our design the original idea was to have a Fresnel lens on top of the IR LED on the cat collar. But through some testing and consideration in weight, we are leaning towards placing a lens directly in front of the IR receiver to focus the incident light from the IR LED onto the receiver. This will allow us to save a bit of weight on the cat collar while also saving us a lot of money only having to purchase one lens for the receiver rather than a lens per emitter. There are a couple of options when it comes to cheap lenses, such as: acrylic or plastic lens. Here, we discuss the various options we can pick for a focusing lens.

Fresnel Lens

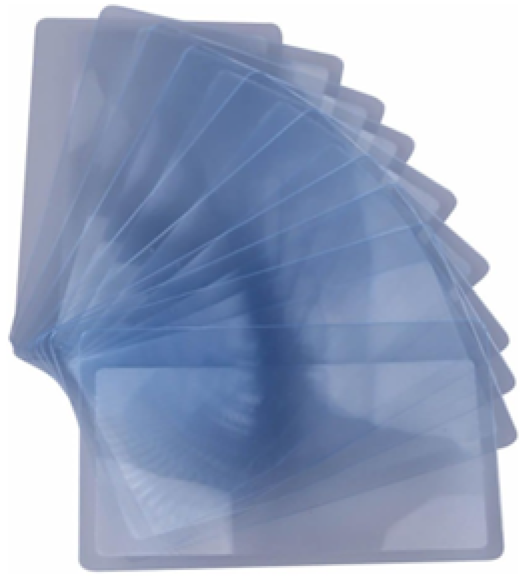
For the cat collar, a fresnel lens was chosen due to its illumination capabilities. Similar to lighthouses, the fresnel lens will help illuminate the IR LEDs on the collar to make it easier for the receiver on the cat door to detect. If the point source, in this case the IR LED, is at the focal point of the fresnel lens then we are capable of collimating the light. We are not worried about doing that because we want the light to diffuse so that our cone of light will stretch wider to take in account the collar rotating around; thus, more than one IR LED and fresnel lens will be attached around the cat collar.

Also, fresnel lenses can be made from plastic rather than glass. This will aid in our weight restriction for the cat collar as well as the cost of buying multiple fresnel lenses. With further testing, a fresnel lens can also be used in place of the focusing lenses at the cat door. Just like the cat collar, this will greatly reduce the cost for the design, maintaining the goal of designing a product that will compete with microchip cat doors.

Although finding a perfect circular fresnel lens can be costly or require ordering from online shops from China, which can require 30 days to ship, small credit card sized fresnel magnifying cards can be cut to the desired shape and size needed to fit onto the cat collar. For example, FUCAS' credit card sized fresnel magnifiers can be purchased in a lot of 12 for about $0.40 each. This will give us plenty of leeway to test multiple sizes to test fit onto the cat collar. In addition to having enough supply to be able to fit all around the collar if necessary.

FUCAS Credit Card Sized 300% Magnifying Lenses from Amazon

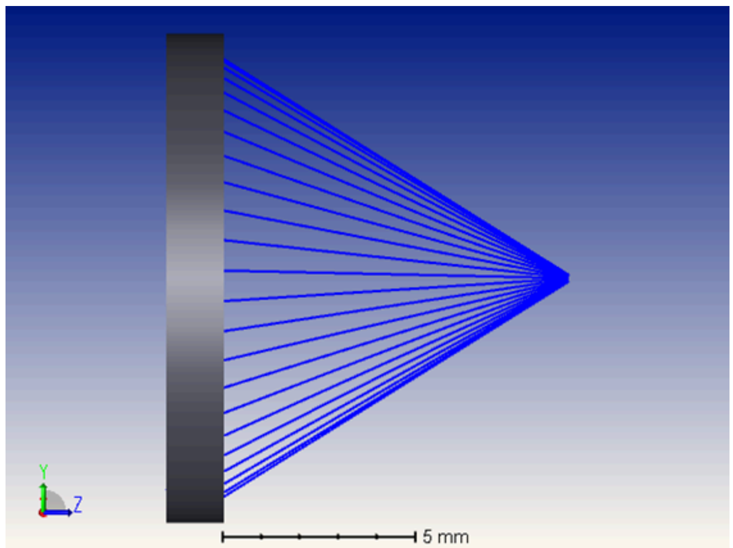
For the cheapest option, we originally went with credit card sized 300% magnifying cards from Amazon. For $4.80 they are sold in a lot of 12; thus, costing $0.40 each card. The dimensions of the cards are 3.25" x 2"; thus, living up to the credit card sized name. If they did work on our design, it would have saved us a ton of money and would only require cutting to the shape needed to fit over the IR LEDs on the cat collar. But through some testing with these at certain distances in between the IR LED emitter and receiver, we noticed the inconsistencies of using these in front of the IR LED emitter. We found that only at certain spots from the center of the Fresnel lens would the light diffract perfectly towards the IR LED receiver. This is not ideal as it would mean the cat collar would have to be positioned almost perfectly at the receiver on the cat door for our idea to work. We hoped that putting multiple IR LED emitters on the cat collar would compensate for this discrepancy. We decided to test this using an LED driver to act as the cat collar approaching the cat door where the receiver should see the light from the emitters. Even if the Fresnel magnifying cards were placed directly in front of the receiver on the cat door, the IR LED emitter would still need to be pointed directly at the receiver for the two to pair. This is because the FUCAS magnifying cards have a focal length that is not ideal for our design. Through testing, we find that the magnifying cards have a focal length of ~21 cm; thus, directing the incident light from the emitters was not improved. Most doors are at most 5 cm thick. And since our cat door is limited to the thickness of a door, focusing the light using the FUCAS magnifying cards would not make a difference compared to no lens at all. Although these cards are extremely helpful in focusing the rays from the sun to start a fire, that has nothing to do with our design.



FUCAS Credit Card Sized 300% Magnifying Lenses from Amazon.

FRP0510 Fresnel Lens from Thorlabs

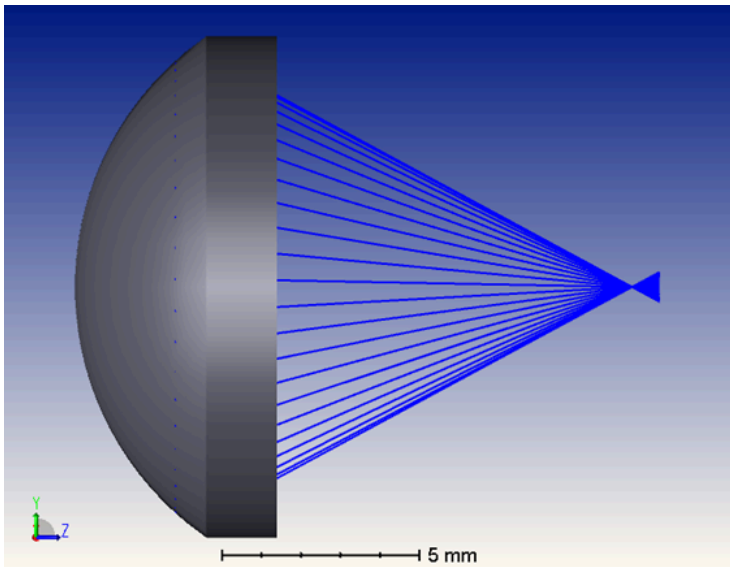
The Fresnel lens idea is not a total loss though. There are several Fresnel lenses on the market that will help us focus the light onto the receiver diode. Thorlabs sells an acrylic Fresnel lens with a focal length that is ideal for our design. The FRP0510 is a 0.5” diameter Fresnel lens with a focal length of 10 mm. With this focal length, we can fit the lens and the receiver diode well within the dimensions of the cat door. Also, the diameter of the Fresnel lens provides us with enough area to collect as much light as possible since its diameter is more than double the diameter of the bulb of the IR LED receiver. Thorlabs provides other Fresnel lenses with diameters up to 2” but their focal lengths increase up to 51 mm, which is about the same length as the thickness of some peoples’ front door; thus, will be too much for our dimension constraints. As mentioned before, the idea of placing the lens directly on top of the IR LED emitter has been changed to placing the lens directly in front of the IR LED receiver; thus, only one focusing lens is needed for the emitter and receiver communication rather than the four considered before. With the FRP0510, we can place the lens and the receiver diode within the thickness of the cat door without having to compensate for the position such as protruding the lens. The FRP0510 Fresnel lens from Thorlabs costs $20.68 per lens and weighs about 18 g. Since we are changing the location of the lens to be at the cat door, the weight of the lens does not factor into the weight of the cat collar anymore. This was an important engineering specification that we must consider avoiding any discomfort for the cat while wearing the collar. Since this lens is made from acrylic, the lens is very durable compared to glass. This is very assuring since the lens will be outside and will have to withstand the weather and unexpected flying objects that can damage a glass lens, such as a twig on a windy day can scratch a glass lens if it were to impact it. Although not an immediate concern, but one we will consider when moving forward with choosing a lens.



Zemax simulation of FRP0510 Fresnel lens from Thorlabs (ray from left to right).

LA1540 Plano-Convex Lens from Thorlabs

Since our goal is to focus the incident light onto the receiver diode, we can always resort to a plano-convex lens. These lenses are nothing special but get the job done when it comes to focusing collimated light to a point. One we are considering is the LA1540 plano-convex lens from Thorlabs. This lens cost $25.18 each while only weighing 22.68 g since they are made from N-BK7 glass. With a 0.5” diameter and a focal length of 15 mm, this lens will cover more than twice the length of the diameter of the bulb on the receiver diode while its focus point is within the thickness of the cat door. A small issue comes with the material of this lens. It is made from glass which can add a durability issue since it will be installed facing outdoors. As mentioned earlier, a windy day outside can cause a twig to fly and hit the lens; thus, scratching or even worse cracking the lens. When the initial idea was to use plastic Fresnel lenses, this was not an issue we had in mind. This lens will less likely be chosen for the fact that it is made from glass, and we want a product that will survive all weather conditions. On the other hand, the receiver diodes used in the cat door to determine when the cat has passed through the door will also need a lens to focus the incident light from the IR LED emitters shining across the cat door to ensure there is enough light for the receiver diodes. Since those diodes will not be on the outermost portion of our design, the lens will not be as susceptible to the outside weather as the lens facing the outside. But whenever the cat door opens, anything can happen so the material of that lens will also be considered when choosing our lenses.



Zemax Simulation of LA1540 plano-convex lens from Thorlabs (ray from left to right).

Focusing Lens Options

Focusing Lens			
	Amazon FUCAS Credit Card Size 300% Magnifying Lenses	Thorlabs FRP0510 Fresnel Lens	Thorlabs LA1540 Plano-Convex Lens
Cost	$0.40 each	$20.68 + 13.87 shipping	$25.18 + 13.87 shipping
Focal Length	~210 mm	10 mm	15 mm
Material	Plastic	Acrylic	N-BK7 glass
Dimensions	3.25” x 2” (Can be cut)	½” Diameter	½” Diameter

3.2.7 Door Battery

The door will contain the majority of the electronic devices used in our project, resulting in the largest power usage. The door will consistently consume a low amount of power while offline, but when active, it will consume a much larger quantity. Due to our decision to charge the battery with solar power, there will be long periods of time where it will not receive charge. The battery we choose must be able to survive these long periods, while remaining safe and cost effective. In this section we will discuss the pros and cons of four battery chemistries and decide which is best for our project.

Li ion

Lithium ion batteries are the most energy dense of the chemistries we considered and for that reason they are very popular. They also require little to no maintenance and will last for a long time. These batteries also have the highest storage to cost ratio of all of the batteries we researched. However, despite all of the benefits of this chemistry, lithium ion batteries also come with the greatest safety risk. If these batteries are not properly charged or discharged, or if they are physically damaged, there is a chance that they will explode. The fire created by this explosion is extremely hot and could cause immense damage to the surrounding area. For this reason, several safety measures would need to be made, increasing the overall effective price of the battery. Although there is this high risk associated with this chemistry, due to their immense popularity, there are several readily available options that would allow us to use and charge them efficiently. The issue of potential physical damage to the battery can also be remedied fairly easily through the use of a sturdy encasement. Since the battery will remain stationary on the battery, there is a much smaller risk of the battery being placed in a harmful situation. For these reasons, we believe the Li ion chemistry to be the best option.

LiFePO4

Lithium Iron Phosphate batteries are another option that we considered. They have a fairly high energy density, albeit lower than lithium ion batteries. LiFePO4 batteries also have a negligible maintenance requirement, and have the second highest storage to cost ratio. Although they fall decently below Li ion batteries in these aspects, LiFePO4 batteries stand much higher in the aspect of safety. Just like lithium ion batteries, they are weak to being overcharged. However, when this happens, they do not explode and will instead expand and release fumes. Similar protective measures will still need to be made to ensure this doesn't happen, but in the case that it does, it is much safer than Li ion batteries.

NiMH

Nickel Metal Hydride is another battery chemistry that we considered using for our project. NiMH batteries are much different from the lithium batteries as their cell voltages are much lower, but their rated currents are much higher proportionally. This means that in order to achieve the desired voltage for our project, we would need to purchase multiple and use them in series. Unlike the lithium batteries, NiMH carry none of the safety risks, while having only slightly lower energy density. The main downside to these batteries is their need for maintenance. These batteries require an occasional full discharge or crystals will begin to form within them, severely decreasing their storage. Although there is no health risk to improperly charging these batteries, they are still very weak to overcharge and are difficult to properly charge. For this reason a specialized NiMH charger would be needed to use it, adding to the effective cost.

NiCd

Nickel Cadmium batteries are the last chemistry we considered for the door. NiCd batteries are one of the oldest rechargeable chemistries yet they still provide fairly useful qualities. NiCd batteries are good for consistent heavy use and can be charged very quickly with few repercussions. On the other hand, NiCd batteries require fairly consistent maintenance or their capacity will suffer. On top of this, they also have the lowest energy density of the batteries discussed and individual cells only output 1.2V as well. Due to our project requiring low consistent power with short periods of higher input, the benefits of NiCd are not very necessary.

Battery Chemistry	Lithium Ion	LiFePO4	NiMH	NiCd
Voltage	3.7V	3.2V	1.2V	1.2V
Amp-Hours	3400mAH	1500mAH	900mAH	1000mAH
Length	65mm	65mm	44.5mm	50mm
Diameter	18mm	18mm	10.5mm	14.2mm
Price	$7.95	$8.99	$2.79	$3.49
Maintenance required	No	No	Yes	Yes
Brand	MORNGC	Power Portable	Power Portable	Power Portable

3.2.8 Collar Battery

Unlike the door, the collar will have few built in electronics. Similarly to the door however, these electronics will be offline for the majority of the time, then all turn on when the collar nears the door. The energy required for this short period of time will be relatively large and will thus require a battery that can hold a fairly large amount of charge and can sustain a high output. However, due to this device being on a collar, the size and weight must also be minimized. It would also be ideal to have a low safety risk for the battery as it will be very close to a pet the majority of the time.

Button Batteries

The first batteries we looked at for this purpose were coin batteries. Of these, we specifically researched the LIR2032 and the VL3032 batteries. The largest benefit of these is their very small size and weight. The LIR2032 is a small 3 gram battery that can store 40mAh at a voltage of 3.6V, which is fairly low. However, this is not necessarily an issue as the collar uses a fairly low amount of power and the rate only increases for short periods of time. Another benefit of the

LIR2032 is that it can withstand a fairly high discharge current, and would thus be able to reliably power the LEDs in the collar. On the other hand, these batteries come with a massive flaw which takes the shape of the glaring safety concerns. As mentioned in the previous section, if a lithium ion battery is improperly charged, discharged, or damaged, there is a high likelihood that it will explode or catch fire. This fact combined with the unpredictable nature of cats creates a risk that we are not willing to take.

VL3032 batteries on the other hand, have a chemistry of vanadium pentoxide and lithium, making them far safer than the standard lithium ion batteries. Alongside this they are only slightly larger at 6 grams, while holding over double the charge at only slightly lower voltage. Unfortunately, these batteries have a fatal flaw, being that they cannot support a consistent current much higher than 0.2 mA. This is not nearly enough to support the roughly 30 mA that the collar will require while active.

LiFePO4 10440

The LiFePO4 10440 battery is a lithium iron phosphate battery that is roughly the size of a AAA battery. This battery has a nominal voltage of 3.2V and storage of 300 mAh, which is far higher than either of the other two so far discussed. Due to its size and chemistry, it is able to maintain the higher discharge current much easier than the other two discussed as well. It also does not pose the same health risk that the lithium ion battery does. Alongside this, the common size that it has means that many standard battery casings will fit it well. The one major downside of this battery is its weight. This battery weighs roughly 17 grams. While this weight is not exorbitantly high, it may cause the collar to become slightly too heavy and uncomfortable for the cat wearing it. This can be somewhat remedied by keeping the other components on the lighter side.

2/3 AAA NiMH

The 2/3 AAA NiMH battery is the next battery we looked at. This battery serves as the in between of the two previous sections. This battery is on the lighter end at 7 grams, and can hold 320 mAh at 1.2V. This puts the storage capacity at a similar spot as the VL3032 batteries. However, what sets this battery apart is that it can support the higher discharge current that would be required for the LEDs to function properly in the system. These batteries also do not carry the same health risks as the lithium ion battery. The largest concern for these batteries is the aforementioned voltage level, which may not be enough to activate the LEDs due to their 1.4V threshold. This could be remedied by using multiple in series, but this would add to the weight of the battery.

LiPo

The final battery we considered was the Lithium Polymer battery. This is a battery commonly used in consumer electronics as it is a very lightweight battery with high charge density. These batteries can also sustain a fairly large discharge current. The main downsides to this battery come with the safety and total lifespan. Similar to Lithium Ion batteries, LiPo batteries must be charged and discharged with care or they can be damaged or catch fire. This problem is made easier to handle as most LiPo batteries come with several built in protections. These protections include over-discharge, over-charge, over-current, short circuit, and over-temperature protections. LiPo batteries also come with a risk of catching fire if they are punctured, but this can be solved by placing them in a sturdy container. The issue of their relatively short lifespan is not a large problem for our case as these batteries can typically last 150-250 full recharges before they begin to fall in capacity. Although this seems low, due to the consistently low power draw of the collar combined with the high capacity of the battery, these batteries would still likely last years before any noticeable capacity drops. On the other hand, these batteries have several positives that we believe put them ahead of the other chemistries we've researched. The main benefits come from the capacity and weight of the battery. LiPo batteries have a very high charge density, allowing them to have a large capacity with a fairly small size. The battery we are considering with this chemistry has a mass of 5g and a capacity of 250mAh at a voltage of 3.7V. This puts this battery's capacity at a comparable level to the LiFePO4 while having 2/3s the mass. This battery also has a rated discharge of 500mAh, which puts it far ahead of the coin batteries we considered. This makes the LiPo battery an ideal middle ground for the main specs we are looking for. On top of all of the already stated benefits, there is one more that comes with the use of this battery in conjunction with the Lithium ion battery for the door battery. Due to the max charge voltage and ideal charge pattern for LiPo and Li ion being the same, we can use the same charging circuits to charge both the door battery and the collar battery. For all these reasons we believe the LiPo battery is the best choice for our project

Battery	**LIR2032**	**VL3032**	**LiFePO4 10440**	**⅔ AAA NiMH**	**LP502030**
Brand	PK Cell	Panasonic	Power Portable	Power Portable	EEMB
Weight (g)	3.1	6.2	17	7	5
Length x Diameter (mm)	3.2 x 20	3.2 x 30	44 x 10	28 x 10	20.5 x 32 x 5.3(WxLxH)
Voltage	3.6V	3V	3.2V	1.2V	3.7V
Capacity (mAh)	40	100	300	320	250

3.2.9 Motor Selection

We chose to use a brushed DC motor as the motor to lift our door, so now we need to find a motor that meets our specifications. First we need to calculate how much power our motor needs to output in order to lift the door. We are using a 9” x 9” x ¼” door, so the total volume of the door is 331.84 cm3. Since the density of acrylic is 1.19 g/cm3, the mass of our door is 394.89 g. Converted to weight in unit newtons, the door weighs 3.873 N, so we need 3.873 N of force just to hold the door in steady state. We also have to factor in acceleration to reach our desired velocity, which we can calculate using the expression a = v/t. Since we want to lift the door in 1 second, which is 9 inches in one second, converted to metric the velocity is v = 0.2286 m/s and t is 1 second. With this the acceleration comes out to 0.2286 m/s2. Using Newton’s law F = ma, we find that the force needed for this acceleration is 0.0901 N, so the total force needed is 3.9633 N.

Since we are using a pulley to pull the door up, the required torque is calculated by multiplying the force by the radius of the pulley. Assuming we use a pulley with a radius of 5 cm, the required torque of the motor is 0.198 Nm. Including loss due to friction and having some margin, our motor should be able to supply 0.4 Nm of torque. We also have to consider the required power of the motor, which is the force multiplied by velocity. The required power then comes out to 0.906 W. With friction and some margin, our motor should be able to output at least 1.5 W.

BRINGSMART 12V DC Worm Gear Motor

This motor is one of the first we found, and has decent specs. It has enough torque to support our application at 0.441 Nm as well as enough power at 3 W. The BRINGSMART motor is a worm gear design, with fully metal gears which provides added durability, strength, and reliability. The shaft is made from high hardness steel, and is a D shaped output shaft. This motor is also available in multiple different RPMs, which allows us greater choice.

CHANCS 12V DC Gear Motor

The CHANCS motor is another motor that we found, which operates at 12 V. It has the highest torque on this list at 0.588 Nm, as well as an RPM of 60. The power output of this motor is lower than the others on this list at 2 W, but this is still enough for our application. This motor uses metal-plastic hybrid gears, which reduces the noise produced by the motor, and reduces the weight, and are cheaper than metal gears. However these gears are weaker than metal gears, are less reliable, and are worse at sustaining higher temperatures. Specs such as the speed, voltage, and shaft length can be customized, which allows us to fine tune the motor to our specifications.

STEPPERONLINE 12V DC Gear Motor

This motor from STEPPERONLINE is another choice we found. It is in the middle of the list in terms of RPM, at 50 RPM, but has the lowest torque at 0.392 Nm. This motor is different from the previous two entries as it uses a spur gearbox instead of a worm gearbox. This means that this motor is better for lower reduction ratios, and operating at higher speeds, while worm gearboxes are better for higher reduction ratios, as well as high torque capacity. The spur gearbox does provide higher efficiency, but is still less desirable then a worm gearbox for our application, so this motor is not the best choice.

Specifications	BRINGSMART	CHANCS	STEPPERONLINE
Rated Current	0.5 A	0.33 A	0.6 A
Output Power (W)	3 W	2 W	3.6 W
No-Load Current (mA)	60 mA	20 mA	100 mA
Rated Torque (Nm)	0.441 Nm	0.588 Nm	0.392 Nm
RPM	40 RPM	60 RPM	50 RPM
Shaft Diameter (mm)	6 mm	7 mm	6 mm
Shaft Length (mm)	15 mm	15 mm	15.5 mm
Cost	$14.99	$12.90	$7.01 ($15.11 with shipping)

3.2.10 Solar Panel

Due to the low power usage of our project, and the periods of higher power usage being short and fairly spread out, we believe that we can use a relatively lower end solar panel without causing battery life concerns. We believe the ideal level of performance for the panels would be enough for them to fully charge the door's built-in battery within a single day of charge. As this output threshold is fairly low, the matter of price and size will be taken more into consideration.

The first option we considered was a medium sized panel made by YCTechCam. This panel provides the greatest quantity of power at 5W which can easily charge our 12Wh battery in a day.. This option is also the most convenient for our design as it comes with a built-in USB connector that would allow us to directly connect it to a power manager. It also comes with a wall mount that would allow the consumer to place the panel in a higher, more optimal position. Although these specs and attachments allow for the greatest output of the options we considered, this also leaves it with a hefty price of $19.99 for the one panel. As our aim is to keep our project as affordable as possible, we believe that this price point is a deal breaker.

The second option we considered is a small panel manufactured by FellDen. This panel's output is a significant step down from the previous option at 1W at optimal conditions. This output reduction is accompanied by lower convenience as these panels do not come with a built-in connector. This does not cause much of an issue as wires are cheap and can easily be soldered onto the terminals. However, these drops in quality and power are accompanied by a much lower price at only $2.10 per panel. This low price combined with the relatively solid power output means we could easily meet our ideal power specifications through the use of 2 panels in parallel while still keeping cost low.

The final option we researched was a tiny panel manufactured by AOSHIKE. This panel outputs by far the lowest power at only about 150mW. Although these panels are slightly more convenient to use than the previous option due to having the wires already soldered on, several more would need to be used to match the performance. These panels are only slightly cheaper than the previous option as well at $1.60, meaning option 2 has a better price to output ratio. For all of these reasons we have decided to use option 2 for our project.

Solar Panel	Option 1	Option 2	Option 3
Current(mA)	1000	200	30
Dimensions(in)	6.89 x 4.76	4.33 x 2.36	2.08 x 1.18
Connector Type	USB C	None(wire must be soldered on)	Soldered Wire
Brand	YCTechCam	FellDen	AOSHIKE
Price Per Unit	$19.99	$2.10	$1.60

3.2.11 Solar Power Manager

The output of solar panels is very inconsistent, varying second to second as a result of several factors including cloud cover and position of the sun. This fickle output can be very dangerous if applied directly to electronics and batteries which cannot handle a high level of variance for input. To remedy this issue we must use a solar power manager to normalize the output to properly charge our batteries and power our project. For this part, the most important criteria are its compatibility with our current components and overall reliability. All of the solar power managers that we will discuss have on-board MPPT functionality to ensure high efficiency of the solar panel input, and several protections to prevent disastrous failures such as over-charge/over-discharge of the battery.

DFROBOT

The first power manager we researched was the Solar Power Manager 5V by DFROBOT. This controller can accept an input voltage ranging from 4.5V to 6V. This range works perfectly with our solar panels as they normally output around 5V, with slightly higher peaks during direct sunlight. This controller outputs at 5V and a maximum of 1A which works perfectly to sustain the low levels of current that the MCU requires while still having a sizable quantity remaining for more power hungry components such as the motors. This power manager's strongest point is its reliability, with most of its reviews being very positive. At the moment, we believe this to be the best option.

Xicoolee

The next power manager we researched is the Solar Energy Manager manufactured by xicoolee. This power manager has a wider input range than the DFROBOT, accepting 5V through 24V. Although this range seemingly gives us more options for the arrangement of the panels, it also limits the use of a single panel. This is a result of the additional components that we will be using in the charging circuit that cause a slight voltage drop. Due to this drop, the panel will likely not be able to output above 5V to the manager outside of optimal conditions. This issue can be somewhat resolved through the use of multiple panels in series, but this will require extra circuit protections to keep one failing panel from blocking the current flow for the series. This power manager also has the option of outputting 3.3V, which our MCU operates at, on top of the option of outputting 5V. The 5V option is also available at a higher current of 1.5A. The biggest downside in our eyes is the lack of reviews for this product compared to the DFROBOT option. For this reason we believe the previous option slightly edges out this one, but if we discover that we need a higher output through testing, then this will be our next option.

Waveshare

The final option we looked at was the Solar Power Manager Module manufactured by waveshare. This module has a similar input range to the xicoolee option, but with a higher bottomline of 6V. This means that we do not have the option to use only one panel and would have to place at least two in series. This option has the highest potential output of up to 3A at 5V. This alone is the main draw of this option, as the price is significantly higher than the other two options and has no visible reviews. For these reasons this is our last choice.

Brand	DFROBOT	xicoolee	waveshare
Accepted Input(V)	4.5 - 6	5 - 24	6 - 24
Output Voltage(V)	5	5/3.3	5
Output Current(A)	1	1.5(5V)/1(3.3V)	3
Price	$13.90	$12.95	$19.99

3.2.12 Wall Adapter

As the wall adapter will be used as a secondary or backup power source, its performance does not need to be spectacular. For this reason we will mostly be focusing on the compatibility and price of the individual options. In order to be compatible with the Solar Power Manager we chose, all of the adapters we looked at were 5V.

Arkare

The first adapter we looked at is manufactured by Arkare and has a maximum current of 2A. This adapter is the most versatile as it comes with 8 different adapter tips. While this gives us more options, the dc terminal tip is the only relevant replacement as it can be used to easily integrate the adapter into the charging circuit.

EIKS

The next adapter we considered was one manufactured by EIKS. This option has the lowest maximum current at only 1A. This option is also the least flexible, having only variations of the barrel connector to choose from. These factors combined with it having the highest price makes us believe that this is the worst option for our project.

N\C

The final adapter we looked at was the one produced by N\C. This option has the highest maximum current at 3A. While this option technically has the least additional adapter tip choices, it still comes with the most useful option of the DC Terminal. These benefits alongside the lowest price of the options we researched led us to the decision to use this adapter.

Brand	Arkare	EIKS	N\C
Maximum Current(A)	2	1	3
Connector options	Barrel, micro-usb, usb c, DC Terminal	Barrel	Barrel, DC Terminal
Price	$7.59	$8.59	$5.00

4.0 Standards and Design Constraints

With a product that can possibly be sold on the market, there are some standards we must follow, as well as some design constraints that restrict our technology choices. Without such standards, our product can put consumers at risk that will greatly back-fire at the designers and engineers, and in this case it is us.

4.1 Standards

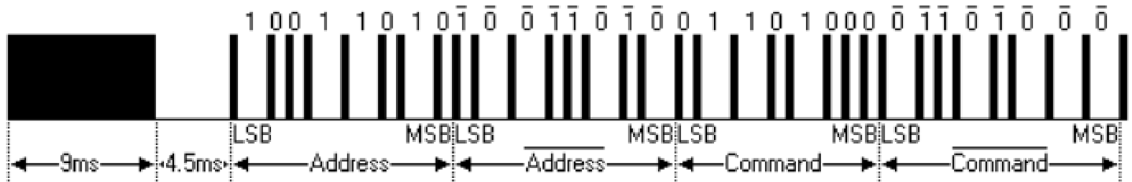
For products with electronics and LEDs, we must follow various safety standards; although, standards are voluntary. Since we are using solar panels and battery chargers for our cat door, there are two standards that cover the two. IEC 61730-1:2023 covers the safety requirements for solar panels and 10 CFR Part 430 covers the safety and regulations of the battery charger, which is necessary when relying on solar panels as the main power source for the cat door. Since we are using LEDs in our system, we must consider its brightness and electrical safety. Two standards we must consider are UL 2592 and ANSI/IES LM-80-21. UL 2592 covers the regulations for proper protection for wires coming from LEDs, such as proper insulation and temperature rating regulations. ANSI/IES LM-80-21 covers the methods of measuring LED luminous, photon flux, and color maintenance, which is very important because we want to avoid the LEDs being too bright in the event the collar stays on and a baby were to play with the animal.

4.1.1 UL 2592

Since we are using LEDs in our design, we must consider the regulations set to safely use them in our product. UL 2592 is the standard for safety of low voltage LED wires for uses such as signs and interior lighting. This standard requires adequate protection for wires coming from LEDs using PVC insulation and PVC jackets. In other cases, this standard also covers internal wiring of audio and video equipment. These wires should pass a temperature rating of 80° C and a voltage rating of 300 V. In our case, the wires coming from our LEDs will never reach anywhere close to 300 V.

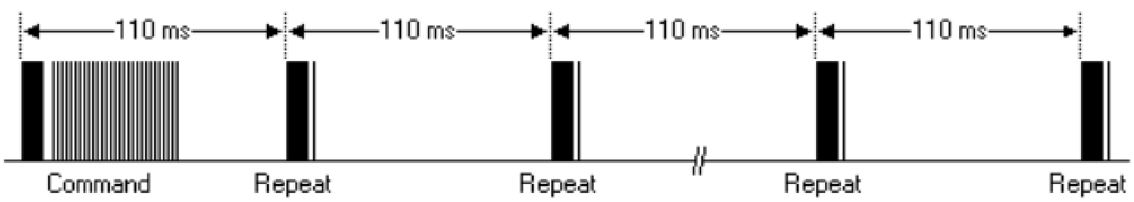
4.1.2 NEC Communication Protocol

In order to transmit IR signals, we will be using the NEC IR Communication Protocol. This standard was developed by NEC (now Renesas), using pulse distance encoding to transmit bits. A logical ‘0’ is made up of a 562.5μs pulse burst followed by a 562.5μs space, a total of 1.125ms, and a logical ‘1’ is made up of a 562.5µs pulse burst followed by a 1.6875ms space, a total of 2.25ms.. This protocol operates using a carrier frequency of 38 kHz, with modulation and demodulation being most effective with a carrier frequency of 38.222 kHz. In this protocol messages are transmitted in 32-bit frames, with 16-bits for the address field and 16-bits for the command field. The address is usually the address of the device, in this case our door. A typical pulse train of the protocol is shown:



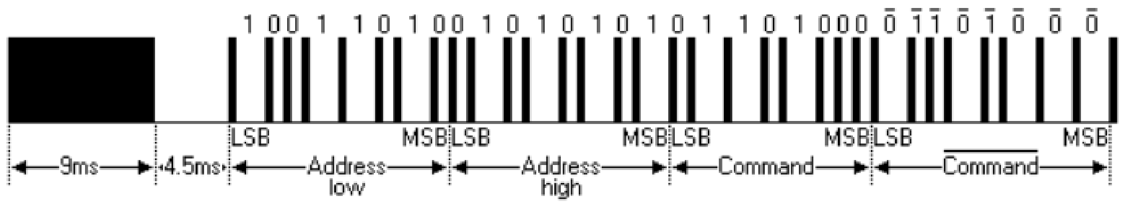
NEC Communication Frame, with permission from SB-Projects by San Bergmans

As seen from the figure, the NEC Communication Frame starts with a 9ms pulse burst to signify the start of the message, followed by a 4.5ms space. Next the address is transmitted, followed by the inverse of the address. Then the command and the inverse of the command are transmitted, followed by one 562.5µs burst to signify the end of the message. There are two reasons that the inverted address and the command fields are also transmitted. The first is that the message can be verified and checked for errors by comparing the non-inverted to the inverted message. The second reason is that each message frame is the same length of time, since the same amount of 1's and 0's are transmitted every time, giving a total message frame of 67.5 ms (excluding the 562.5µs burst at the end of the message)



NEC repeat command frame, with permission from SB-Projects by San Bergmans

The NEC protocol also supports a repeat command which tells the receiver to repeat the previous command. It is comprised of a 9ms pulse burst followed by a 2.5ms space. In IR remotes, this is used when the button is held down to repeat the command every 110ms, and continues to be transmitted as long as the button is held.



Extended NEC protocol frame, with permission from SB-Projects by San Bergmans

There is also an extended form of the NEC protocol, which allows more addresses to be used by using the inverted address frame to transmit another 8 bits of address, making a 16-bit address, which extends the possible addresses from 256 values to 65536 possible values. Drawbacks of this method are for one, the address can no longer be verified by comparing it to the inverse address and two, the message frame is no longer a constant time. This inconsistent time can be fixed by making sure the amount of 0's and 1's transmitted in the address are the same, that is 8 0's and 8 1's, but this does reduce the possible addresses to about 13,000.

4.2 Design Constraints

As mentioned before, our product contains some design constraints that we must consider to have a reliable product. Since we are creating a pet collar, we must consider the weight of the collar, as well as the possible dangers of putting an electronic device close to our pet. It's impossible to avoid the rain when our pet goes outside, so we must consider water-proofing as well, especially if electronics are that close to our pet.

4.2.1 Collar Weight

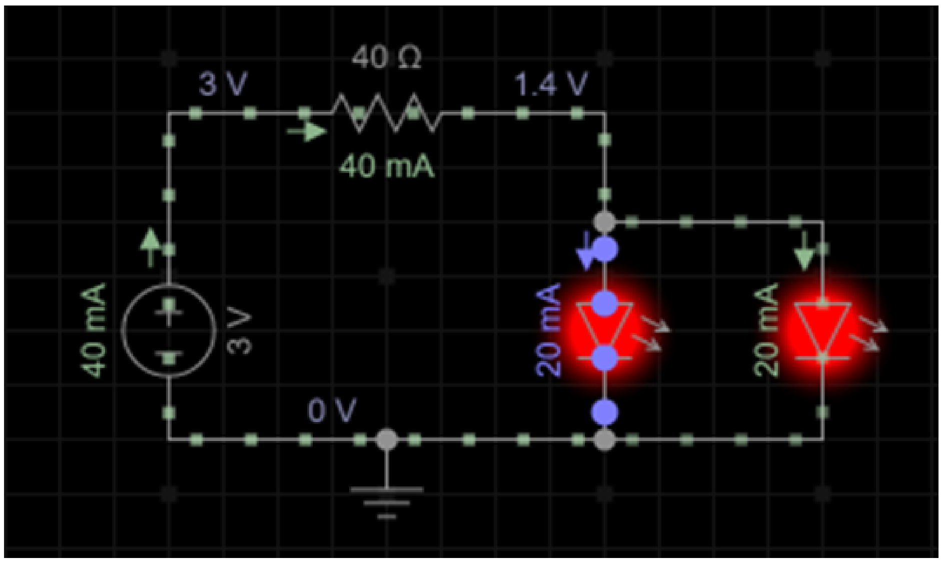
One major constraint imposed on our project is the weight limit on the collar. This constraint is created as a result of the discomfort that the cat would face when wearing the collar. If the collar is too heavy and thus uncomfortable, the cat will refuse to wear it. To ensure we do not face this issue, a weight limit of 100 grams has been placed on the collar. This constraint requires us to make sacrifices in nearly every aspect of the collar, from battery life to detection reliability.

4.2.2 Collar LEDs

For our LEDs to work onto our collar, we simplify the circuit to get an idea of our required voltage and resistance needed just to power the IR LEDs. Since the IR LEDs are rated with a forward voltage of 1.4 V, we can calculate the necessary resistance and source voltage using the equation below:

$$R = \frac{V_s - V_{LED}}{I_{LED}}$$

Let's say we use a battery configuration that will supply us with at least 3 V, V_s, and our IR LEDs will take up 1.4 V, as stated on the Amazon store page of the LED, we calculate that the resistance needed for two IR LEDs in parallel is 40 Ω, 30 Ω for three IR LEDs, and 20 Ω for four IR LEDs. Below, we can see a simulation done in a free online circuit simulator called EveryCircuit.



Simple circuit simulation of IR LEDs for cat collar.

In our design, we will have a microcontroller that will receive a signal from our microcontroller from the cat door that will modulate the frequency of our IR LED so that we can have a unique channel for the cat collar to communicate to the cat door. Not only does this allow us to ensure only our collars will work with the cat door, but also ensures an added measure of safety so that no bad neighbors can simply make their own IR LED collar that will set off our cat door and give them access to possibly break into the home.

4.2.3 Collar Material

Most cat collars are made from cotton, but there are some made from leather, velvet, silicone, and even hemp. It's possible to buy cotton or velvet by the square foot, but since some of the group members have cats of their own, we have extra cat collars we can use rather than spending more money on crafting a collar from scratch. Ideally, we'd want a material that will not cause any irritation on the pet nor be an issue for our electronics that will be on the collar. We must consider that the material of the collar can cause an electric shock that can destroy the components. Or worse, cause the components to catch on fire, thus harming our pets. Since the extra cat collars we have are made from cotton, we must use electric tape to mitigate any electrical accidents that may occur.

If our old cotton collars are not usable due to any electrical or weight issues, then we may consider buying silicone to craft our collars. Silicone collars are known to be easy to clean and waterproof, which is necessary since the collars will consistently face the outside weather.

Faux leather collars are a viable option since they are also easy to clean and can generally withstand the rain very well. But buying leather by foot can cost at least $10 per foot (54” x 12”); although, most sellers normally offer at least $20 per yard (54” x 36”), both from Amazon.

Velvet is a nicer material that can be considered for cat collars. It is also cheap, costing at least $3.15 per foot from Amazon. The biggest issue that comes with using velvet is the dangers in terms of flammability. Fabrics with raised fibers, such as velvet, are easily flammable, which is more likely to happen since we will be attaching electronics to our collars. Another issue with velvet collars is the difficulty of cleaning and caring for the collars. Since the collars will be exposed to the outside weather, keeping them clean will cause more hassle for the owners than necessary. With too many negatives, this option will not be considered.

4.2.4 Cat Door Dimensions

The cat door will ideally be installed in a door such as the front or back door of someone’s home. The consumer has the option to install it into a wall if they please, but our design is meant to be installed in a door. As such, most doors leading to the outside are at most 2” (5 cm) thick. Because of this, our IR LED emitters and photodetectors in the door must fit within that thickness otherwise we would have to protrude the cat door either towards the outside or inside of the house. The cat door itself will be limited to a big enough size to fit any sized cat; although, they tend to act as liquid and should have no problems fitting through a 9” x 9” opening. As a security measure, this dimension is small enough that no normal sized human can fit through the doorway. This will ensure to the customers that they will not have to worry about someone using the cat door as a way to break into their home.

The focal length of the Fresnel lens that will sit to the side of the cat door will be limited to less than the thickness of the house door, and the focal length of the lens we selected is 10 mm. Ideally, the smaller the focal length the better since the photodetector will also take about 10 mm in length inside the frame of our design. Since a door is about 2” (50 mm) thick, the total length of the focal length of our focusing lens and the length of our photodetector must fit within 50 mm. In total, our components will take up about 20 – 30 mm in thickness, which is well within the desired thickness of our cat door. In our model, we extruded the cat door tunnel by an additional 20 mm in total: 10 mm outwards and inwards. This allows extra room for the door mechanism and weather protection sealant as well as a little overhang to keep water from getting into the tunnel.

For the photodetectors aligned within the cat door that will be used to verify if the cat has passed through the door, the bulbs of the photodetectors are only 5 mm in diameter. Thus, it is possible to align the photodetectors in a vertical line or bundle them into a square or pentagon shape. Either shape will be at most 10 mm in thickness which is also well within our restricted dimensions. The IR LEDs that will shine across the cat door onto those photodetectors are also 5 mm in diameter, so following the same configuration as the photodetectors will fit within our dimensions for the cat door thickness.

For the motion sensor, the length of the bulb is only 8.7 mm in length; thus, the bulb can fit parallel to the cat door tunnel while it is pointed outwards. Similarly to the Fresnel lens, the motion sensor will sit on the other side of the cat door tunnel. Due to the short detection range of our IR motion sensor, it is necessary to install the motion sensor lower to the height of a cat rather than installing it on top of the door. This should help with our detection accuracy. As discussed earlier, weather protection is very important. The motion sensor and Fresnel lens can be angled 45 degrees towards the ground and an awning would be installed over them to protect the components from rain and other weather conditions.

4.2.5 Door Frame Material

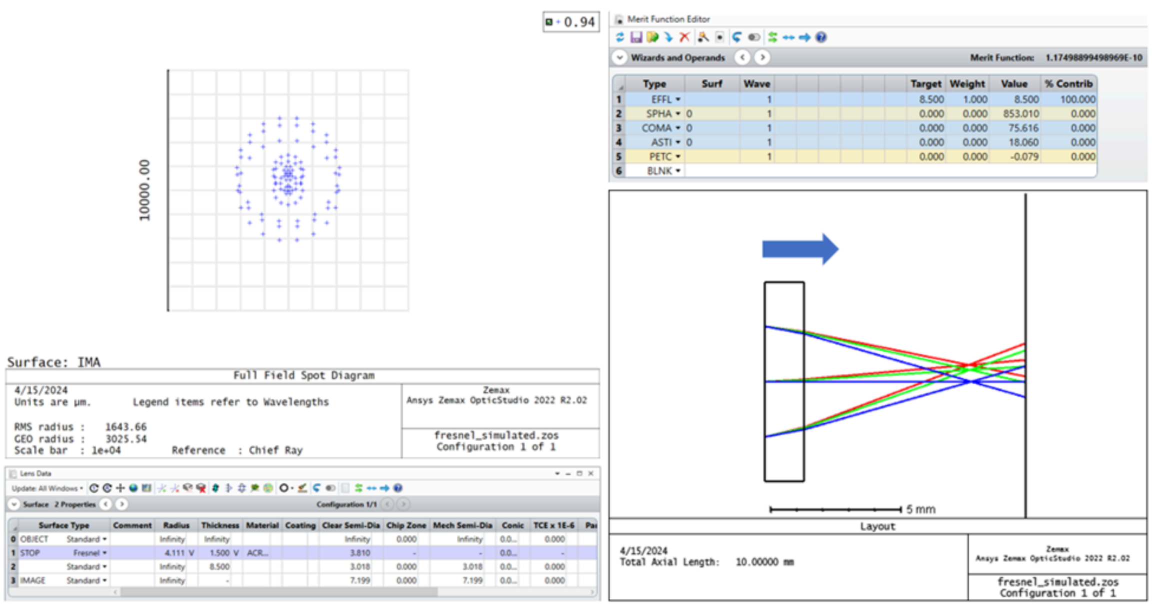
As discussed in our section of the cat door material, we need to consider material that will provide adequate weather proofing and strong enough to withstand external threats and outside weather conditions. For the sake of our design, we will opt to go with 3D printing the door frame since it will be the easiest to adjust the model we are currently working on. Also, 3D printing is the most reliable and time efficient procedure to bring our model to life without having to resort to a third-party or spend more than twice the amount of time cutting plywood over and over. There are various filaments we can choose from to 3D print our design and each have their advantages and disadvantages. Some filaments are not suited for what we are trying to achieve, such as PVA (polyvinyl alcohol) which dissolves in water and would not survive a week with Florida’s weather conditions. PLA (polylactic acid) is useful for prototyping because it is odorless and biodegradable, but that is as far as it gets because it is brittle and not resistant to heat; thus, will also not survive very long since it will be exposed to the outside heat. Two viable options include PETG (polyethylene terephthalate glycol) and TPU (thermoplastic polyurethane) filament. PETG filament requires lower temperatures; thus, faster printing times to pump out more prototypes. On the other hand, TPU filament is very flexible and has high impact resistance. TPU filament will be our likely choice as it is durable enough to withstand the randomness of anything outside that may impact the door.

A disadvantage when it comes to 3D printing is the randomness of quality control. Since 3D printing is done by melting plastics in layers, there are times when the printer runs into issues of creating gaps in the layers. This is a huge problem when it comes to stress control of a prototype as any invulnerability can end up destroying the product if a random object like a rock were to hit it when installed on a door or if someone were to try and break in through the cat door frame.

4.2.6 Focusing Lens Simulations and Constraints

Fresnel Lens

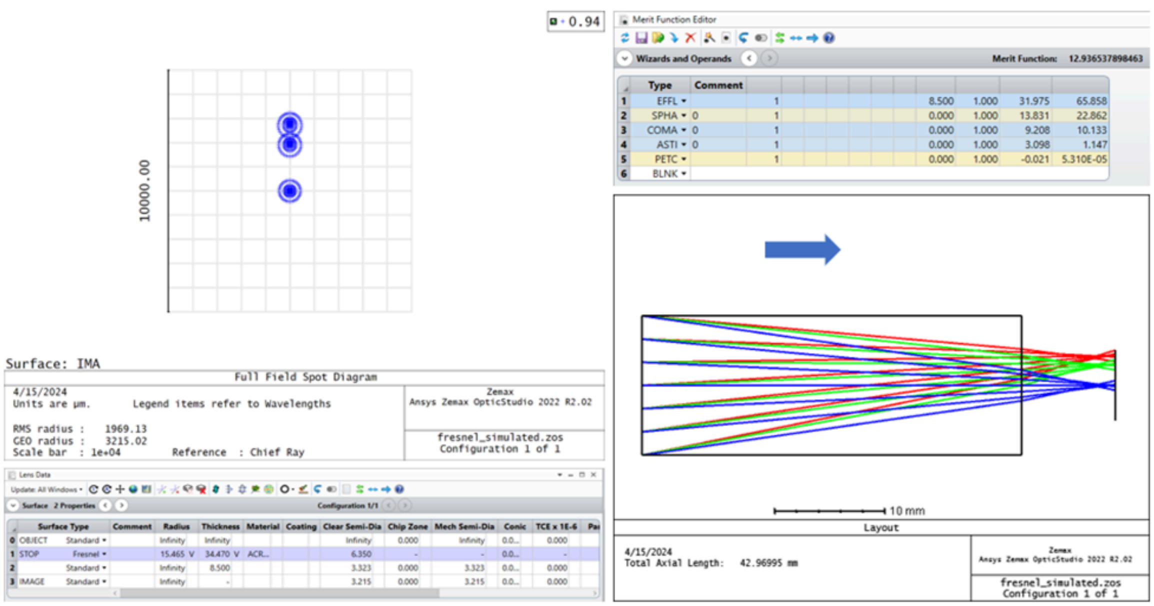
If we want to use a Fresnel lens for our design, we simulate the desired parameters in Zemax. In our case, we want a small enough focal length so that our lens and length of our photodetector component can fit well within our cat door's limited thickness. The limitations of the cat door's thickness are discussed further in a later section of this document. Below are the combined screenshots from Zemax with a fixed focal length distance of 10 mm.



Zemax screenshots of a Fresnel lens with a fixed focal length of 10 mm and a variable thickness.

As shown above, the thickness of our Fresnel lens will need to be about 1.5 mm and the radius at the Fresnel surface will need to be about 4.111 mm. With these parameters, we find that the FRP0510 Fresnel lens from Thorlabs to be a matching fit to our Zemax simulated Fresnel lens since it also has a focal length of 10 mm and conveniently has a 0.5” diameter, which is bigger than the bulb of our photodetector and will allow more light to be collected.

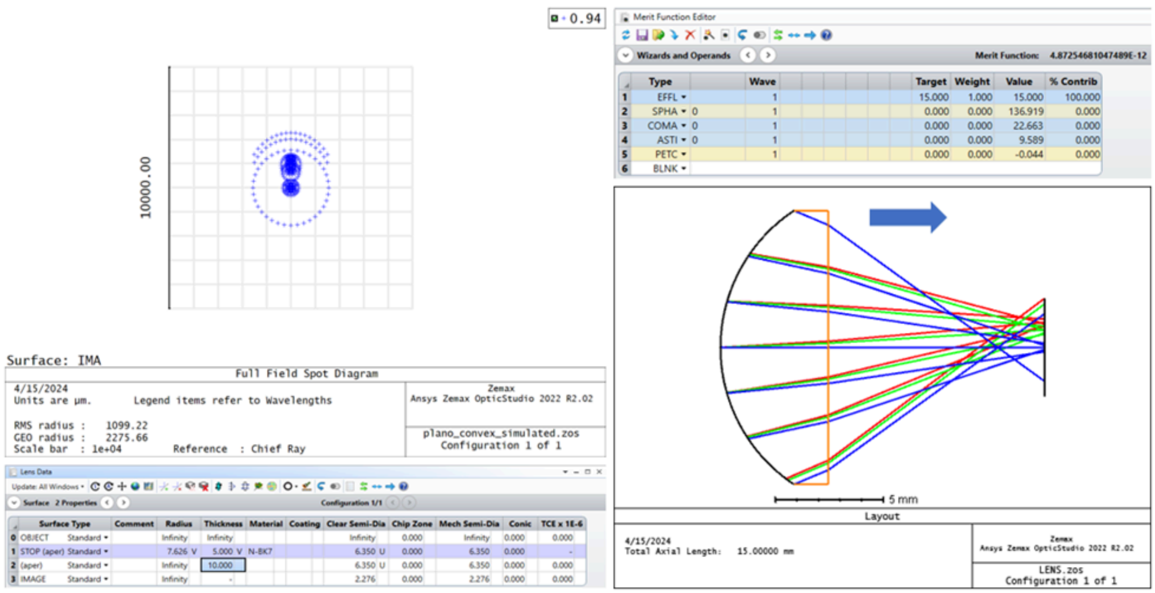
One downside of this Fresnel lens we simulated is the huge aberration it suffers from, especially spherical aberration. But since we are only using the lens to collect as much light as possible onto our photodetector, aberrations are not a huge factor that needs to be considered now. If we were to consider fixing the aberrations of our Fresnel lens, such as if we needed to include a camera into our design, our Zemax simulation fixes it by increasing the thickness of our Fresnel lens to 34.47 mm and the radius at the Fresnel surface to 15.465 mm. Since our cat door thickness is at least 50 mm, using a Fresnel lens with a 34.47 mm thickness will not be ideal when combined with the length needed for the photodetector bulb. And there is no Fresnel lens on the market that matches such parameters of the aberration fixed lens. The combined screenshots from Zemax of the unnecessary aberration fixes are shown below.



Zemax screenshots of the aberration fix of a Fresnel lens with a fixed focal length of 10 mm and a variable thickness.

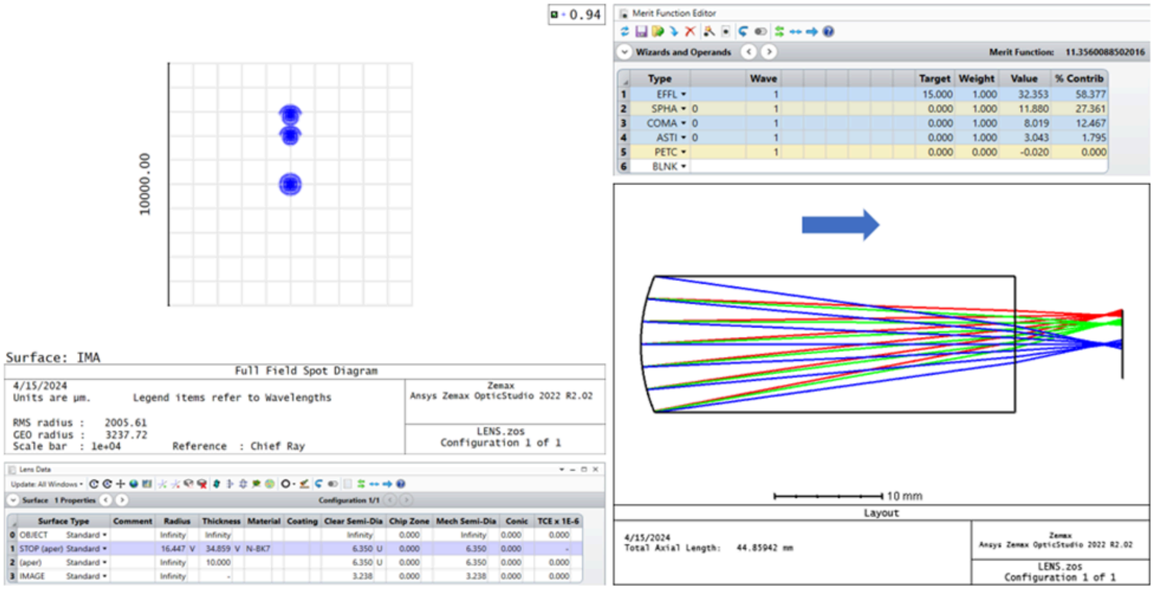
Plano-Convex Lens

Like our Fresnel lens we simulated, we want to simulate a plano-convex lens as well so we can open our options for a focusing lens for our design. We chose similar parameters for a plano-convex lens such that the focal length should be small enough to fit the plano-convex lens and photodetector within the thickness of our cat door. On the other hand, plano-convex lenses are usually thicker than Fresnel lenses on the market; thus, the focal length limitation is increased to 15 mm. Below are the combined screenshots from the Zemax simulation of a plano-convex lens with a 15 mm focal length.



Zemax screenshots of a plano-convex lens with a fixed focal length of 15 mm and a variable thickness.

As seen in our simulations of the plano-convex lens in Zemax, the lens we designed still suffered from a lot of aberration, especially spherical aberration just like our Fresnel lens we simulated. As mentioned before, aberration will not be a problematic factor since we are just using the lens to collect more light to shine onto our photodetector. But if we were to go through the troubles of fixing aberrations for our plano-convex lens, we end up with a new thickness of 34.859 mm and a radius of 16.447 mm. With that thickness, we need to consider the total length taken by the lens and the bulb of the photodetector. Since the thickness of our cat door frame is about 50 mm, we cannot consider a lens this thick. Also, there are no lenses on the market that match these parameters of the aberration fixed plano-convex lens. Below are the Zemax screenshots of the new lens when aberration is accounted for.



Zemax screenshots of the aberration fix of a plano-convex lens with a fixed focal length of 15 mm and a variable thickness.

5.0 Comparison of ChatGPT with other Similar Platforms

5.1 Limitations of LLMs

Today, tools such as LLMs (large language models) are available for anyone to take advantage of. Students can make AI (artificial intelligence) write their entire essay or report within a matter of minutes if the student decides not to tweak the response from the LLM. Of course, this poses huge risks to the student's academics and the legitimacy of academics. Without proper experience to spot when a piece of work is written by AI, the future of academics will falter and be filled with faux research. From experience, these risks outweigh the benefits, and we will not be utilizing LLMs to come up with a prompt or assist us in writing our paper.

5.1.1 Pros of LLMs

Some of the pros when it comes to utilizing LLMs to write up reports such as this are time saved, giving a general direction to writing and research, and supplying the student with more words to fill up the page count. These all come with a cost that will be discussed later in this section, but all the pros do allow the students to procrastinate their work while simultaneously filling in the requirements to turn in their assignments.

To begin, the time saved on using LLMs can be beneficial for the student if they need to work a job while in school. While not everyone has the luxury of financial aid or assistance from their parents/guardians, some students may run into the problem of needing to work to pay for school and living expenses all while juggling school work. At the same time, many students may not be in a situation where they can take out a school loan to help mitigate the lack of funds. Students in these tough situations can find it beneficial to utilize LLMs to finish their schoolwork on time while being able to make a paycheck to survive. However, a student solely relying on LLMs for their schoolwork will find it difficult to grow as an academic and will eventually get caught when faced with a grader who has the experience to recognize or utilize third parties that can detect the use of LLMs. This will be discussed in a later section on the cons of using LLMs.

LLMs assist in giving students a general direction of how to approach their assignments without having to come up with an outline like how we were taught in school. If you just give the prompt or directions of the assignment to the LLM, it can write out the introduction with supporting examples without the student needing to put any thought into it. If the student wants to, they can do a little bit of research to add to those supporting examples or just ask the LLM to write more while having it cite supporting articles/papers.

Another viable option to utilize LLMs is to complete a word minimum assignment, or for the writer to sound like they know more just by having more words. It is possible for the LLM to write a completely bogus statement because they overwrite and use sophisticated word play, which will be discussed more in the cons of LLMs. It is possible to ask the LLM to complete a prompt within a set word count and it will do its best in writing enough to fill said requirement. Although it is not very consistent in matching the desired word count the user prompted, it is at least a good start for the user to continue asking the LLM to elaborate on each point made. For example, if the user prompts the LLM to give three valid points on a topic, the user will just have to ask the LLM to go into detail of each point one at a time which will easily get the student to whatever word count they need for their assignment. And as mentioned earlier, if the grader is untrained in recognizing when an essay was written using LLMs, then all the better for the user.

5.1.2 Cons of LLMs

As mentioned earlier, there are various negative costs associated with students utilizing LLMs, especially for Senior Design. The pros may aid the student in the short term, but in the long term the student will suffer from various disadvantages such as difficulty growing their academics, serious problems with plagiarism, and the LLM's inability to give the user a correct answer when told it is wrong.

If a student wishes to pursue academics and wish to grow, then they require time dedicated towards studying and working on their assignments rather than cheating and copying their way through their classes. With LLMs, students can give an AI their homework questions or prompts and get an entire essay out of it within a matter of minutes. Students who continuously take advantage of this will not give time to fixing the output from the LLM and will not get any practice in writing their own papers. Students will not work on doing their own research and formulating their own opinions if they only rely on LLMs to write for them, especially since LLMs will write whatever it can find throughout the web without any forms of paraphrasing. This will lead to plagiarism.

Nowadays, there are third-party tools that allow teachers and professors to upload their student's work to see if there is any plagiarism and now any forms of LLM usage. Since most LLMs will just copy word for word what it can find online on the topic it was prompted, these third-party tools will be the downfall of those students who lack the effort to even change anything of the LLM's output. In high school, the student will at worst suffer from a failing grade for their assignment when caught. But in college, and especially in Senior Design, the student will fail the course and must meet with academic integrity committees which can result in the student being kicked out of the school.

One of the biggest issues that we have experienced when trying to use LLMs is the platform's inability to give the correct answer. For example, if the user were to ask the LLM a simple calculus question, the user can continuously reply that the answer the LLM gave was incorrect. The LLM will then continue to respond with different solutions while sometimes never changing the process it takes to solve the problem. Even if the solution was correct and the user still responded that the answer was incorrect, the LLM will not dispute the user's command and will spit out a different answer. From experience, this has been tested multiple times with other subjects such as organic chemistry and programming. Although the platform is decent at giving a code that works and will output whatever the user needs, the user can continuously tell the platform that it does not work or outputs something completely different and the platform will not argue with the user even if the code indeed works.

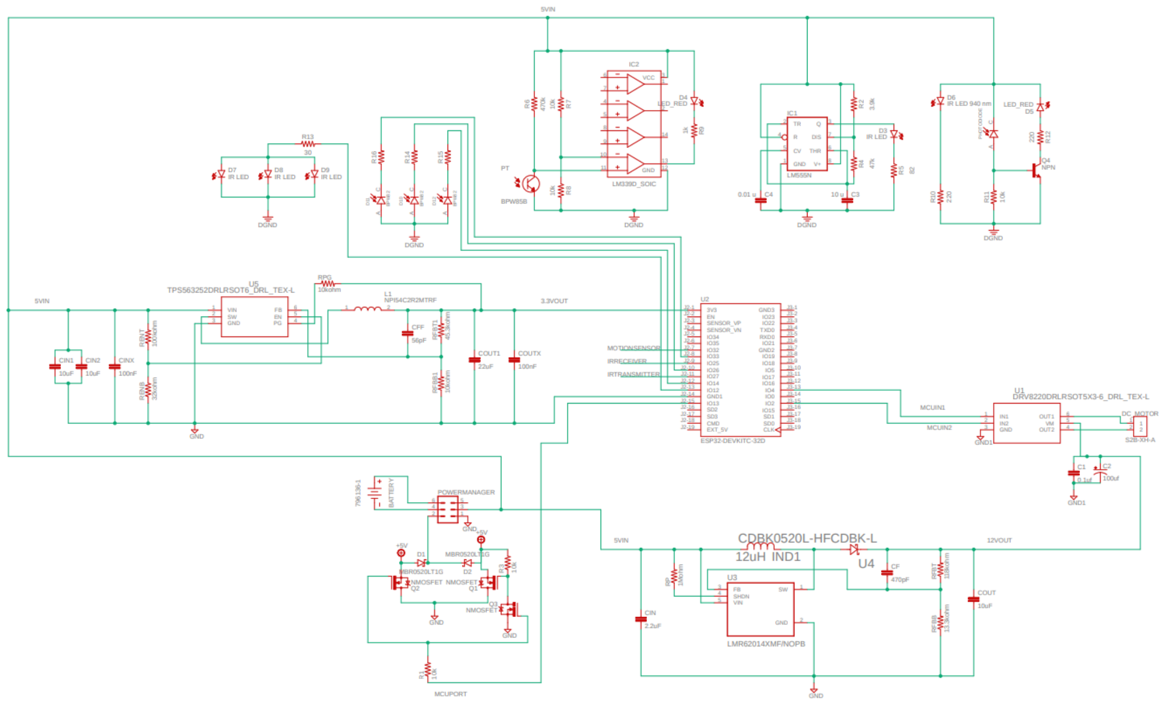
6.0 Hardware Design

6.1 Overall Schematic

For our design, we have two overall schematics: one for the main system and one for the collar system.

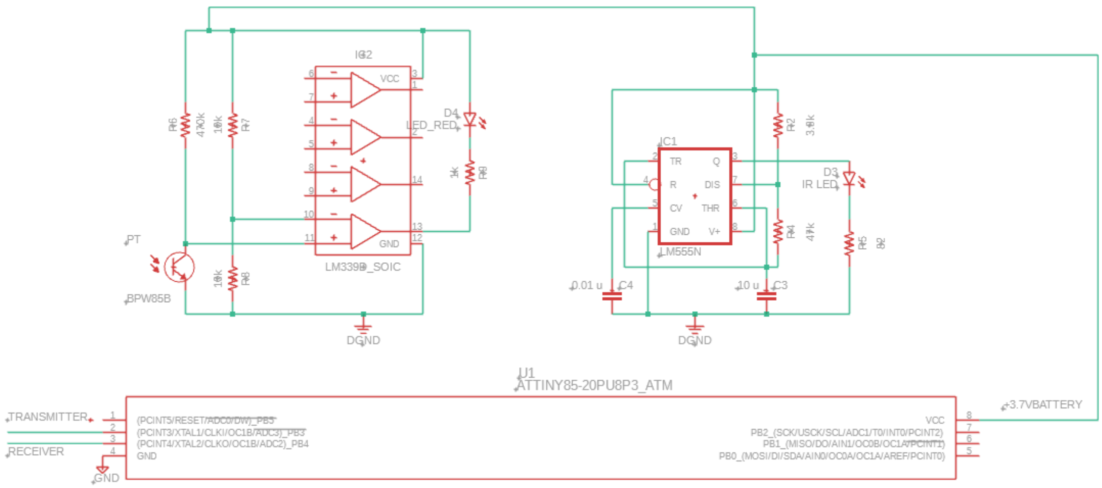
6.1.1 Main System

Our main system schematic consists of the bulk of our design, being comprised of the IR receiver, transmitter, and motion sensor circuits, the battery system, motor system, and the DC/DC converters, as well as the microcontroller in the center. The battery system in the bottom left of the schematic has its 5 V output connected to both of our DC/DC converters, as well as the IR circuits at the top of the schematic. The battery system is also connected to IO pin 13 of the microcontroller, which controls whether the power is sourced from solar or from the outlet. The 5V/3.3V DC/DC converter shown on the left of the schematic has its output connected to the 3.3 V input of the microcontroller, and the 5V/12V DC/DC converter on the bottom right has its output connected to the power input of our motor driver. The motor driver input 1 and 2 pins are connected to IO pins 4 and 2 respectively of the microcontroller, which control the output power and direction of our motor driver. Since the current iteration of our IR circuit schematics do not have microcontroller inputs, we have put placeholder connections on the microcontroller where these IR circuits will connect to once their schematics include microcontroller connections. The IR receiver is connected to IO pin 25, the IR transmitter is connected to IO pin 27, and the motion sensor is connected to IO pin 32. The LED portion of the occupancy sensor is connected to IO pin 12, though it consists of three LEDs they can all be driven by one pin. The photodiode portion of the occupancy sensor is connected to IO pins 14, 26, and 33, where each pin is connected to one photodiode. It is particularly important that the motion sensor is connected to an RTC pin, since it needs to connect to one of these pins in order to wake up the system from hibernation mode, but since there are 16 RTC pins, we had no problem finding a pin to connect our motion sensor to. Most of the pins on the ESP32 can be used as GPIO pins, so the specific pin the rest of our components connect to was not as important, therefore we connected them to pins whose functionalities we would not be likely to use, like some ADC pins and touch sensing pins, and avoiding connecting to pins for communications like I2C pins, UART pins, and SPI pins, just in case we would need to use these pins in the future.



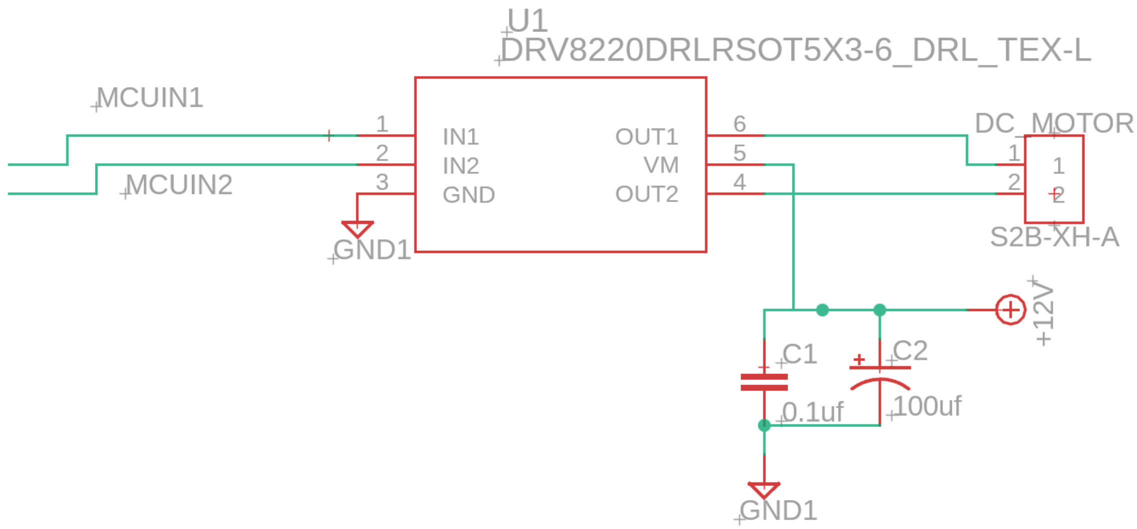
6.1.2 Collar System

The collar system has a much smaller overall schematic than the main system, consisting of the ATtiny85, an IR transmitter and IR receiver, as well as the 3.7 V collar battery. Since we could not find a specific footprint for a 3.7 V battery, we just labeled the node which it will be connected to as a placeholder, but we will design our own 3.7 V battery component and replace this placeholder in a future iteration. In addition, we will likely have to adapt our IR receiver and transmitter circuits to run at 3.7 V, since they were designed for usage at 5 V, but this adjustment should be relatively simple. Since we would like to keep our collar system simple and low power, using a voltage regulator to increase the voltage for these IR circuits would be undesirable, which is why we have opted to adapt these circuits for a lower voltage instead. We have connected our IR receiver circuit to pin PCINT4, and our IR transmitter to pin PCINT3, using placeholders much like we did with the main system schematic. We could have connected the IR components to the other pins on our microcontroller, but we decided on using these pins since we were not using these pins for anything else, but we were using the rest of the IO pins for programming the microcontroller. Of course in our final design we would not be using these pins for programming, but it still makes it simpler not to connect our IR circuits to these pins.



6.2 Motor Driver

A motor driver is required in order to control the speed and direction of our motor's rotation. The motor driver uses an H-bridge made up of four MOSFETs which control the direction of current based on which MOSFETs are on or off. Using a PWM signal from the microcontroller, we can change the amount of time each MOSFET is on, which allows us to change the voltage going to the motor for speed control. For our application we are using the DRV8220, which can supply more than the 12 volts and 0.33 amps of current needed to run our motor. The IN1 and IN2 pins are connected to the MCU which control the mode of the driver, and the OUT1 and OUT2 pins connect to the + and - terminals of the motor, which power the motor. VM is connected to the 12 V power supply, along with a 0.1 uF bypass capacitor and a bulk capacitor, following what was recommended in the datasheet for the DRV8220. For our bulk capacitor we are using a 100 uF electrolytic capacitor, we may be able to get away with a lower capacitance but we chose to overshoot for the time, since too little bulk capacitance has the risk of not being able to keep a stable voltage and current supply. The downside of this is increased size and cost of our motor driver circuit, so after further testing we may decide to decrease our bulk capacitance if we find we don't need a value nearly as large.

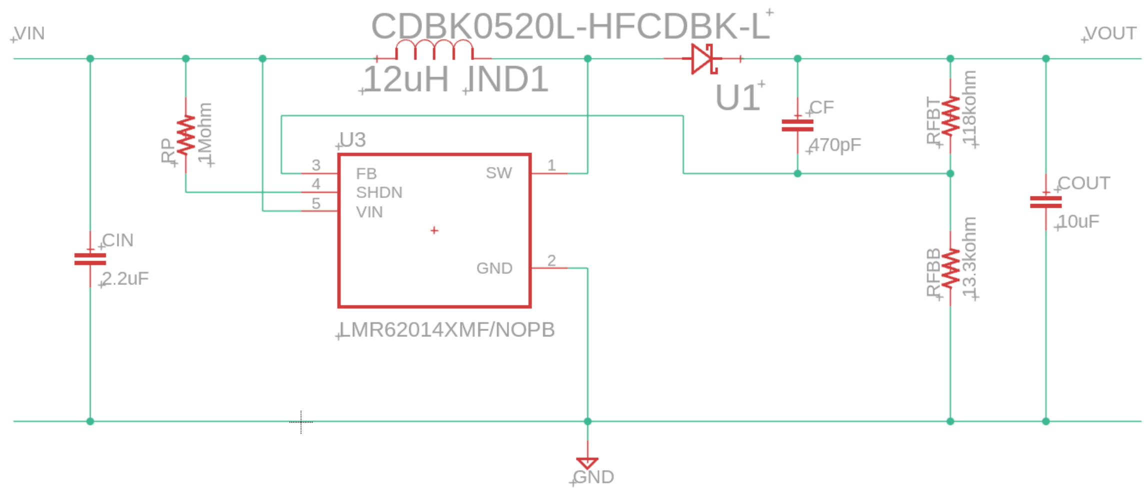


6.3 DC/DC Converters

Some components of our system, namely the motor and the microcontroller, require a different operating voltage than our charge controller output which is 5V. In order to supply the correct amount of voltage to these components we need to step up and step down the voltage. We have decided the best way to do this is using DC/DC converter circuits, which use voltage regulators to change the voltage. For our design we have decided to use switching regulators, since they are more power efficient than linear regulators. We used the power designer tool on WEBENCH, provided by Texas Instruments, in order to design our DC/DC converters.

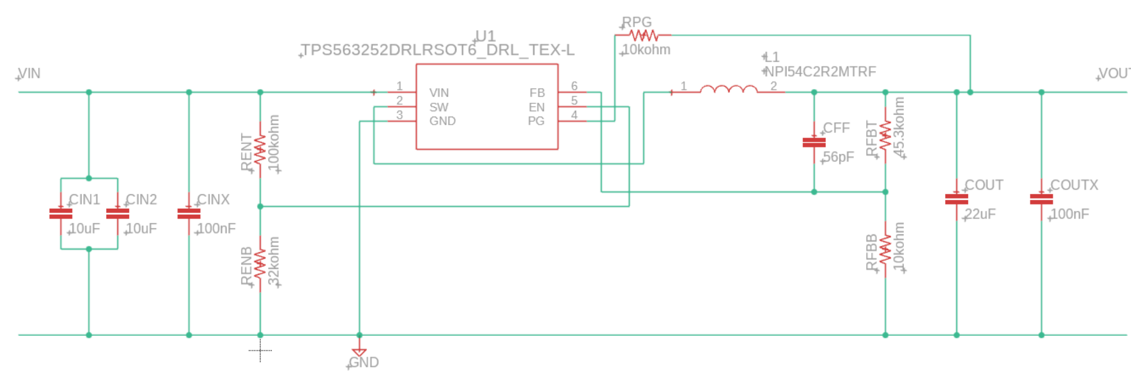
6.3.1 5V/12V Converter

Firstly we needed to step up 5V to 12V, for our motor to have the correct voltage supply. This design uses the LMR62014, which is a switching boost regulator that can output up to 20 V and switches at 1.6 MHz. This design has a max output of 0.4 A, and our motor takes a maximum of 0.33 A, so this design should be able to provide enough current to our motor. Having more excess output current would significantly increase the cost of our design since this is a boost regulator, it takes more input power to step up voltage than it does to step down. The datasheet for the LMR62014 recommends that we use ceramic capacitors for the external, input, and output capacitors, due to their low ESR, so those are what we will use. The output voltage for our DC/DC converter is set by a voltage divider between resistors RFBT and RFBB, where RFBB is generally set to 13.3 kΩ for a divider current of approximately 92 uA. The formula for calculating RFBT is then RFBT = RFBB x (Vout/1.23 - 1), which for our design of Vout = 12 V, RFBT = 116.46 kΩ, which is close to the 118 kΩ we are using for our design.



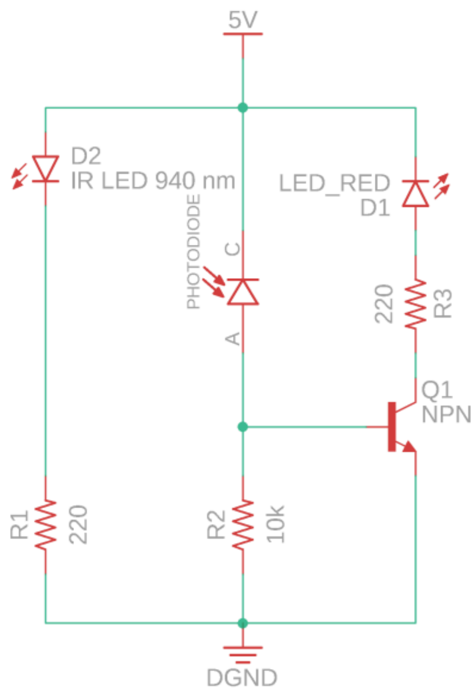
6.3.2 5V/3.3V Converter

We also need a DC/DC converter in order to supply our ESP32 with the correct operating voltage from our charge controller. This design uses the TPS563252DRLR as the voltage regulator. It is a switching buck regulator, with a 3 V - 17 V input range, and a 0.6 V - 10 V output range, switching at a frequency of 1.2 MHz. The rated max output current for this design is 1 A, which is plenty to supply our microcontroller, which even with both RF modules enabled uses a max of 400 mA of current. Since this is a buck regulator design, we can achieve a high output current at a lower cost when stepping down voltage, compared to a boost regulator like for our 5V/12V converter. The output voltage is determined by a voltage divider between resistors RFBT and RFBB, with the formula Vout = 0.6 x (1 + RFBT/RFBB), where RFBB is selected to be 10 kΩ, giving us an RFBT = 45 kΩ for an output of 3.3 V. The TPS563252 is designed to be used with low ESR capacitors, so for our application we are using ceramic capacitors. Our inductor footprint in our Fusion 360 schematic does not show the inductance, but we are using a 2.2 uH inductor for this design.



6.4 IR Motion Sensor

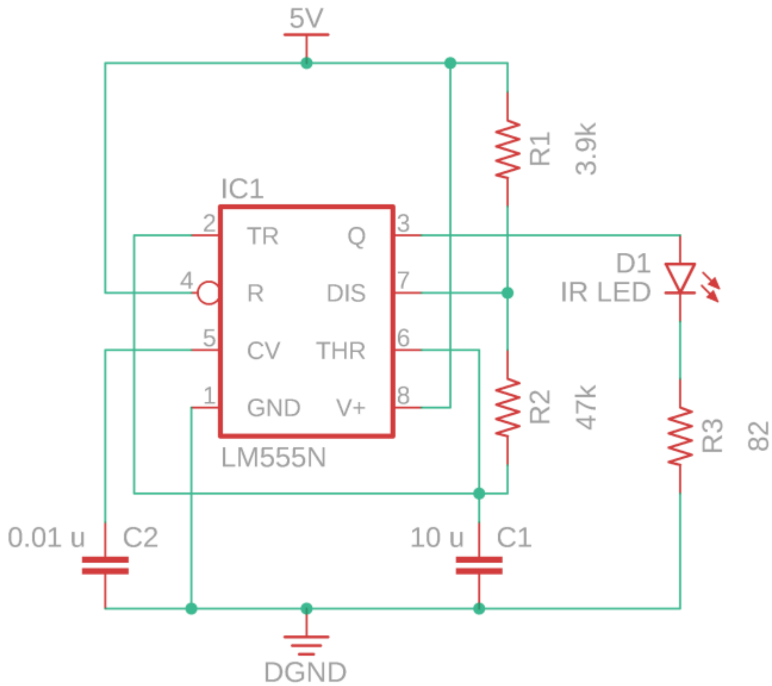
As shown in previous sections, we will be using a simplified motion sensor circuit. The circuit schematic will be altered in the final design.



Simplified IR motion sensor circuit.

6.5 IR Transmitter

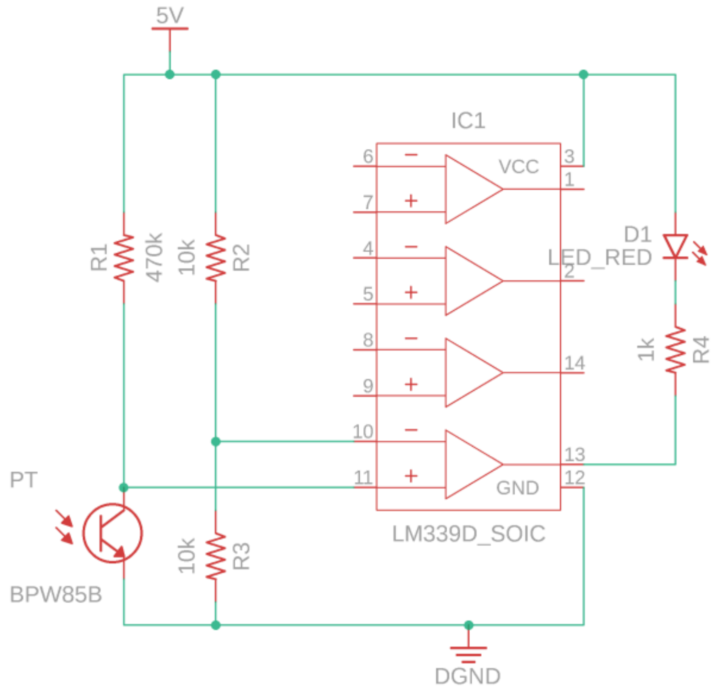
For the cat collar to communicate with the cat door, a modulated signal will be sent from our IR LED using this transmitter circuit below. The IC in the transmitter circuit is used as a pulse generator to flash the IR LED and act as a signal carrier. If we set a square wave to flash the IR LED on and off, we are using the light intensity to transmit our signal. And if we were to input a sine wave, our IR LED will flash as a sine wave. Since we cannot see IR, this acts as a practical way to carry information without being seen with our IR LED being the transmitter of our communication.



IR transmitter circuit.

6.6 IR Receiver

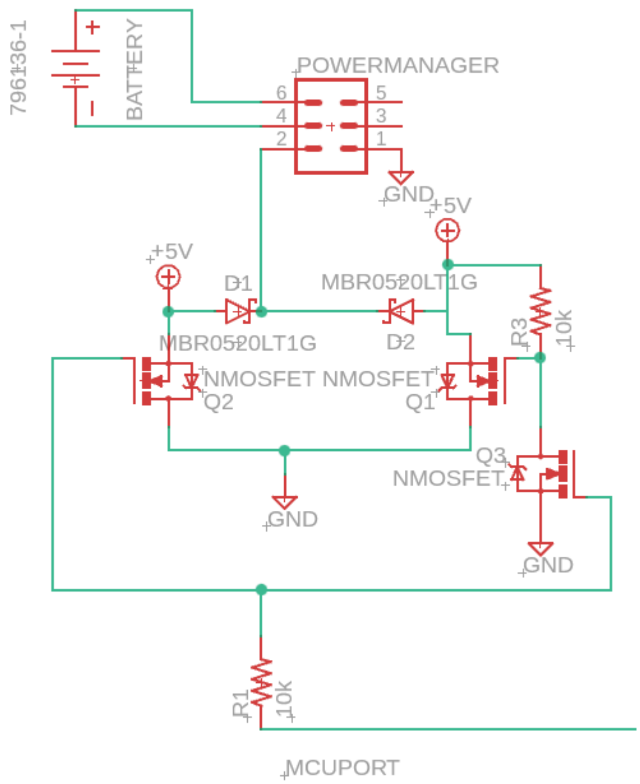
From the modulated signal, the cat door will receive the signal using the receiver circuit shown below. The transmitter and receiver circuits act as an electric filter and the phototransistor in the receiver circuit is how we will pick up the signal from the transmitter circuit. When the light is picked up by our phototransistor, an internal base current is amplified by the transistor and the current generates a voltage in a resistor that is in series to a red LED that we use to see if a signal is picked up by the phototransistor. The IC comparator is used to compare two analog input signals and outputs a digital signal of whichever input signal is greater.



IR Receiver circuit

6.7 Battery System

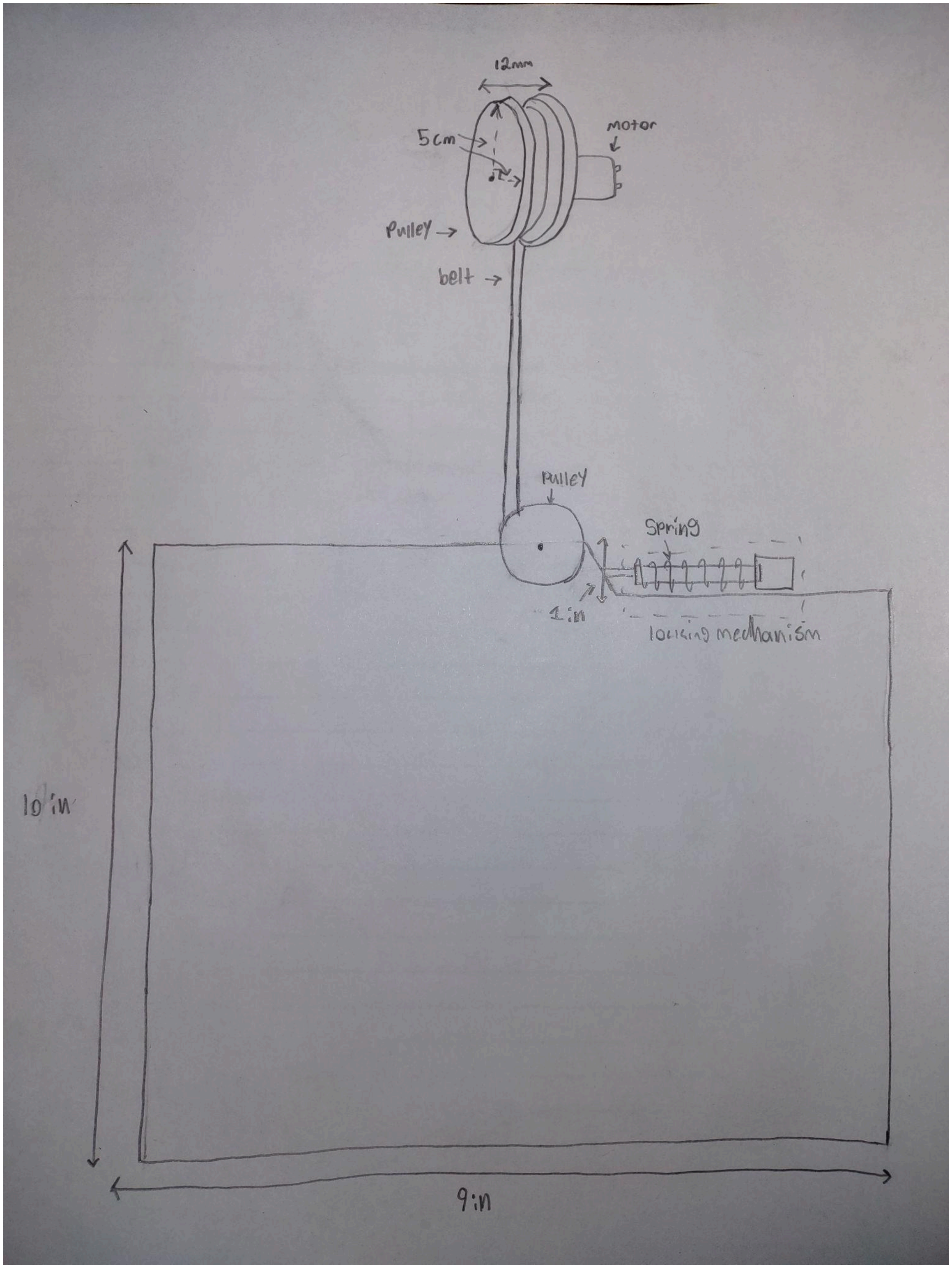
Shown below is the circuit diagram for the battery charging system. This system is designed to only allow input from one source at a time. This is to ensure that the inputs do not combine and overload the power manager. This circuit consists of three N channel MOSFETs, with NMOS 2 and 3 being controlled by a pin out voltage from the MCU. NMOS 1 then inverts the effect of NMOS 3, creating the effect of only NMOS 1 or 2 being active at a time.Through this effect, all forward current is halted in either the solar panel or the wall adapter, while the other works at full capacity. To ensure that no reverse current flows as well, a Schottky diode is placed at the mouth of both the solar input and wall input. The use of a Schottky diode ensures that the forward voltage drop is minor resulting in less power loss. The pin out voltage that controls the MOSFETs will be turned on or off at the discretion of the consumer, allowing them to choose which input they prefer.



Battery System Circuit

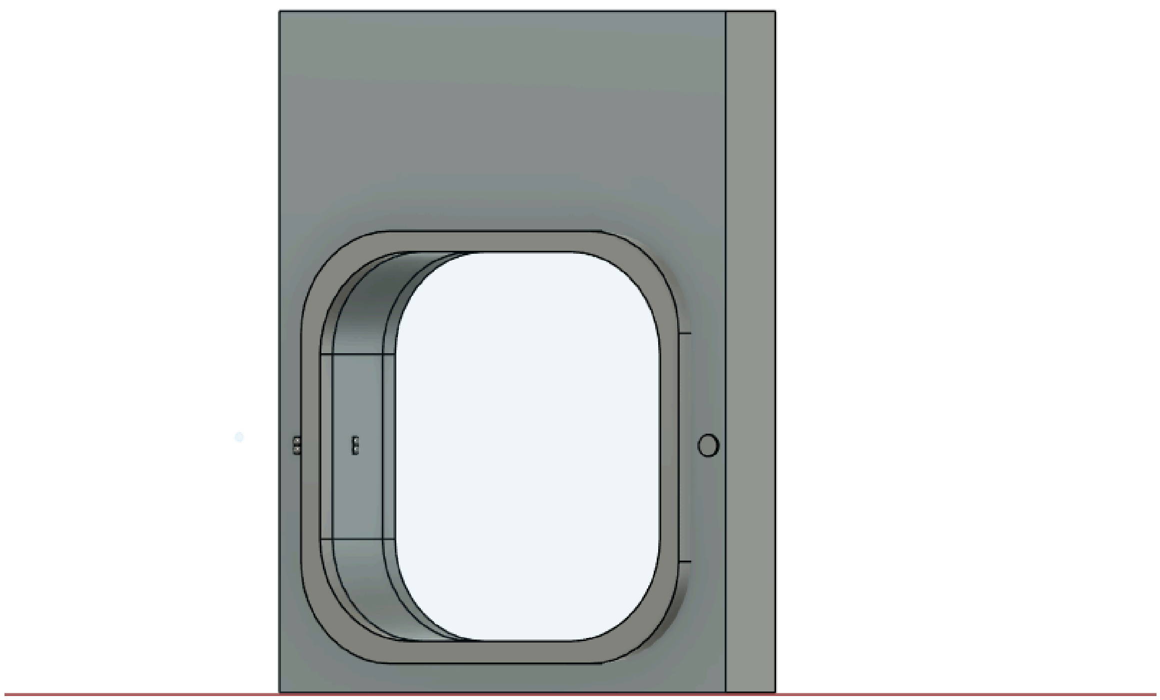
6.8 Mechanical Design

Lastly we must cover the mechanical design for our cat door. Since we are not mechanical engineers, this was not as big of a priority for us as the electrical components of our system, but is still something we had to come up with a design for. As of now we only have a sketch of our idea of a mechanical design, but we plan on creating a better design in Fusion 360 once we are more comfortable using the software for 3D designs. Our door will be driven by our motor rotating a pulley with a 5 cm radius, which we calculated when selecting our motor. The pulley is 12 mm wide, since that is the length of our motor shaft. The pulley will lower and raise the door via a belt and another pulley attached to the door. In addition we have also sketched out our idea for a locking mechanism, based on using the elasticity of the spring combined with the motion of the belt. This relies on the belt compressing the spring when the door is opened, and when the door is closed the spring is extended, which would lock the door via a deadbolt. The benefits of this design are that we only need one motor to drive both the door and the lock, as opposed to having a separate motor for the lock, but we are still unsure if we can actually implement this design, if we cannot we would have to use a separate motor and a different locking mechanism.



6.9 Cat Door Frame Model

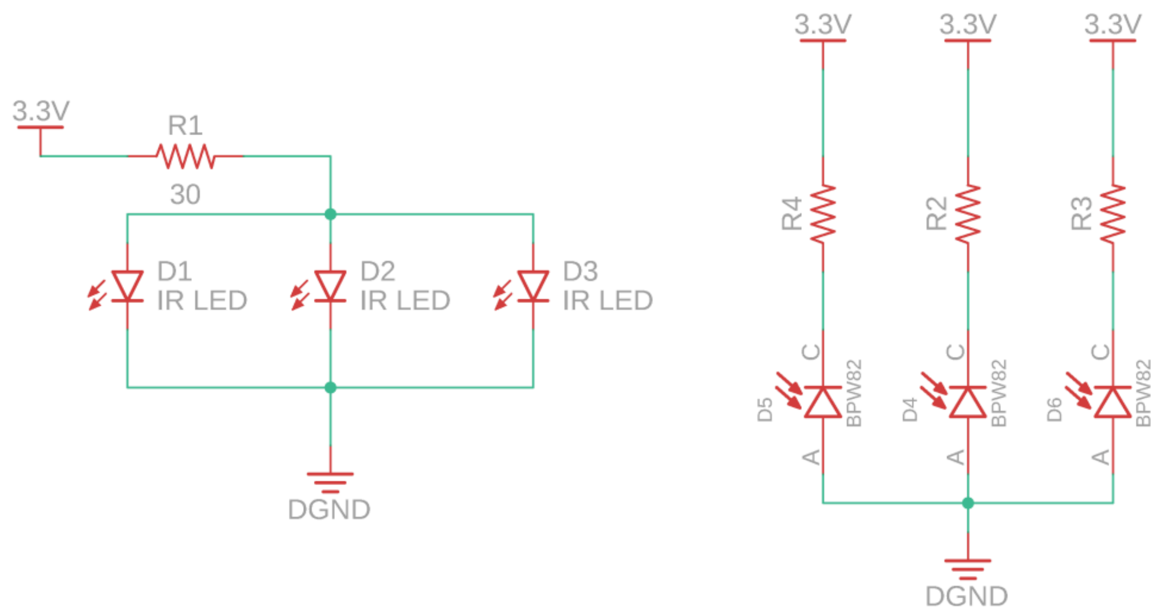
We modeled our cat door frame in Fusion360. The figure below is just an early version of our design and does not yet include the awning that will be placed above the IR motion sensor and Fresnel lens that will help protect the components and possibly provide a place for our solar panels to sit. The frame measures 300 mm x 400 mm (11.8” x 15.7”).



3D rendering of cat door frame that will be installed in a door.

6.10 Occupancy Sensor

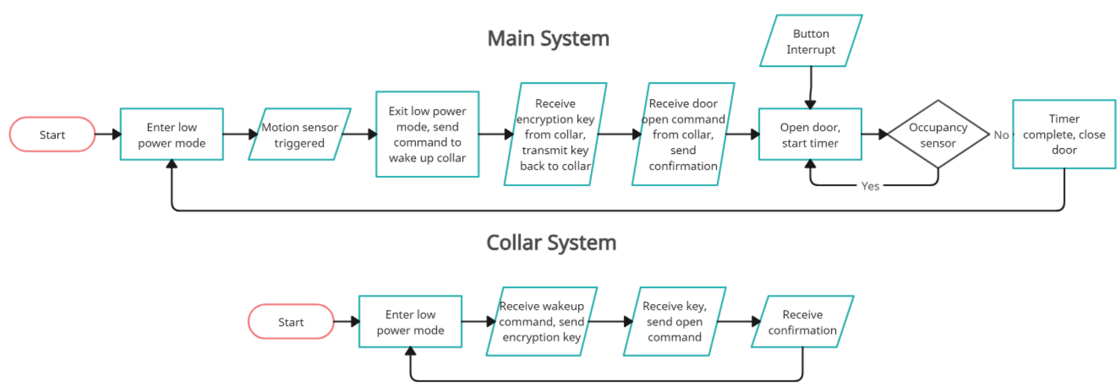
At the cat door, we will have an occupancy sensor to detect whether or not the cat has passed through the door. This will consist of IR LEDs and photodiodes that each are supplied with their own source voltage from the MCU. This will allow the MCU to detect which photodiode is blocked so we can rely on it to act as a verification step in our automated cat door system. Below is the circuit schematic of the occupancy sensor.



Occupancy Sensor circuit at the cat door.

7.0 Software Design

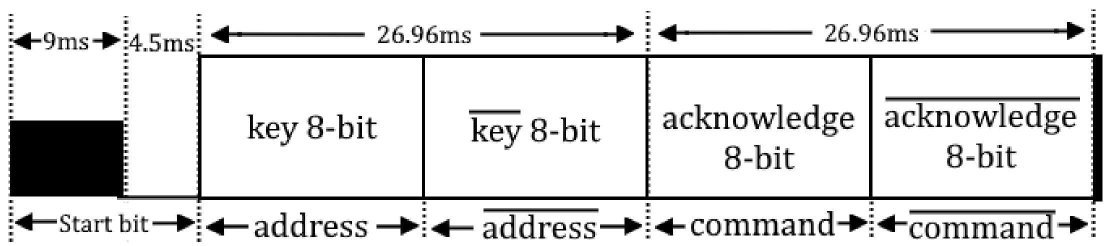
All of the main system software will be run on our main microcontroller, and the collar microcontroller will only be handling communication with the door. Since we want to conserve as much power as possible, our software will disable peripherals when they are not in use, and for the majority of the time will be in a low power mode waiting for the motion sensor to trigger. Once the motion sensor does detect something, the main system wakes up and sends the wakeup command. If the motion detector just detected something random which is not the cat, then the system will go back to sleep after a time. If the cat is present, then the collar will receive the wakeup command, and begin the IR communication routine. This routine consists of the collar receiving the wakeup command, the collar then sending the encryption key to the system, followed by the main system sending the key back to confirm it was received. The collar will then send the command to open the door, and then the main system will send a confirmation command back to the collar so the collar knows the door is opening. After this confirmation is sent, the main system will open the door and start a timer. Once the timer reaches a certain value, the door will close. Additionally, when the occupancy sensor is triggered, the door will be held open as long as the sensor is triggered, and once the sensor is no longer triggered then the timer will be reset to a shorter value of approximately 5-10 seconds. The following block diagram shows the overall function of the system:



7.1 IR Communication Protocol

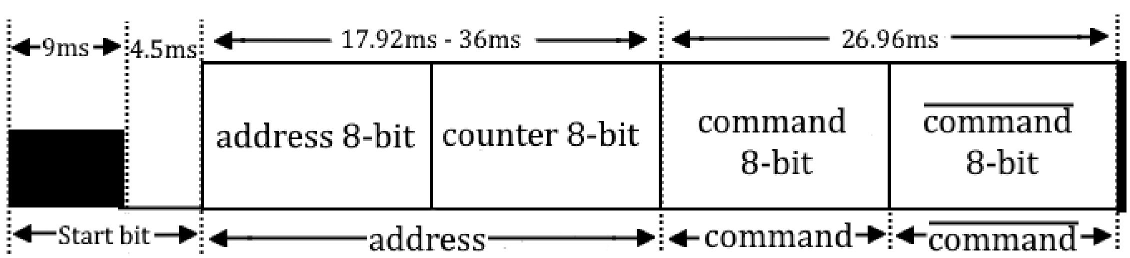
Our IR communication protocol will be responsible for transmitting information back and forth from the collar and door. We will be using the NEC Communication Protocol as our base for IR communication, since it is widely used and supported, and there are public libraries available which provide functions for NEC communication. In addition we want our system to be secure from outside interference, so we will be using a similar encryption scheme as discussed in the paper “Eavesdropping Vulnerability and Countermeasure in Infrared Communication for IoT Devices” we discussed in section 3.1.1. This encryption scheme relies on using a randomly generated 8-bit key and doing an XOR operation with the key and the command we are transmitting.

Using a timer on the collar microcontroller, we will randomly generate an encryption key based on the timer value whenever the wake up command is received from the door system. There are several timers we could use to generate this key, like the watchdog timer or the I/O timer, it just depends on what timer we end up using in our design. This key will then be transmitted to the door system so that both parties have the same encryption key.



Transmission frame for sending encryption key from collar to door

For every transmission that is sent, the command will be XOR’d with the encryption key. The receiver will then be able to decrypt the command by doing another XOR operation using the encryption key and the 8-bit command field to extract the command. In addition to the encryption key, we will also use an 8-bit counter to provide additional security. Every time a command is sent from the collar, we will have a counter increment by one and this counter value will be placed in the address field of the transmitted packet, specifically where the inverted address would go, using the extended NEC protocol. The encryption key and the counter will be added together to create a new 8-bit key, which will be XOR’d with the command. During the decryption, the counter will be extracted from the address field, and then added to the previously received encryption key. The door system will then extract the command field, and do an XOR operation with the 8-bit command and the new key, in order to extract the command.



Transmission frame for sending command from collar to door

We wrote some pseudocode to show what transmitting an encrypted command would look like (this is not actual programming code, just a demonstration of the steps involved in transmitting a command):

```
// Encryption key is only generated once after collar wakes up, not for every transmission
enc_key = rand(timer_value);
counter = 8-bit integer
address = 8-bit device address;
command = 8-bit command;
key = enc_key + counter;
enc_command = key ^ command;

// Create 32-bit data frame according to NEC protocol
16-bit_address = (address << 8) + counter;
16-bit_command = (enc_command << 8) + ~enc_command;
32-bit_message = (16-bit_address << 16) + 16-bit_command;

// Send message via IR communication
IR_send(32-bit_message);

counter++;
```

7.2 Power Saving Techniques

One of the biggest constraints for our system is power consumption, since we would like to run the system fully on solar power when possible. Therefore we need to design our software to use as little power as possible using power saving techniques like low power modes and disabling peripherals when they are not needed.

7.2.1 Main System

To save power for our main system, we want to have as much of the system off as we can while the system is dormant. The only peripheral that we need to be active while the system is in a dormant state is the motion sensor, so we will turn off as many of the functionalities on the microcontroller as we can to maintain functionality, and wake up the system based on an external interrupt from the motion sensor.

The ESP-32 has several low power modes we can use, but the ones we are most interested in using are the deep-sleep modes and the hibernation mode. Deep-sleep mode consumes more power than hibernation mode since more modules of the microcontroller are on, including the ULP coprocessor, the RTC timer and the RTC memory. We can also change which of these modules are on, if we have them all on the power consumption is 150 μA; with only the RTC timer and memory on, it is 10 μA. In hibernation mode, only the RTC timer is active, consuming 5 μA. Deep-sleep mode allows a couple different sources to wake up the microcontroller, but in hibernation mode only the RTC timer or the RTC GPIO pins can wake the chip up. One problem with hibernation mode is that since the RTC memory is disabled, data stored in the temporary storage will not be saved. This can be fixed by storing data we need in the flash instead.

Considering these low-power modes, it would be best if we used the hibernation mode. With this we can connect our motion sensor to one of the RTC GPIO pins so that if the pin goes high, our system wakes up. This can be implemented using the function esp_sleep_enable_ext1_wakeup(bitmask, mode), where we set the bitmask to whatever RTC pin we connect the motion sensor to, and the mode being ESP_EXT1_WAKEUP_ANY_HIGH, which sets it so if any of the GPIO pins we selection are high the microcontroller will wake up.

7.2.2 Collar System

Power saving is especially important for the collar since it runs on a battery and does not have an option to be charged from an outlet if it runs low. The collar system has few components, being the microcontroller and the IR receiver and emitter, so our options for saving power with software are limited. The IR emitter is easy to save power on, since it will only be active when sending IR signals.

For our microcontroller, we plan on keeping it in a power-saving mode for as long as possible, ideally only when transmitting IR signals. The ATtiny85 we are using has 3 power-saving modes: idle mode, ADC noise reduction, and power-down mode. Out of these modes we will definitely not be using the ADC noise reduction mode, since this is intended for getting better resolution with the ADC which we are not using. The idle mode would be the easiest for us to use, since it only disables the CPU and flash clocks, so waking the microcontroller up from this state is no problem. Power-down mode would provide the highest reduction in power consumption, since it disables all clocks, but in our case can only be woken up by a USI start condition interrupt, an external level interrupt on INT0, a pin change interrupt, or a Watchdog reset.

One design we considered is a design that relies on periodically turning on the system for a brief moment to check for any IR signals, and going back to low power mode after. For example, we could keep the system in low power mode for 800ms, check for signals for 200ms, and then continue repeating this cycle. It is a fairly simple solution to implement, all we would need to do is use a timer to time when to turn the system on or off, and then disable everything except for that timer in the off time. This method would reduce the power consumption to the fraction of the on time over the total cycle time, in our example this would be

200 ms / (200 ms + 800ms), coming out to ⅕ of the power consumption. Still, we would need to have at least one clock running all the time with this method, which increases our power consumption.

A disadvantage of this approach is that if a signal is sent in the downtime, the system will not receive this signal. This can be circumvented by repeatedly transmitting the same signal to the collar, so that the collar would eventually pick up the signal when it turns on. This does introduce some latency however, and the longer we make our downtime period the longer latency there will be for the signal to be received. Additionally, there is a limit on how short we can make the uptime period, as the system needs enough time to reactivate the microcontroller and the IR receiver and also to receive and process the signal. Despite these disadvantages, this method could still considerably reduce our power consumption, and it is relatively simple to implement.

Another design we considered relies on having an interrupt triggered by the IR receiver whenever a signal is detected, keeping the system in low power mode until then. For this method to work, we could only wake up the microcontroller with a low level interrupt on the INT0 pin. The interrupt could also be triggered by a falling or rising edge, but this would require an I/O clock to be running for the edges to be recognized, which would consume power.

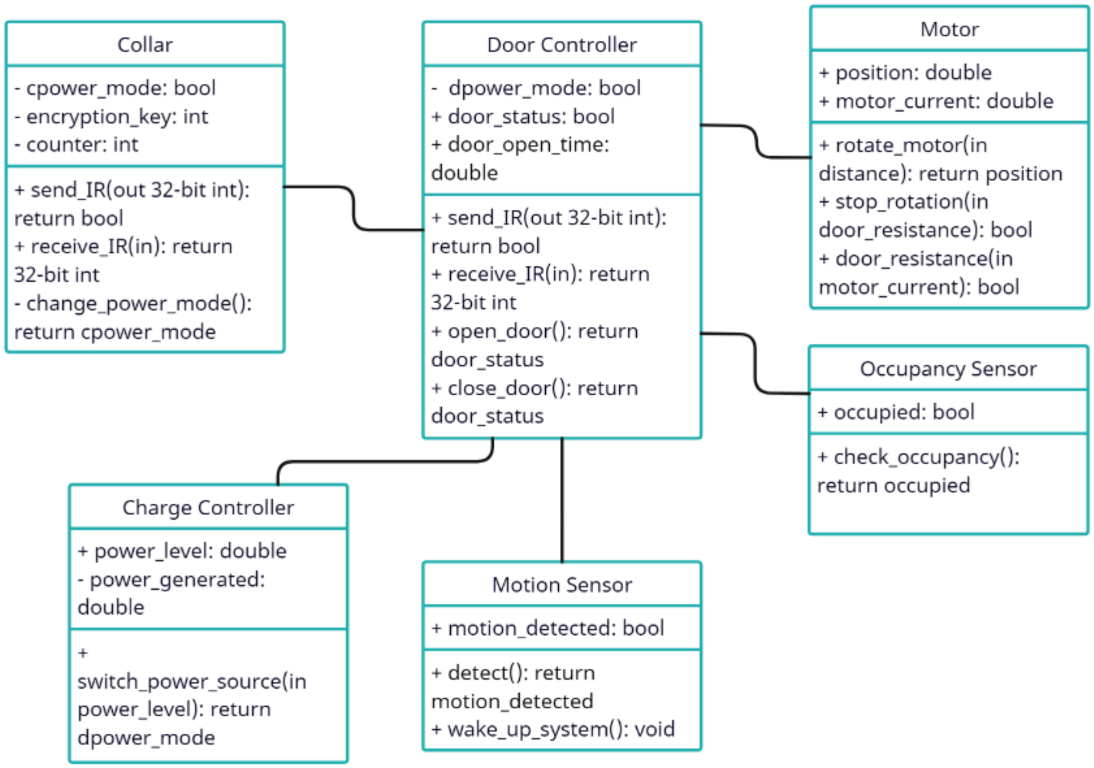
A disadvantage of this method is that we would need the IR receiver to be active all of the time for this method to work, which would consume additional power. The advantage of this method is the low latency compared to our first method, since the receiver is always on it will immediately respond to the wakeup signal. The method we choose to use will be based on which method consumes less power, but due to the added complexity of the second method and the fact that the IR receiver must always be on with this method, it is likely that we will use the first method.

In addition to our power saving scheme, there are some modules that the ATtiny85 datasheet recommends disabling for saving the most power. One module we can disable is the brown-out detector, since when it is on it is consuming power actively monitoring the voltage supply. The brown-out detector is automatically enabled when exiting sleep mode, but it also increases the wake-up time, so our choice of whether or not to disable it depends on which of our power saving schemes we use. Another module we can disable is the watchdog timer, since we are not going to need to use it we will save a lot of power by disabling it. Lastly, we need to make sure to configure our port pins to use minimum power. We need to make sure that none of our pins are floating between ground and Vcc, this causes excessive power draw, so we must ensure these pins are set to either ground or Vcc.

7.3 Class Diagram

The class diagram shows the different classes in our system. Our class diagram shows six classes: the door controller, the dollar, the charge controller, the motion sensor, the occupancy sensor, and the motor. The IR transmitters are included within the classes of the collar and the door controller, since both systems have IR transmitters. The door controller is the main element of our system and has communication with every element, so every class is connected to it.

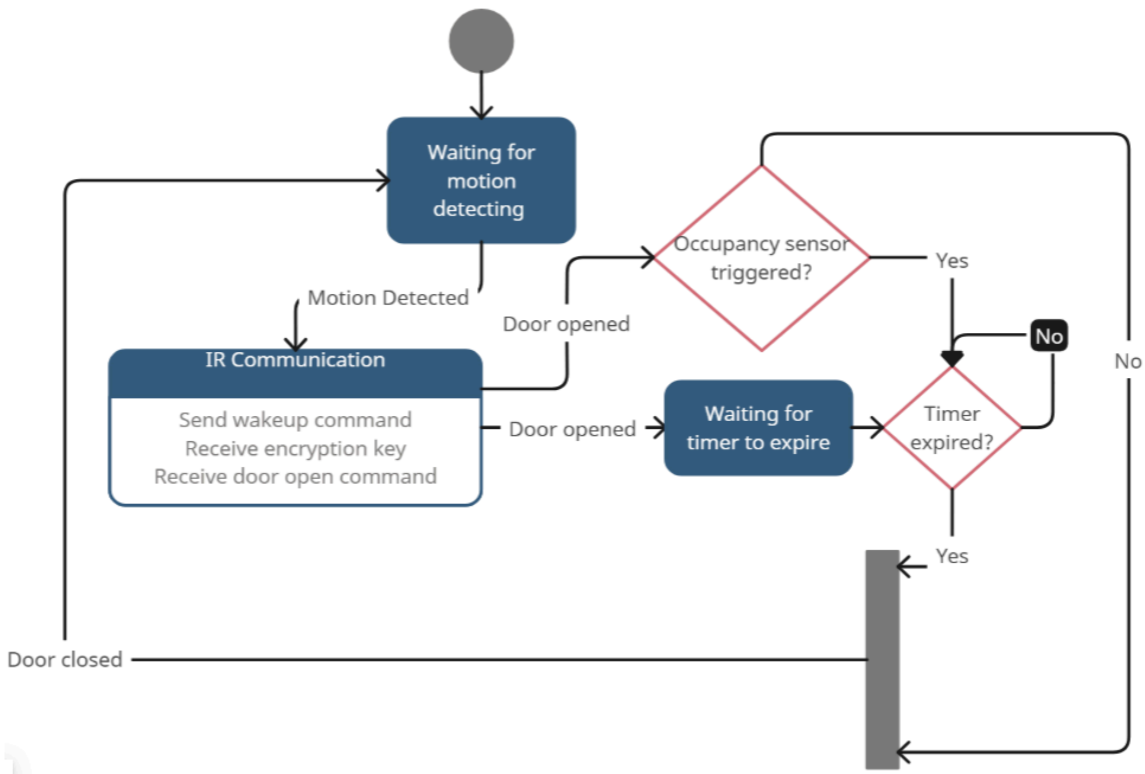
The controller communicates with the motor to tell it when to open or close the door, and the motor communicates with the door telling it whether or not the door is open. The motor can also tell the current position of the door and how much it needs to rotate to get to that position, as well as detecting any resistance on the door by how much current is running through the motor. The occupancy sensor tells the controller if the door is occupied, and the controller tells the occupancy sensor when it should be on or off. The motion sensor can detect if there is motion and return this as a boolean value, which is communicated to the controller and wakes the controller up if true. The charge controller can tell how much charge the system has, communicating this information with the controller, and based on the amount of charge can switch the system to be powered by the electrical outlet. Finally the collar is woken up by the door controller through an IR wakeup signal, which changes the power mode of the collar to active. The door controller and the collar then communicate to each other through IR signals, sending the encryption key and door opening commands.



7.4 State Diagram

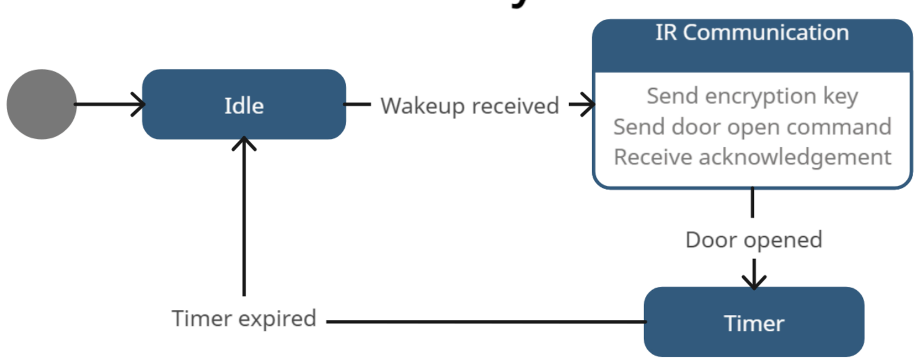
The state diagram shows the different states of our system and what actions cause the system to transition from state to state. This diagram covers the states of both our main system and our collar system.

Main System



Our main system starts in the idle state, where it is waiting for the motion detector to activate. Once motion is detected, the system moves to the IR communication state, where the wakeup command is sent, the encryption key is received, and the command to open the door is also received. The system then moves to the state where the door is open, and is waiting for the timer to expire. If the occupancy detector is triggered during this time, the timer will be reset. Once both the timer has expired and the occupancy sensor is not triggered, the door will be closed. The system then moves back to the idle state, since in our system there is no final state.

Collar System



In our collar system, the system also starts in an idle state. It remains in this state until the wakeup command is received, which then transitions the system to the IR communication state. The collar system then sends the encryption key to the main system, sends the door opening command, and finally receives acknowledgement that the door is open. The collar system then moves into the timer state, where the collar system is still active and able to receive signals. Once the timer expires, the collar system returns to the idle state.

8.0 System Fabrication/Prototype Construction

One of the most important parts of our project is designing a PCB, where most of the components of our system will be placed on. While we have not yet been able to design a full prototype of our PCB, we have researched multiple PCB manufacturers which we can order our customized PCB from once we have it fully designed. In addition, we have made technical considerations for us to follow when designing our PCB, which will help us in designing our PCB.

8.1 PCB Manufacturers

There are many companies out there who can print a customized PCB, some companies offering benefits that others do not. We researched some of the most popular PCB manufacturers which we would consider using for our PCB, highlighting the benefits they provide.

JLCPCB

JLCPCB is one of the most popular PCB manufacturers, being the choice of many other senior design groups. They offer some of the cheapest prices for PCBs out there, generally having better prices then PCBWAY. JLCPCB is based in China, so their shipping times will be longer than those from a manufacturer in the US, but this extra shipping time may be worth it considering the lower cost of manufacturing in China. JLCPCB also offers PCB assembly services, which may be useful for certain components that they have in stock which would be more expensive for us to purchase ourselves, or for components which are difficult to hand solder.

PCBWAY

PCBWAY is another popular PCB manufacturer, also based in China like JLCPCB. Their boards tend to be more costly than those from JLCPCB, but customers tended to get better quality boards from PCBWAY than JLCPCB. PCBWAY also has an assembly service, and seems to be better for PCBs that have components which require more sensitive handling then JLCPCB's assembly.

OSHPARK

OSHPARK is different from JLCPCB and PCBWAY since it is a company based in the US, in Oregon, rather than in China. The manufacturing costs are more expensive then these Chinese companies, but they offer free shipping for US orders which is a big perk for us. OSHPARK also has more catering to smaller-scale orders for prototyping and hobbyists, so we could place a smaller order with them then with one of the Chinese manufacturers. The downside of OSHPARK is that they do not offer PCB assembly services, but if this is a service that we do not end up needing, OSHPARK could be a good option for us.

8.2 PCB Design Considerations

To make a working PCB, there are some design considerations that PCB designers recommend we should follow, some which are more general, and some which are more specific to components like ICs and voltage regulators.

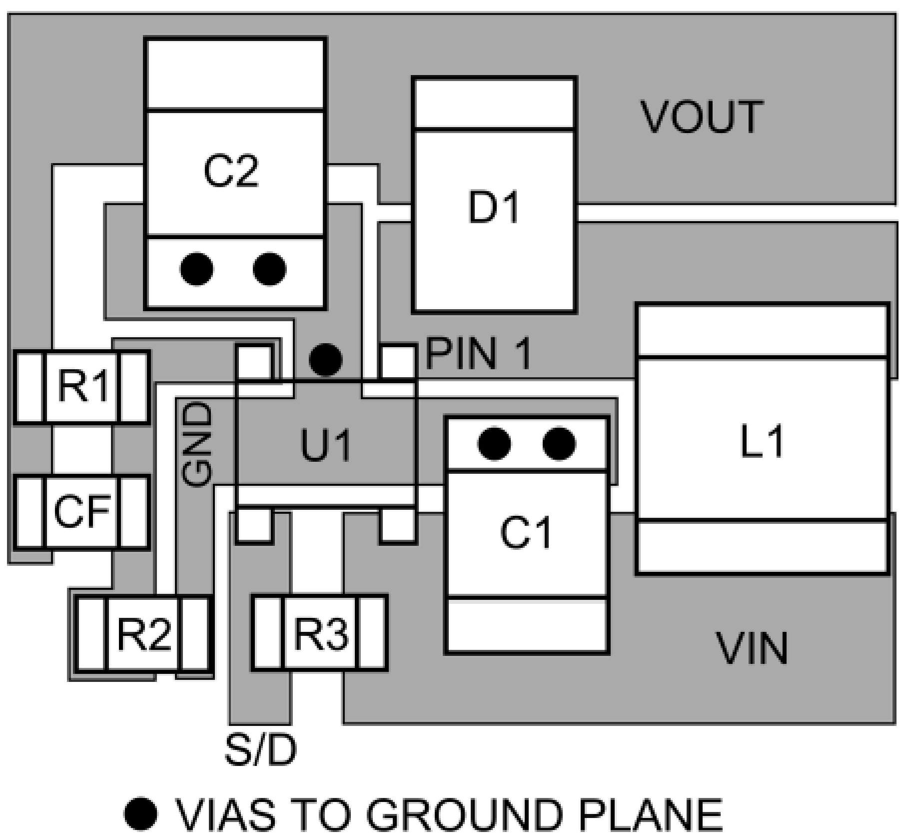
8.2.1 General Design Considerations

When designing our PCB, there are many technical elements we must consider to ensure our PCB works properly. Ideally we will try not to use component sizes smaller than 0603, since anything smaller is quite small and difficult to solder on by hand, but if we must use these smaller sizes, then we need to have these parts assembled onto our PCB by the manufacturer. For our ICs, we should get those with pins that are on the sides of the IC, not those with pins that are under the chip. This will make our ICs much easier to work with, they will be easier to remove if we need to remove them, such as if our IC fails for whatever reason and additionally having pins on the side of the IC makes it much easier to analyze the signals from it.

Another important factor to consider is our trace widths, we need to make sure we select the right trace width for each component. Generally, we should use a minimum of 0.033” wide traces when possible, but for certain components we may need to make the traces smaller in order for them to fit. In addition, we need to make the power supply traces much wider than the signal traces, since they draw much more current. The exact width can be calculated based on how much current is expected to flow through the trace. In addition to trace width, we must also consider the space between traces, and between traces and ground planes, we should generally use 0.033” or more of space.

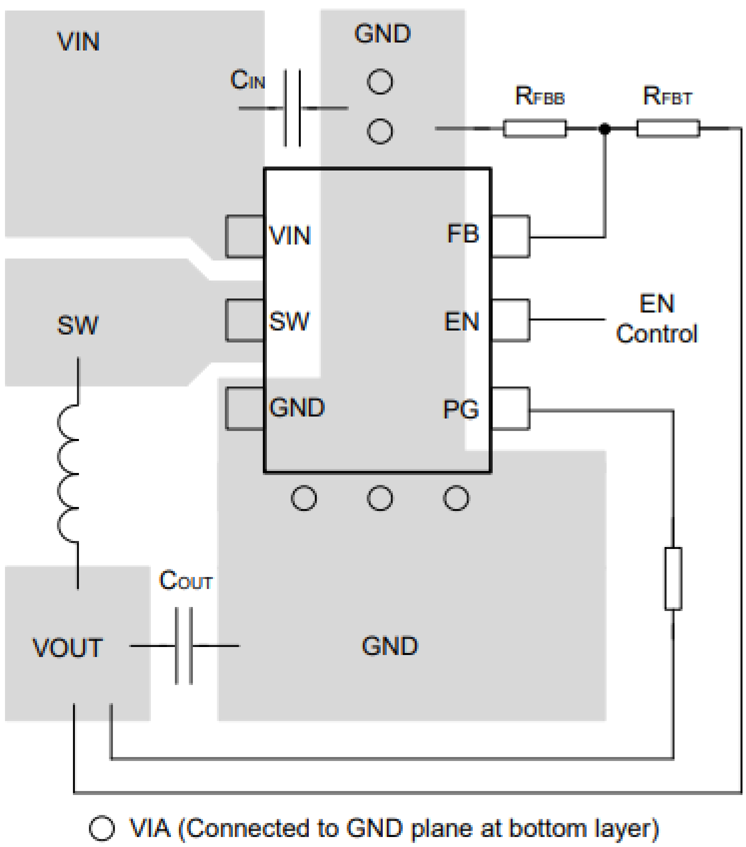
8.2.2 Regulator Design Considerations

When it comes to the regulator circuits, it is recommended that we include a 0-ohm resistor at the output of each regulator, since this makes it much easier to read the output of the regulator and debug the circuit. We must also consider the thermal specifications of these regulators. Regulators can get quite hot, so depending on the load we require from them we may need to use a heatsink to meet these thermal specifications. Therefore we will need to do the temperature calculations for our regulators to make sure they can handle the thermal requirements, otherwise our PCB may have major problems with overheating and not function. In addition to this, we are using switching regulators, which since they switch at high frequencies like 1.2 MHz and 1.6 MHz, we need to take extra considerations for these for stable operation and low noise. The datasheets for the switching regulators we are using provide certain recommendations and PCB layouts for us to follow.



LMR62014 PCB layout recommendation from datasheet

For our LMR62014 boost regulator, which is being used in our 5V/12V DC/DC converter, the recommended layout of components is shown. The datasheet recommends that we keep the path between L1, D1, and C2 extremely short, since parasitic trace inductance in series with D1 and C2 increases the noise and ringing. Additionally R1, R2, and CF need to be close to the FB pin of the regulator to prevent noise injection on the FB pin trace. Finally, it is recommended to use vias to connect the ground plane directly to the ground pin of the regulator, as well as the negative terminals of C1 and C2. The datasheet also specifies that all of the components need to be as close as possible to the LMR62014, due to the high switching frequency.



TPS56325 PCB layout recommendation from datasheet

For the TPS56325 buck regulator, which is being used in our 5V/3.3V DC/DC converter, the recommended PCB layout of the components is shown. The datasheet recommends that we make the VIN and GND traces as wide as possible to reduce trace impedance and dissipate heat better. It also recommends keeping the SW trace as short and wide as practical to minimize radiated emissions. Another recommendation is to not allow switching current to flow under the device, since it could interfere with the regulator operation. It is recommended to connect a separate VOUT path to the upper feedback resistor, as shown in the layout recommendation, and to also make a Kelvin connection to the GND pin for the feedback path. Placing a voltage feedback loop away from the high-voltage switching trace with a ground shield is also recommended, as well as making the trace of the FB node as small as possible to avoid noise coupling. Finally, the datasheet suggests making the GND trace between the output capacitor and the GND pin as wide as possible to minimize its trace impedance. Likely many of the recommendations for both regulators can be applied to both, but we will have to do additional research to make sure this is the case.

9.0 System Testing and Evaluation

Before building our design, some testing is necessary for our individual components. Then further testing is needed for our subsystems before putting it all together.

9.1 Microcontroller Testing

We need to make sure that our microcontrollers work and are not defective, so we will be performing some simple tests on them.

9.1.1 ESP32

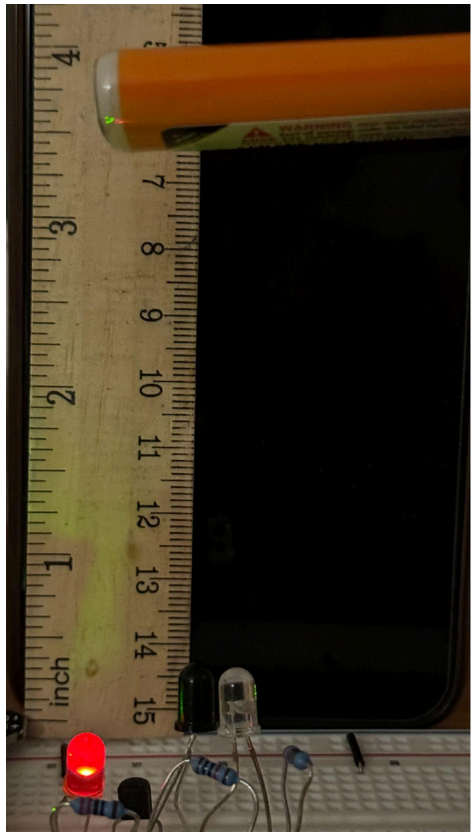
To make sure that the ESP32 was working properly, we plugged it into the computer to make sure it turned on, and it did. We then did a simple blink test with an external LED like we did for the ATtiny85 to make sure the microcontroller could properly output from the pins, and the test was successful. We tried the same test with a few of the other pins, which all worked.

9.1.2 ATtiny85

In order to test if the ATtiny85 is working we first need to burn the arduino bootloader onto the chip so that it can run arduino programs. We did this by using an Arduino Uno we had lying around, and made a setup to program our ATtiny85. We then did a simple test with a program to blink an LED, which was successful.

9.2 Motion Sensor Tests

Since our IR motion sensor works when the photodetector collects the reflected light from the IR LED, we require some reasonable detection range for our motion sensor to work as desired. To test our IR motion sensor, we constructed the simplified motion sensor circuit as seen in section 3.2.5. We wanted our motion sensor to be able to pick up reflections from objects up to a foot away, at least. We are not quite done with testing and improving our setup, but with just the motion sensor alone, we are able to easily detect objects up to 6 inches away. We wish to improve this detection range so that it does not require our cat to essentially rub up against the motion sensor. In our testing we used a lighter as our object, but further testing will need to be done using objects that are less reflective.



Initial testing of IR motion sensor using a lighter as our object.

To be fair, cats are known to rub their scent onto things so they can remember where they come from. Thus, we believe that the current detection range of our IR motion sensor will still work perfectly fine since cats will most likely learn to rub their bodies against the door frame as they approach the cat door.

9.3 Focusing Lens Tests

The Fresnel lens we chose to sit in front of the photodetector to collect more light from the IR LEDs of the cat collar has proven to give us a wider angle for our IR communication. Without a lens in front of the photodetector, we measure the collecting semi-angle to be only 10 degrees. With a lens in front of the photodetector, the collecting semi-angle increases an additional 13 degrees. This test is necessary because the IR LEDs from the cat collar will not always be pointed directly towards the photodetector. Sometimes the cat will pace side-to-side or just sit a little off-angled from the photodetector. Thus, the Fresnel lens helps to mitigate these scenarios.

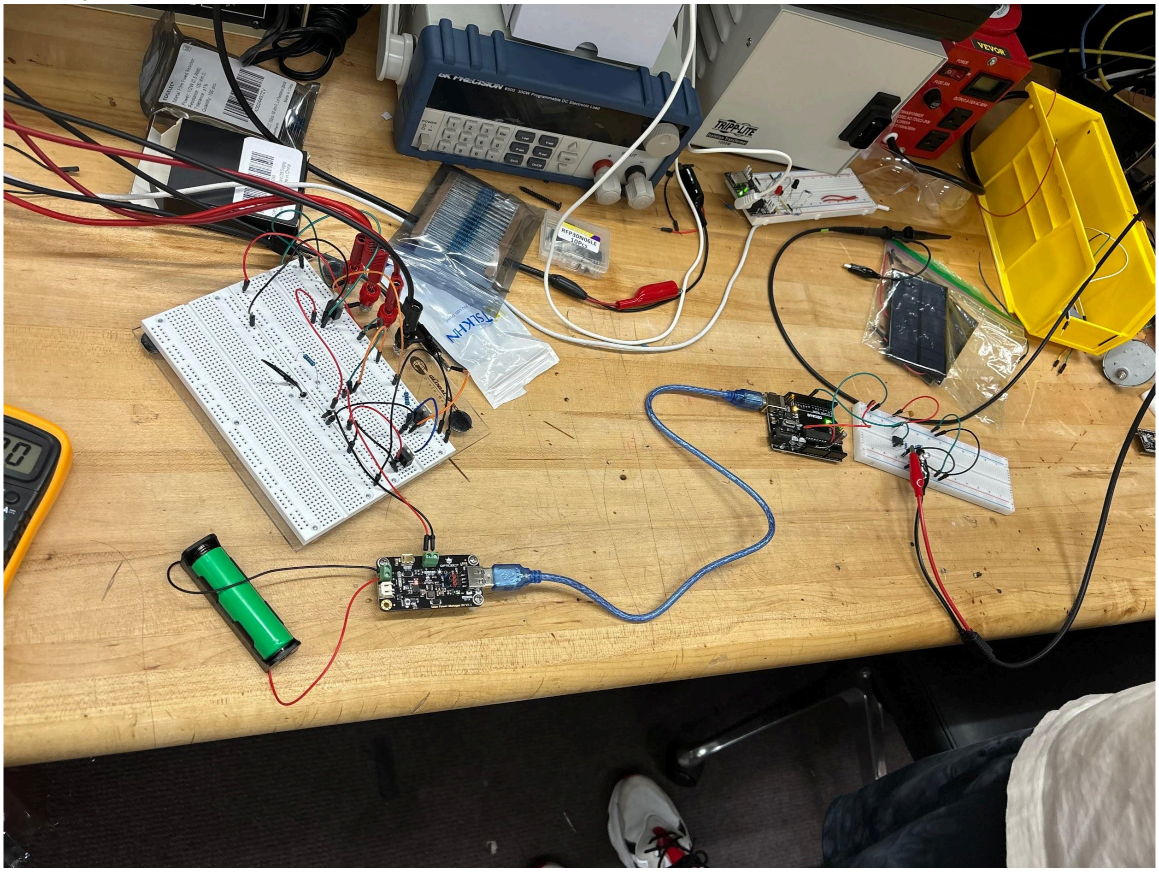
An option to possibly improve this test is to use a bigger Fresnel lens. In our testing, the Fresnel lens used has a diameter of 0.5 inches. There is a Fresnel lens with a 1-inch diameter available on Thorlabs, but that lens has a focal length of 25 mm. Fortunately our door frame can still fit that lens and photodetector bulb within the constraints of the thickness of our cat door frame. Additionally, we were advised to bring the photodetector closer than the focal length of our lens because the actual photodetector is a lot smaller than the bulb of the photodetector. So ideally, it would be best for us to have a wider spread of light onto the photodetector rather than focusing the light to a point at the focal plane. As seen in section 4.2.6, the focal point shifts greatly at various field angles. So keeping the photodetector directly on the focal plane will actually give us more problems at greater incident angles onto the Fresnel lens.

9.4 Power Manager Tests

In order to test the reliability of the solar power manager, several small tests were performed. The first test we tried was to ensure the module was able to throttle the input current it received to prevent over charging. To do this, we plugged the 5V 3A wall adapter directly into the solar in and measured the current that was inputted. When there was no battery installed or when the battery was full, the power manager completely shut off all input to prevent over charging. When the battery was not fully charged, the power manager throttled the input current to 900mA, which is the rated maximum current that the module can receive.

Next we measured the effect of having secondary components in series with the primary components that were hooked into the power manager. For example, we tested the effect of having a resistor in series with the wall adapter connected to the solar in. This resulted in a much lower voltage across the terminals and an extremely low current into the module. Next we tried using a mosfet which when activated allows for all of the power to flow into the solar in terminal with no issue. We also tested if it would be possible to step down the voltage applied to the battery terminals to charge a lower voltage battery such as a LiFePO4 battery, but every attempt ended in failure. These attempts included the use of a buck converter, voltage divider, and a potentiometer, all of which ended with the same result. When we put any of these components in series with the battery, the power manager would always read that the battery was done charging and would stop all input current. These tests made it clear that this power manager was designed strictly for 3.7V batteries.

The final test we performed was just to measure the output in different scenarios. We discovered that regardless of what is plugged into the solar in terminal, if there is a battery with charge connected to the battery terminal, then power would be properly sent to the output. Power would also be properly sent to the output if there was an appropriate amount being applied to the solar in terminal, even if there was no battery connected. If both the solar in terminals and battery terminals are connected to their respective components, and there is a component drawing from the output, then the power would first be drained from the solar terminal. Any excess power would then be added, or taken from the battery.



9.5 Plans for SD2

9.5.1 Improvement in Optics

As seen from the tests done with the motion sensor, the detection range is far below what we'd like to have for our system. In the following semester, we will work to improve the detection range of the motion sensor. This can be done by improving the circuit schematic or possibly implementing a lens in front of the photodiode to collect more of the reflected light from the IR LED. Further testing will be done to test if increasing the diameter of the lens will improve in light collection for the photodiode as well.

9.5.2 Microcontroller Optimization

Since power consumption is such an important constraint in our design, we want to ensure that we optimize our microcontrollers to use the least amount of power possible. We will test different methods of reducing the power consumption of our microcontrollers by disabling certain features, testing different hardware configurations, and optimizing our software to not use unnecessary resources. We also plan on moving the actual microcontroller chip of the ESP32 from the development board on our custom PCB, so we will adapt the development board circuit to our PCB with only the necessary components to run our ESP32. This will also help with the power consumption, since the extra components on the dev board consume extra power.

10.0 Administrative Content

For college students, we are very limited in accessible funds to complete our product. As such, a budget is made based on our current situations. We expect our design to cost no more than our estimated budget by the end of the Senior Design 2.

10.1 Budget Estimates and Financing

Component	Quantity	Estimated Budget	Total Budget
Microcontroller	1	$15	$15
Infrared Photodiodes	3	$1	$3
Infrared LED	6	$0.60	$3.60
Infrared Detector	1	$1	$1
Infrared Motion Detector	1	$5	$5
Lens	1	$50	50
Wireless Receiver	2	$3	$6
Wireless Transmitter	1	$3	$3
PCB	10	$200	$200
Motors	3	$5	$15
Motor Drivers	3	$5	$15
Solar Panel	1	$20	$20
Rechargeable Battery (collar)	1	$3	$3
Rechargeable Battery (door)	1	$20	$20
Cat Collar	1	$1	$1
Power Supply Unit (PSU)	1	$15	$15
Total Cost			$375.60

- Note - PCB and PSU costs include miscellaneous electronics like resistors, voltage regulators, etc.

10.2 Bill of Materials

Component	Quantity	Price Per Unit	Total Cost
Solar Panel	2	$2.10	$4.20
Solar Power Manager	1	$13.90	$13.90
Door Battery	1	$7.95	$7.95
Collar Battery	1	$7.99	$7.99
Wall Adapter	1	$5.00	$5.00
ESP32	1	$9.99	$9.99
ATtiny85	1	$1.66	$1.66
DC Motor	1	$12.90	$12.90
IR LED (940 nm)	10	$0.31	$3.10
Photodiode (940 nm)	10	$0.31	$3.10
Fresnel Lens	1	$20.68	$20.68
Total Cost			$90.47

10.3 Table of Work Distributions

Photonics Engineering	Responsibilities
Christopher Vanle	Optical Design and Implementation
	Computer Integration
	Mechanical Design
	Software Design and Implementation (Secondary)
	Administrative Content
Electrical Engineering	**Responsibilities**
Davis Rozel	MCU Selection and Implementation
	PCB Design (Secondary)
	Wireless Communications
	Software Design and Implementation (Primary)
	Website Design and Management
Electrical Engineering	**Responsibilities**
Daniel Hemmerde	PSU Design and Implementation
	PCB Design (Primary)
	Motor Control and Implementation
	Solar Power and Power Storage
	Software Design (Secondary)

10.4 Project Milestones

Task	**Who**	**Duration**	**Status**

Team Formed	Group C	January 4th, 2024	Completed
Design Brainstorming	Group C	January 16th, 2024	Completed
Design Final Selection	Group C	January 23rd, 2024	Completed
Role Selection	Group C	January 25th, 2024	Completed
Research Components	Group C	February 2nd, 2024	Completed
Initial Project Document - D&C	Group C	February 2nd, 2024	Completed
Design Schematic	Group C	March 14th, 2024	Completed
Bill of Materials	Group C	March 25th, 2024	Completed
Table of Contents	Group C	March 28th, 2024	Completed
Half-way (45-page) Draft	Group C	March 29th, 2024	Completed
¾ Way (65-page) Draft	Group C	April 9th, 2024	Completed
Final Document (90-page)	Group C	April 23rd, 2024	Completed
Order Components	Group C	April 23rd, 2024	In Progress
Senior Design 2	Group C	Fall Semester	
PCB	D.R. and D.H.	Fall Semester	
PSU	D.H.	Fall Semester	
MCU	D.R.	Fall Semester	
Motors	D.H.	Fall Semester	
Sensors	C.V.	Fall Semester	
Diodes/LEDs	C.V.	Fall Semester	
Computer Software	D.R. and C.V.	Fall Semester	
Collar	D.H. and C.V.	Fall Semester	

Design Testing	Group C	Fall Semester	
Demo Presentation	Group C	Fall Semester	
Redesign and Testing	Group C	Fall Semester	
Final Testing	Group C	Fall Semester	
Final Presentation	Group C	Fall Semester	

11.0 Conclusion

From the start of the semester our team was convinced that our project had to be the automatic cat door. This idea originated from most of us having indoor-outdoor cats and the struggle that comes from letting them back in when the time that they would return was a mystery. This problem compounds when the owner must leave the house or is put in a situation where they cannot open the door. Despite our initial proposal being denied due to the lack of photonic components, we persevered and simply worked around this feedback to evolve our plan to include IR sensors and an LED collar. With this updated proposal being accepted, we began to pour our everything into ensuring the success of this project

We believe our project will carve itself a healthy spot in the pet door market due to its innovative approach and lower end price. Most other pet doors tend to either be a single physical flap with no protections or overly expensive, and we seek to hit a happy medium between these. Through the use of an LED collar, we can add protections to the door while avoiding expensive microchips that can only be used by one pet. We believe that our product will give cat owners the option to let their pet roam free to their heart's content, without the worry of them being unable to re enter without them, while simultaneously keeping out any unwanted visitors.

Declaration

We hereby declare that we have not copied more than 7 pages from the Large Language Model (LLM). We have not utilized LLM for drafting, outlining, comparing, summarizing, nor proofreading purposes.

Appendix A - References

[1] Foreman-Worsley R, Finka LR, Ward SJ, Farnworth MJ. Indoors or Outdoors? An International Exploration of Owner Demographics and Decision Making Associated with Lifestyle of Pet Cats. Animals (Basel). 2021 Jan 20;11(2):253. doi: 10.3390/ani11020253. PMID: 33498511; PMCID: PMC7909512.

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Appendix B - Permissions

1: NEC Communication Protocol figures from https://www.sbprojects.net/knowledge/ir/nec.php

Sure You Can

Sometimes I'm being asked if it is allowed to use a copy of a certain picture, or a piece of my text. What can I say? Of course you can! If it's just a picture, go ahead, take it. If it's a piece of text or an entire project, go ahead, take it. However the bigger it gets, the more I'm inclined to urge you to put a reference to your source somewhere.

Can I take your hardware project and turn it into a commercial product? I guess you can. I'm not interested in making it a commercial product, unless I specifically state otherwise.
However I would appreciate it if you would want to share a bit of your profits if it turns out to be a big hit.

Appendix C - Datasheets

1. Super-bright 5mm IR LED - 940 nm
   https://cdn-shop.adafruit.com/datasheets/IR333_A_datasheet.pdf

2. Espressif Systems. ESP32 Series Datasheet. report, 2024, www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pd.
3. Atmel. “ATtiny25/45/85 [DATASHEET].” ATtiny25/45/85 [DATASHEET], Aug. 2013, ww1.microchip.com/downloads/en/devicedoc/atmel-2586-avr-8-bit-microcontroller-attiny25-attiny45-attiny85_datasheet.pdf.
4. TPS56325 Switching Buck Regulator https://www.ti.com/lit/ds/symlink/tps563252.pdf?ts=1713864848386
5. LMR62014 Switching Boost Regulator https://www.ti.com/lit/ds/symlink/lmr62014.pdf?ts=1713831508918