ECE 2799
Homework 6
Electronic Dog Door

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Introduction

For this project, we were tasked with developing an electronic device that enhances the relationship between pets and their owners. With our budget of $50, our product needed to assist in the safety, health, monitoring, or analysis of any pet we chose.

To meet this goal, we decided to create an electronic dog door. This door would unlock when the dog gets close and relock when the dog leaves. It would only unlock for the customers' animals, thus keeping out wild animals such as raccoons.

This report explains the entire process of creating our electronic dog door. We begin by summarizing the market research and explaining how this research influenced the requirements of the dog door. Using these requirements, we conducted a competitive value analysis to determine how our product would compare to similar products already on the market. Next, we discuss the overall design of the dog door and the design of its individual modules. We explain how each module works, how it has been tested, and how it has changed over time. Finally, we describe the final functionality of the product, its final cost, and its shortcomings.

Market Research

The amount of dogs in the United States shows that the pet industry in the United States is a large business. According to the American Pet Products Association, American Veterinary Medical Association, and the Simmons National Consumer Study, America has anywhere from 77 to 90 million pet dogs. This accounts for 38% to 48% of households. (Brulliard and Clements, 2019)

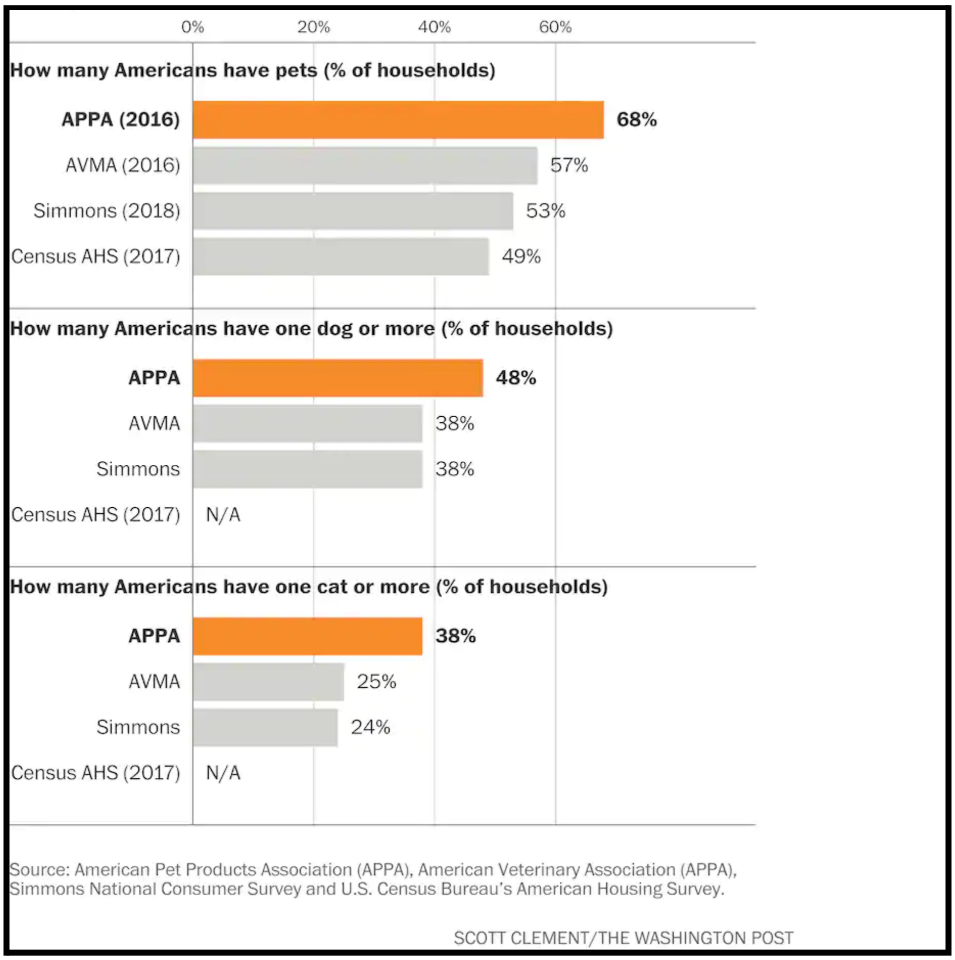

Figure 1: Percentages of pets owned by Americans measured by different organizations

Because there are so many dogs in the United States, the dog door market is large and continues to grow. According to Absolute Reports, in 2019 the dog door market was worth 450 million dollars. This is expected to grow by 7.1% over the next five years to 2024 where it is estimated that the market will be worth around 670 million dollars in the United States alone (Absolute Reports).

After getting a general overview of the dog door market in the United States, we researched products that would be our competitors. When searching “automatic dog door with collar” on Amazon, the first result is the PetSafe Electronic Smart Door with a list price of $110. In addition to being the first result found on Amazon, the websites, Technobark, SmarterHomeGuide, and SmartHomePerfected, rank the PetSafe Electronic Smart Door highly among similar products (Braeden, 2021; Snead, 2021; Miller, 2021). This door will unlock when the Smartkey, which is typically attached to the dog’s collar, gets close to the door. To lock, the door’s hard flap is slightly lowered such that the bottom falls in a crevice preventing it from moving. The dog must push its head through to open the dog door. To install this product, one must cut a hole in their exterior door and screw it in.

People have dogs of many sizes. For this reason, PetSafe has two different sizes for the product.

Door Size	Pet Size	Flap Opening	Frame Dimensions	Cut Out
Small	Up to 15 pounds	5 1/2" X 7 7/8"	9" x 15 5/8"	8 3/8" x 14 3/4"
Large	Up to 100 pounds	11" X 16"	16 1/8" x 23 5/8"	15 5/8" x 23 1/4"

Figure 2: PetSafe Electronic Smart Door sizes (Amazon 2021)

We wanted to know how much of the large version they sell as opposed to the small. We could not find any hard data on this topic, but we did notice that the large version was considered “Amazon’s Choice” while its counterpart was not. This indicates that the larger door is a better seller than its counterpart, and, by extension, that the people who make up this market tend to have bigger dogs.

Next, we looked through the people who left reviews of the PetSafe Electronic Smart Door. Based on the profiles that were available, it seems that the people who bought this product were generally between 30 and 60 years old. People in this age range are usually busy with work, and they may not want to worry about letting their dogs outside. This demographic also tends to be more financially secure. They are willing to spend money on a product that is not necessarily essential to their lives but is useful to them. Additionally, we noticed that people bought this product from all over the continental United States. Consequently, this product has a market across many different climate zones and it must operate in all of them.

The negative reviews generally targeted the product's reliability. People were often upset that their dog door had stopped functioning properly, especially after paying $110 for it. It seems that the number one thing customers want is a product that will not break or require time to maintain.

The High Tech Pet door is another product that we found on Amazon. It has a list price of about $350 - $400 and a 4.5-star review. This product also ranks high on Technobark and SmartHomePerfected (Miller 2021).

This product uses a motor to raise and lower a flap that lets the dog in and out. An ultrasound transmitter is placed on the dog's collar to activate the door and the door is able to stay shut with the use of a mechanical deadbolt lock. The manufacturer claims that the door is bulletproof and is so airtight it will not let any wind from even a hurricane through. Unlike with PetSafe, High Tech Pet does not have its two different sizes (medium and large) under two different listings, so it is more difficult to see which one the users prefer.

Looking at the profiles of the reviewers, we can see that the buyers generally consist of the same demographic mentioned for PetSafe. Overall, customers gave positive reviews of this product. People described the door as being tight and strong. One trend that we see in the negative reviews, however, is the problems with functionality over time. These reviews complain about collar parts not working and mechanics behind the door breaking. These are understandably harsh reviews as these customers have paid $350 - $400 for this dog door. For this price point and for their effort in installing this door, they would want something reliable and that would last a very long time. Most negative critics run into these issues within 4 - 8 months.

Beyond looking at the reviews of competitors, we couldn't find much data on where most of these pet door products were being sold and who would be interested in these products. To fill this gap we created a survey and sent it to the class, friends, and family to fill out. Our survey was 12 questions long. The questions establish if the responder has a dog, cat, and/or a pet door. The questions also ask if they would want to buy a regular dog door and/or a smart dog door.

We wanted to know the size of our respondents' dogs to determine the size of the dog door that would be most commonly needed. Figure 3 shows the data from that question below. There is a reasonably even split between small, medium, and large dogs. The data shows if our respondents bought a dog door that a larger size dog door would be commonly needed.

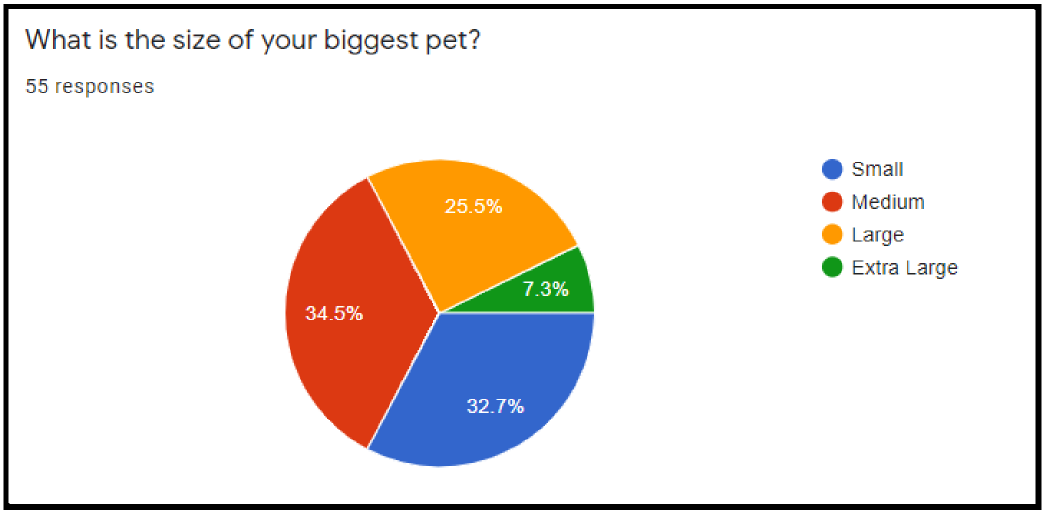

Figure 3: Size of Survey Respondents Pets

With the survey, we established how many people had pet doors. From our data, 10.9% of people had a pet door already, and 43.6% of people might be interested in buying one. However, 76.4% of the respondents said that they would be interested in an electronic pet door. This shows that not many people have dog doors and a little less than half of the people that don't already have a dog door might be interested in buying a regular one. Interestingly, there is a dramatic increase in interest in an electronic dog door. This indicated that there was a market of people who would want to buy our product.

We also conducted in-depth interviews as a part of our market research. Unlike the surveys, the interviews allowed us to get detailed information. We interviewed eight people for about ten minutes each. These interviews allowed us to get more data on what specific requirements individuals needed based on the particular situation customers had for a dog door.

We targeted people that had dogs and asked them questions similar to the survey. When asked whether they would buy a dog door, they generally answered no or were a bit hesitant to answer. Some did not understand how a dog door would be useful for them or thought that it would be a hassle. We then explained how our dog door would work. We talked about having a smart collar on the dog in order to let them in and out and manually being able to lock the dog door. After discussing this idea with them, they seemed more interested in the idea of dog doors and some people changed their previous answer and said they would invest in this kind of dog door.

Customer Requirements

First, we looked into the basic requirements of an electronic pet door. The dog door must let the dog travel through the door to the outside of the house. This sounds simple but includes making the door the correct size and shape for the dog and being able to be correctly installed into a door or exterior wall. Our door needs to be able to securely lock and only let the dog through the door. Once we had those basic features we looked at our data to determine more specific customer requirements.

In addition to providing information about our market, the reviews of competitors led to several customer requirements. First, we noticed that many people complained about it malfunctioning a short time after purchase. In the PetSafe Electronic Smart door reviews, some users were frustrated with malfunctions such as motor failure or inconsistencies in the SmartKey range. Generally, many users said that this product lasted for two to three months. For this reason, the number one customer requirement we have identified is reliability. If a customer pays the cost of a door like this and takes the time to install it, they expect a product that will not break easily and will last over time. If the dog door breaks, the consumer either has to find a dog door that fits a hole of the same size, buy the same product, or buy another door. This leads to an increased focus on the longevity of the product.

One major comment we saw regardless of brand or type of dog door was that the doors needed to be weatherproof. The doors must be able to keep out the rain and the cold. It must be able to work in different climates and at a wide range of temperatures. We have seen reviews ranging from excited that the door was able to keep out the tumbleweeds to distressed that the door constantly blew cold air and snow into the house. Our dog door must be able to seal out the weather from coming in.

The design of the flap on the dog door is critical. For example, the weight of the flap can prevent small dogs from passing through. Many customers complained that their smaller dog wasn’t able to move the flap. Although our design will not be able to accommodate all dogs due to the wide range of dog breed sizes, we will try to accommodate as many as we can. Additionally, in one interview and in many reviews customers commented on wanting the flap to be clear so that their dogs are less likely to be afraid of going through it. The person interviewed discussed how the clear flap let many of their dogs go in and out without worrying about bumping into each other. Clearly, the design of the flap is very important to the comfort of the dog.

Another complaint about the PetSafe Electronic Smart door product was battery life. The product takes 4 D batteries, and, according to reviewers, they do not last long. They claimed that replacing these batteries is not only expensive but also annoying. For similar doors, there were also complaints of changing the batteries on the dog collar. Therefore, another customer requirement of our product is that it must require less frequent battery changes.

Quiet operation has also arisen as a customer requirement. People who bought the PetSafe Electronic Smart door often complained that it would make too much noise when unlocking. They claim that it is annoying and distracting. For this reason, we will make our product such that it locks quietly.

In our survey, we asked the respondents to tell us how much they would be willing to spend on a dog door. We then later asked how much they would be willing to spend on an electronic dog door. The figures with this data are shown below. Our survey responses show us that the most people are willing to spend on a regular dog door is $100 but they are willing to spend up to $100-200 on an electronic dog door. People are willing to spend more on an electronic dog door.

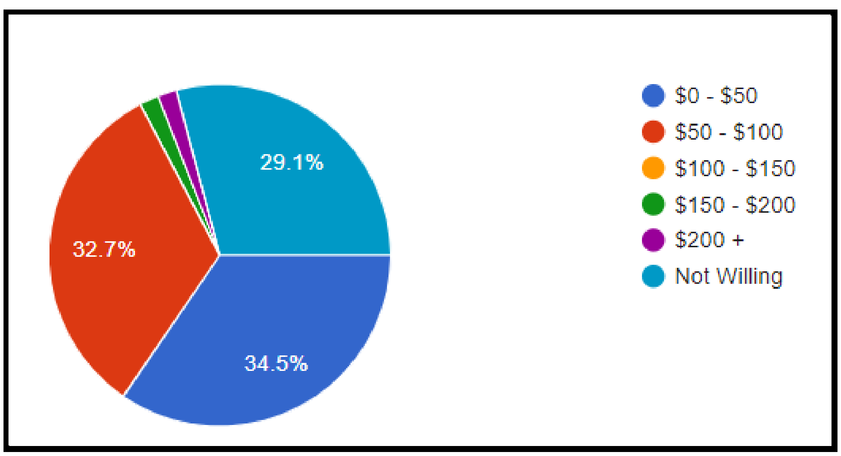

Figure 4: Price respondents were willing to pay for a regular dog Door

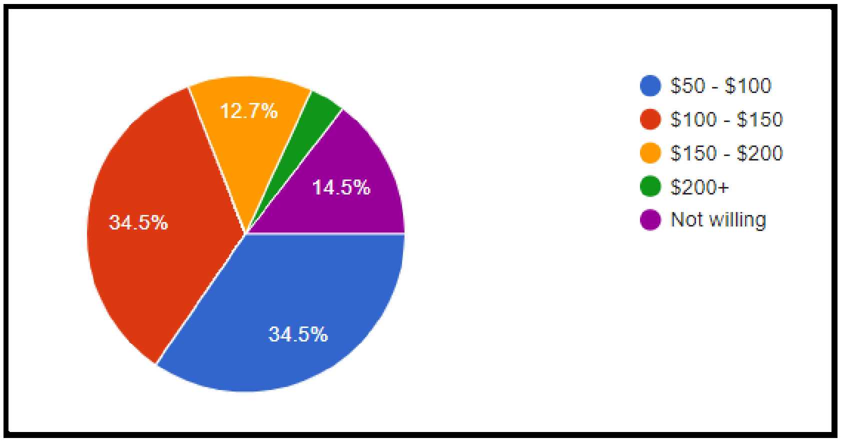

Figure 5: Price respondents were willing to pay for an electronic dog door

For this project, our core customer requirements are listed below. These requirements were taken from surveys, interviews, and reviews. They show us what is most important to the customers. Here is a summary of customer requirements.

- Basic Requirements
    - Door opens correctly
    - Door locks securely
    - Unlocks when the dog gets close to it
- Reliability
    - Weatherproof
    - Temperature resistant
    - Lightweight and clear flaps
- Accommodating door size
- Long battery life
- Quiet
- Price of $100 - $200

Product Requirements

After determining what customers would like to see in an electronic pet door we derived our product requirements. We first discuss the basic requirements of the product. We then discuss the requirements that we derived from our market research. Satisfying these requirements will make our product stand out among competing products. They are:

- Strong Materials
- Low power circuitry
- Inexpensive Materials
- Temperature independent circuitry
- Quiet

Every electronic dog door must either unlock or automatically open when a dog approaches it. We created a door that will only unlock, as a fully automatic door would likely have involved too much for a seven-week project. We do not believe that this hurts our product, as one of our most successful competitors, the PetSafe Smart Door, just locks and unlocks. Additionally, every electronic dog door comes with a collar that will trigger the door.

To make our product durable, we emphasized the use of strong, reliable materials in our mechanical design. The door itself needed to last against forces like strong winds. Additionally for the final product, we needed to use a material that will not weaken or warp when exposed to cold or warm climates. The weight of these materials was of little concern, except for the door flap itself. We found that dogs prefer when the flap is lighter, so they can go through more easily. The door flap needed to strike a balance between being light and strong. We also needed to ensure that the dog collar itself is durable. Like the door flap, a dog could not be able to break the collar, but also it could not be too heavy.

We also made our product more durable by using temperature-independent circuitry. Our transmitter needed to transmit the same signal regardless of temperature or our product would have ceased to function as intended.

One of our requirements was to create a product with reduced power consumption. To achieve this we designed circuitry that operates with low power consumption. We planned to implement simple circuit designs for our transmitter, receiver, and locking mechanism, in the hopes that this saves power consumption. The most important of these was the transmitter circuit as the door itself would be powered by a wall outlet. For the collar, we needed to use a small battery to ensure weight is minimized. We expected that using low power circuitry will enhance the durability of our electric components as well.

We wanted to keep the cost of our product as low as possible, so we tried to use inexpensive materials and components. However, we did not sacrifice durability to cut costs. As shown in our market research, products that are not durable frustrate users. We thought that people would pay more if they believe they are getting a product that will not fail soon after receiving it.

Lastly, we ensured that our product operates quietly. Amazon reviews of the PetSafe Electronic Smart Door suggest that it is too loud, and this is irritating to the consumer. The sound was considered when we designed the locking mechanism of our dog door.

Product Specifications

Our system is made up of two main components: the door and the collar. The door electronics will be bigger and stationary while the collar components will move around with the dog. These two components can communicate with each other using a transmitter and a receiver. The collar has a battery and a transmitter on it. The door has many more components including the power supply, receiver, swing detector, logic processor, and locking mechanism.

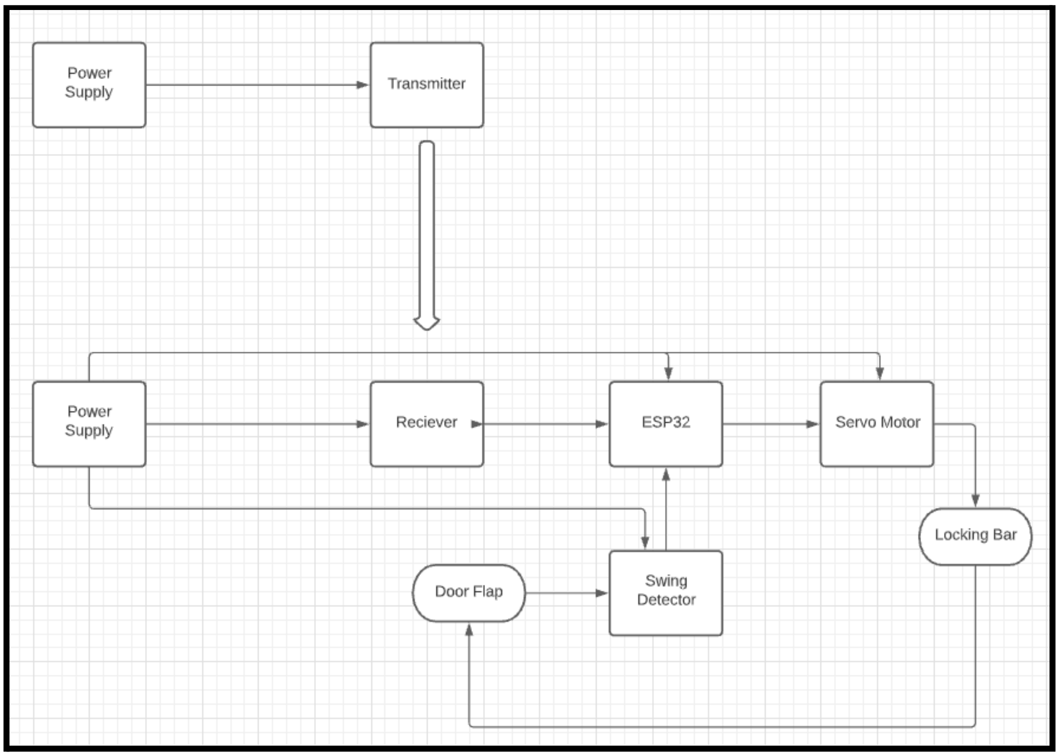

Figure 6: Electronic Dog Door System Diagram

The first part of our system is the collar. The collar contains the battery and the transmitter which will be used to communicate with the door. Our collar component is designed to attach to an existing collar that the dog already wears. This way, we won't have to worry about the durability or size of the strap that goes around the dog's neck.

The first main component of the collar is the battery. Due to it being mounted on a collar and worn by a dog this battery will need to be small and light. We want a max collar weight of half a pound based on the size of the smallest dog breeds. For this purpose, we used small cell batteries. The larger cell batteries have more amp hours so will last longer before needing to be changed. The collar batteries must last 1-2 months before being changed. We balanced the battery life versus the size of the battery. Also when designing the transmitter for the collar we made it low power in order to maximize the battery life.

Attached to the collar of the pet will be some kind of signal transmitter. There are many options that can be used for a transmitter like infrared, radio frequency, and ultrasound. Our door uses radio frequency. Due to the size requirements of the battery, the signal will need to be generated with relatively low voltage. The signal transmitted should not use too much power to ensure it can transmit a signal for a long time without fail. The signal should also transmit at least one meter so the dog does not have to be directly touching the door in order for the door to activate.

The second larger part of our system is the door itself. The door has to be reasonably easy to install using hardware that is easy to find and replace. Our door should be no bigger than 24" by 17" which is the size of the large PetSafe Door. This size door will fit most dogs based on survey results. This door will process signals from the collar and the swing detector and will lock and unlock based on those signals.

To power the electronics on the door, we needed a power supply. In our door, we use a 120V AC to 5V DC power supply. We do not want temperature changes beyond the range of 0 to 100 degrees Fahrenheit to impact this voltage. The power supply will provide power to the receiver, locking mechanism, processor, and swing detector.

The receiver can take the signal from the collar. The receiver takes the signal input and the processor interprets it as a value of zero or one that indicates if the transmitter is in range. This electrical signal output of the receiver is a small digital signal that feeds into our processor. The door should be able to detect signals coming from both sides of the door and at a reasonably short distance of about one meter.

We also implemented a swing detector to control the lock. If our lock is controlled only by the receiver, the door may lock while the door flap is still swinging. This could cause our locking mechanism to malfunction. The swing detector tells the logical processor if the door has stopped moving and if it can lock. To implement this, we used a sensor to detect if the door is still swinging. This would allow the unit to lock as soon as the door has stopped swinging.

For logic processing, we used a microprocessor unit. This microprocessor takes input from the receiver, switch, and swing detector and outputs a signal to the locking mechanism. This logic processor must be able to quickly process these inputs and outputs to control the door.

One option that we added to the door was the ability to give the dog owner control over what times their dog could go outside. This input is a simple switch which when on the dog can pass through the door normally and when the switch is off the dog can no longer go outside. This allows the user to choose when the dog is allowed outside.

To enter the door, the dog pushes its head through the door flap. The door flap rotates about the top of the door like in regular dog doors. Our door flap is unbendable, so it can lock securely. We need a balance between weight and durability for the door flap. For the final product, we would like to use a strong material that will not break over time, but it will need to be light enough that a dog will be able to push it. Ideally, it would also be a transparent material so that the dog will be more comfortable going through it.

Lastly, there is a mechanism to lock the door. This mechanism securely locks the door to ensure that nothing can get through when the door is locked. It should be able to withstand the pushing force of at least a large dog. The door will be normally locked and only be unlocked when the dog collar gets within range. When the door is locked the locking mechanism should be only drawing minimal to no power. This mechanism is a mechanical piece that stops the movement of the door and is moved out of the way by electrical means to unlock.

Competitive Value Analysis

In this section, we compare our door to others on the market. To do so, we made a value analysis chart. Here is the following table for the dog door comparisons:

	Reliability (20)	Lightweight and clear flaps (5)	Accommodating door size (4)	Long battery life (12)	Quiet (3)	Price (6)	Total
Pet Safe	12	3	3	4	1	4	27
High Tech Pet	15	5	4	10	1	3	38
Our Product	16	3	3	8	2	4	36

Figure 7: Value analysis for current marketplace products

While looking at customer reviews many expressed frustration with the lack of longevity in the competitor products. Given that the dog doors are reasonably expensive and that in order to install the door the consumer must cut a hole in an exterior door the expectation of reliability over time is reasonable. For our competitive value analysis, we gave reliability a weight of 20. We gave the Pet Safe door a 12 out of 20 because many of their reviews said that the door broke after about 2-3 months. For High Tech Pet, we gave them a rating of 15 because they also had some reviews indicate they broke over time as well. We gave ourselves a 16 due to our reliable design but since it has not been tested for longevity that was the highest value we felt we could go.

Dog breeds are many different sizes and later we will discuss creating a door size to accommodate the most number of dogs. First, we will discuss making the flap functional for as many dogs as possible. Especially on larger size doors, the flap will need to be very light for the smaller dogs to be able to move it enough to get through the door. The flap also should be transparent to make the dogs feel more comfortable going through the door. We weighted this criteria at a 5 on our value analysis. We gave Pet Safe a 3 on this because their flap is not clear but is lightweight. High Tech Pet also does not have a clear flap but we gave the door a 5 because the door moves on its own when the dog gets close. In this way, they avoid both the need for a lightweight or clear flap. We gave ourselves a 3 because our flap will be light but is not clear.

As stated above, our doors need to be able to accommodate all different types of breeds of all different sizes. This requirement isn't as important to us, as small dogs should be able to open medium-sized doors. The market also shows that there are more medium-sized dogs than any other size. PetSafe has doors that come in small and large sizes. Since they have multiple-sized doors, we gave them 3 points. High Tech Pet gets full points on this category as they have an automatic opening door, meaning that the dog won't have to push their way through. Our door would be a similar build to the PetSafe door, where it would only lock and unlock. This means that we would also have to build doors of different sizes. This is why we gave ourselves a 3.

For the PetSafe door, there were many complaints about the battery life. They complained that the door took too many batteries (4 D batteries) and the collar does not have a replaceable battery. This means that the customer would have to purchase a new smart collar if the old one runs out of power. This is why we gave the PetSafe door, a 4 out of 12. The High Tech Pet door does a much better job at battery management. You can either use AC power from a wall outlet or you can use their included rechargeable battery. Due to the multiple options given and the fact that you don't have to buy batteries, we gave this product a 10 out of 12. Our product will exclusively use a wall outlet. Which loses some flexibility but means that the customer doesn't have to change any batteries in the door. We run the collar with cell batteries to make them easily replaceable. Given this, we gave ourselves an 8 out of 12.

Quiet operation was another customer requirement. If the product is loud, it will be annoying for customers and could potentially scare a dog. Compared to the other customer requirements, this requirement was relatively unimportant, so weighted it as a 3. On Amazon, both the PetSafe Electronic Smart door and the High Tech Pet Door received reviews indicating that their products were too loud and therefore annoying to customers. For this reason, we gave these products a 1 for this category. We believe that our product will operate more quietly, but we do not expect to eliminate noise entirely. Unlike the other two products, whose locking mechanism moves the entire door flap, our locking mechanism only moves a servo. Because we will not need to move a large load, our product operates more quietly than those already on the market.

Electronic doors come in a variety of prices. According to our market research, price is not the most important factor in designing an electronic dog door, as consumers are more concerned with buying a quality product. However, these products still must be cheap enough, so they don't deter customers. We weighted the price as a 6 in terms of importance. The High Tech Pet Door is by far the most expensive door, with a price of $350 to $400, so we ranked it as a 2. The PetSafe Electronic Smart door is much more affordable, with a list price of $110, so we ranked it as a 4. Our product is $129.99, which is more expensive than PetSafe but much less than High Tech Pet. We gave ourselves a 4 for the price.

Design Approach

RF Receiver

Attached to our dog door is the RF receiver which will take a signal from the collar. The receiver outputs constant voltage pulses which are averaged in order to determine whether it is getting a signal or not. We are using the AM-RX12E-433 module for its low current draw and ease of use.

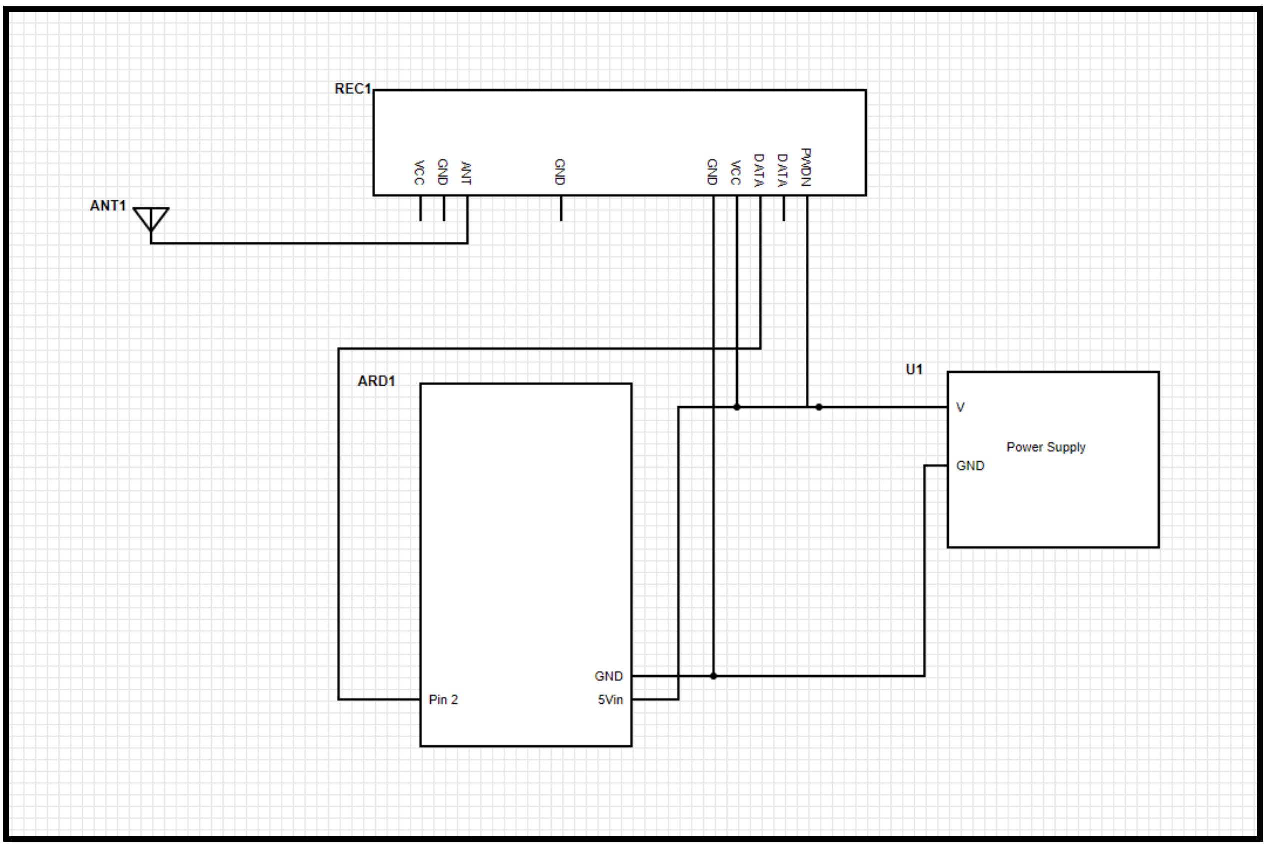

Figure 8: Receiver module schematic

RF Transmitter

In choosing our RF transmitter, we had to keep two main things in mind. We had to be able to transmit at a specific range and the transmitter had to have a very low current draw in order to save battery. Luckily, we were able to do both of these things with the TXM-433-KH3 transmitter. It had a very low current draw of 2.7mA and there was a pin that could be combined with a resistor in series in order to limit the transmission range. Here is our schematic for the collar transmitter:

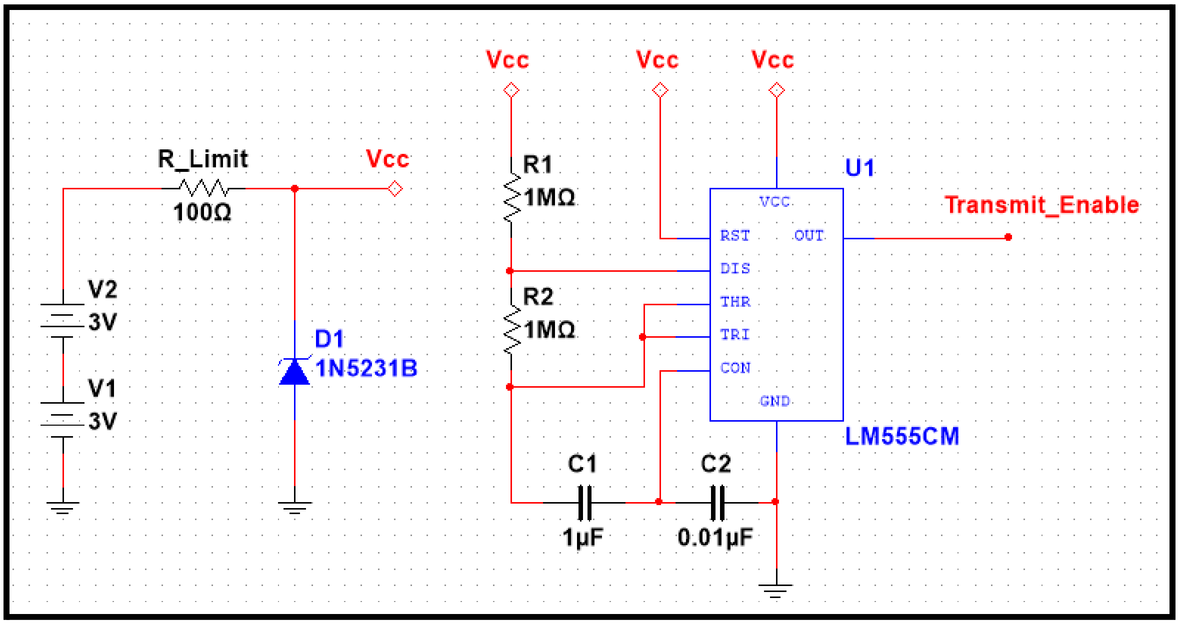

Figure 9: Transmitter schematic

For our collar, we are using two 3V coin cell batteries in series. D1 is the Zener diode used to regulate the voltage going to the timer circuit. The timer circuit is set up to be an astable oscillator to save further battery life. With the current setup, the transmitter has an on-time of 1.384 seconds and an off-time of 0.693 seconds.

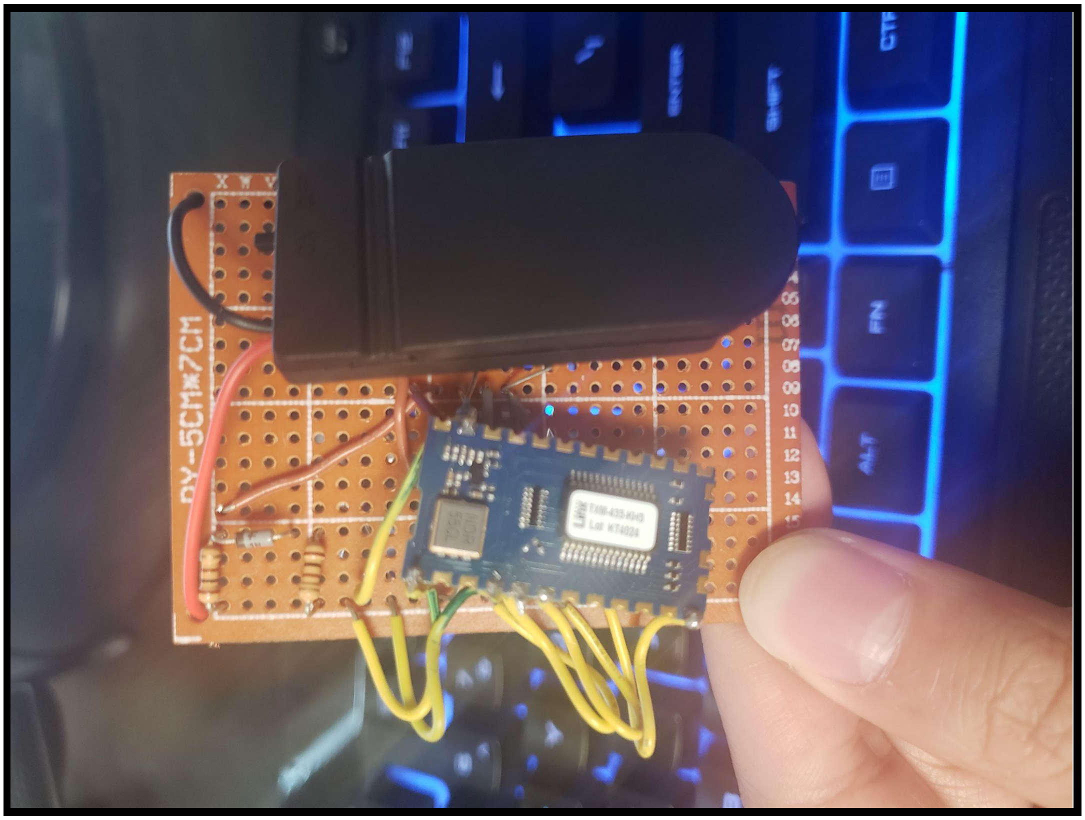

Figure 10: Completed transmitter circuit

Locking Mechanism

The locking mechanism on the dog door will lock the door by moving a bar to stop the motion of the door. The door will unlock when the dog gets close and lock when the door stops swinging. The unlocking mechanism on our dog door uses a servo motor and a C-channel bar made of aluminum. The servo motor gets a PWM signal from the processor and moves the bar in and out of place.

The locking mechanism's servo motor was selected because of its size and torque. We needed a small motor to fit within the frame of our door and a high enough torque to prevent the door from being forcefully unlocked. We selected the MG996R High Torque Motor for these reasons.

After obtaining the servo motor, we measured the current for this motor both while moving and not moving. While moving the current draw is 60-80 mA and while not moving the current draw is 2-3 mA. Considering most of the time that the door is operating the servo will not be moving this current draw is acceptable in our application.

The servo motor will move to a particular angle dependent on a PWM signal. This PWM signal will be generated from the processor. The duty cycle of the PWM determines the angle of the servo motor arm. For example, when the PWM has a 1ms on time the servo motor will be at zero degrees. The motor itself will not be powered by the ESP32 and instead will be powered by the power supply. This was done to ensure that the servo isn't limited by the maximum current the ESP32 can supply.

Processor

The processor on this product will take inputs from the swing detector and the receiver and output to the locking mechanism. When the dog gets close the receiver will detect the collar and the processor will send a signal to the locking mechanism to unlock the door. Then when the dog gets far away and the door stops swinging the processor will receive that information and send a signal to the locking mechanism to lock the door.

The servo motor takes a PWM signal and moves to a specific position. This signal is generated by the processor and is based on the current state of the inputs. As can be seen from Figure 6 below. This figure shows the two inputs to the processor from the swing detector and receiver and the one output to the servo motor.

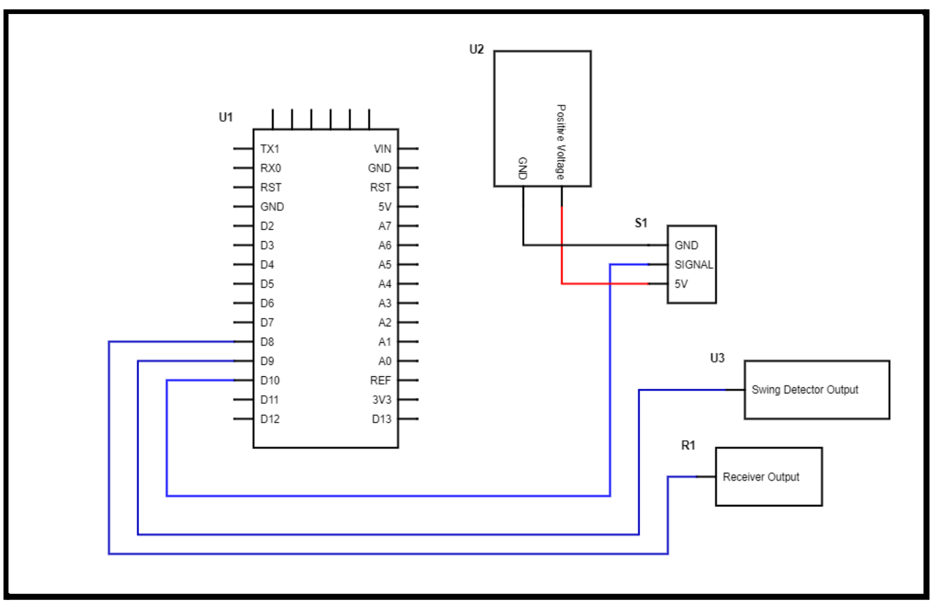

Figure 11: Diagram of inputs and outputs to the processor

For the swing detector input, it will have to be debounced in order to get a clear signal to see if the door has truly stopped swinging. The output of the comparator will swing high and low as it goes in and out of the range. The processor will take this input signal and debounce it. To debounce the input the processor detects the input signal with an interrupt. It waits until five seconds pass in between interrupts. If enough time has passed the door will begin to lock. This debouncing will make sure that the door only locks once it has stopped swinging.

The processor will also take the input from the receiver. The input will be a square wave which we then turn into a digital output that we can use. This has a baud rate of approximately 9600 baud. Our code takes the average duration of the pulses of the square wave and uses that to determine if it is receiving a signal. When the collar is out of range and the flap has stopped swinging then the door will lock again.

Swing Detector

The swing detector module of the door detects whether the door is swinging and provides the corresponding signal to the processor. We need this module to prevent the door from locking during the time it's swinging. Figure 12 is the schematic for the swing detector.

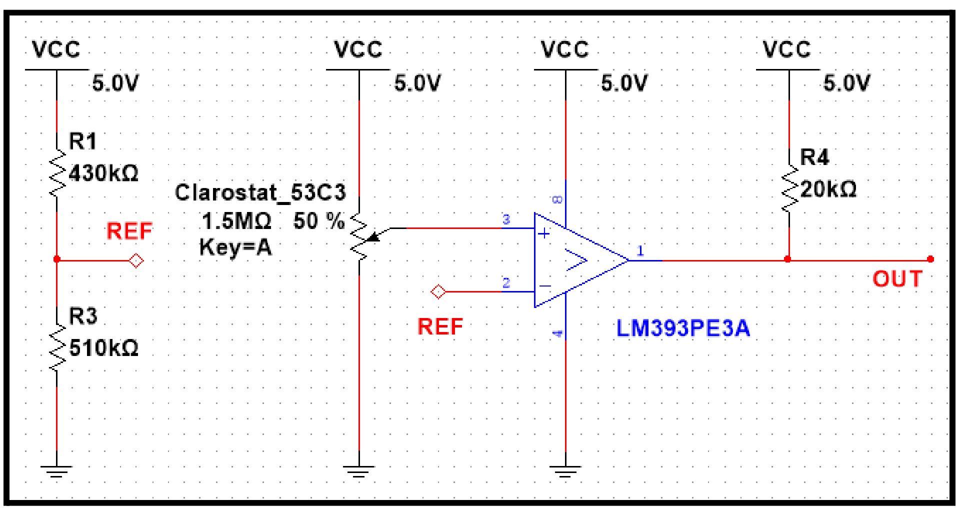

Figure 12: Schematic of the swing detector.

The Clarostat 53C3 potentiometer is the heart of the swing detector. The body of the potentiometer was attached to the door frame and the knob was attached to the door hinge. Therefore, when the door swings, the potentiometer's output voltage changes. We selected the

Clarostat 53C3 potentiometer because it is very low torque. A high torque potentiometer would have caused the potentiometer's connections to fail. Additionally, this potentiometer has a long life. It can swing from one end to the other about 100,000 times before failing, making it durable.

The output voltage of the potentiometer is then compared with a reference voltage, created by a voltage divider. We chose the reference voltage to be equal to the potentiometer's output if its knob is about 10 degrees off-center. Therefore, the comparator will output a high voltage whenever the door flap is more than +10 degrees off-center. We chose the LM393 because it is a general-purpose comparator easily available for our use. Additionally, the LM393's output voltage is very close to its supply rails, making it ideal for interfacing with a processor.

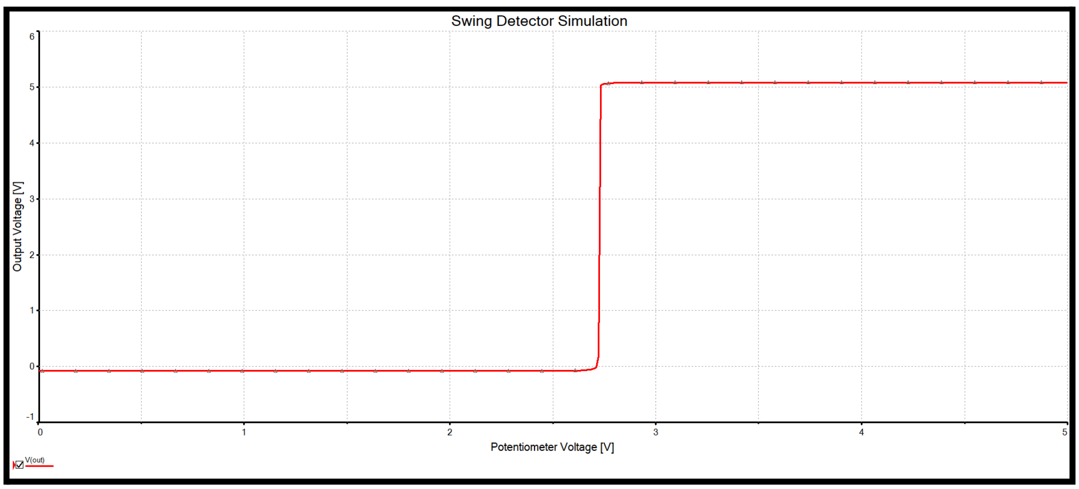

Figure 13: Simulated output of the swing detector as potentiometer voltage changes.

It's important to note that the comparator has an open-collector output. This means that a logic zero corresponds to a low impedance while a logic high corresponds to a high impedance. To convert this impedance to an output voltage, we used a 20 kΩ pullup resistor at the output of the swing detector.

The current flowing through the potentiometer and voltage divider is about 6 μA while the current flowing into the comparator is about 100 nA. Because the potentiometer and voltage divider conduct about 60 times the input current of the comparator, the comparator did not load the voltage divider or potentiometer.

In total, we expected that the swing detector would draw about 2.5 mA of current. The voltage divider and potentiometer each draw 6 μA while the comparator draws 2.5 mA. Multiplying the total current drawn by the voltage of the power supply, we find that the swing detector consumes about 12.5 mW of power during normal operation. Most of this power is drawn from the comparator.

Power Supply

Initially, we were going to use batteries to power our dog door, as we thought that this would be the most convenient for users. However, as we better understood the power needs of our door, we learned that our door would only be able to last for about one day operating on D batteries. Additionally, in our market research, we learned that our main competitor, the PetSafe Electronic Smart door, is often criticized for its short battery life. For these reasons, we decided to power our door through AC mains, so that no battery changes would be required.

To step AC mains down to our required 5 V DC, we used the PW118RA0503F02 power adapter. This circuit converts a 110 to 120 V RMS signal to a constant 5 V DC. At maximum, this adapter can output 3 A which is suitable for our needs. Throughout the design process, we estimated that our door would only require about 500 mA at a time.

Figure 14: Power supply

Our main concern with the power supply was its voltage drop when the current is being drawn. If the voltage were to drop too much, the servo may not have been able to completely turn. For this reason, we immediately tested whether the supply could power the servo while the servo was turning. When we found that it was successful, we used it to power the rest of the door.

Physical Door

Our physical door is composed of two main parts: the door frame and the door flap. The door frame houses the electronics and will be installed into an exterior door of the consumer's house. The door flap is the piece of material that the dog will push to use the door. The flap is connected to the door frame using a hinge. From our market research, we discovered that light door flaps are important. Our prototype is made of wood that has large gaps between the door frame and the flap. Both the material and the gaps will be changed for the final product.

Product Results

In Figure 15 below we can see all of the circuitry we used on the door itself. The top portion of the breadboard has the swing detector circuit. The middle is the processor with all of its inputs and outputs. Lastly, the bottom of the breadboard has the receiver circuit.

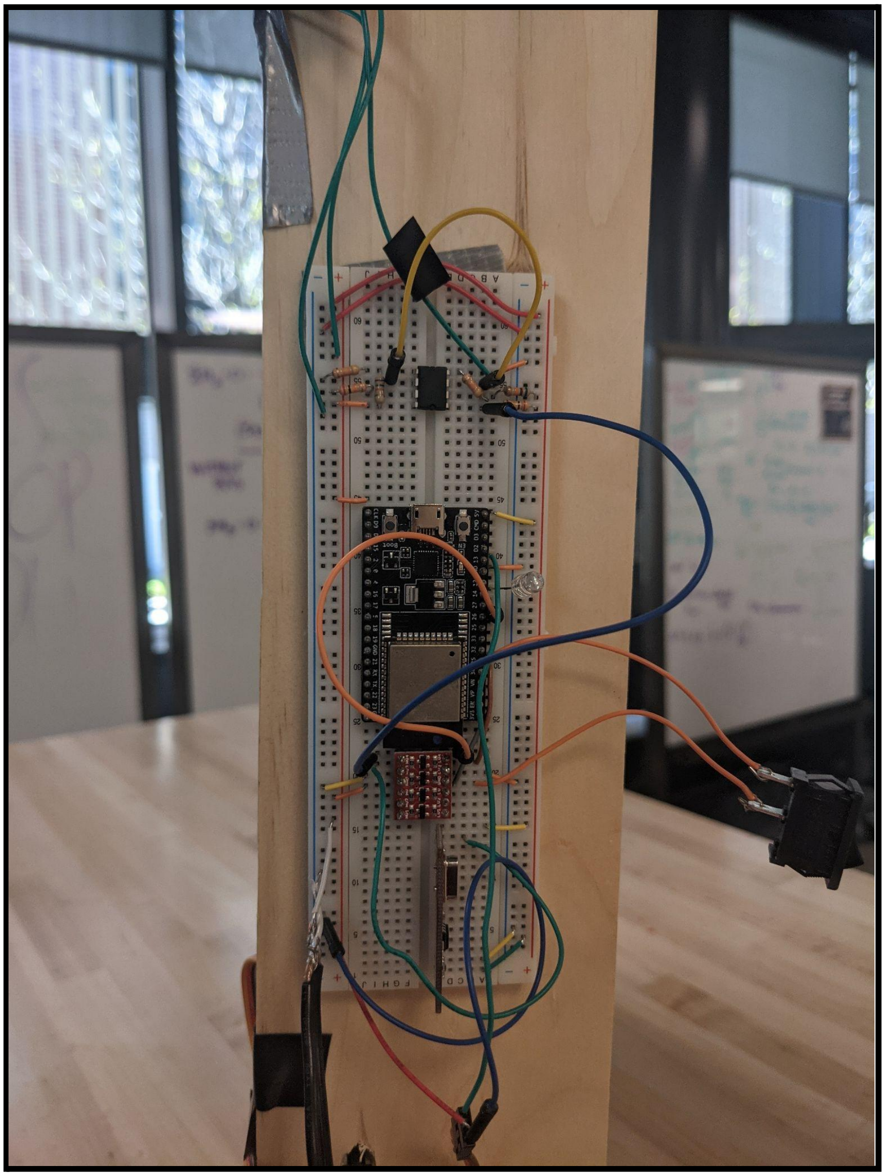

Figure 15: The final circuit on the door frame

Figure 16 below shows the locking mechanism in its locked state. As can be seen in the picture, the door flap is being prevented from moving while the door is locked. To unlock, the servo motor arm moves 90 degrees and the bar is moved out of place. This will allow the door to swing.

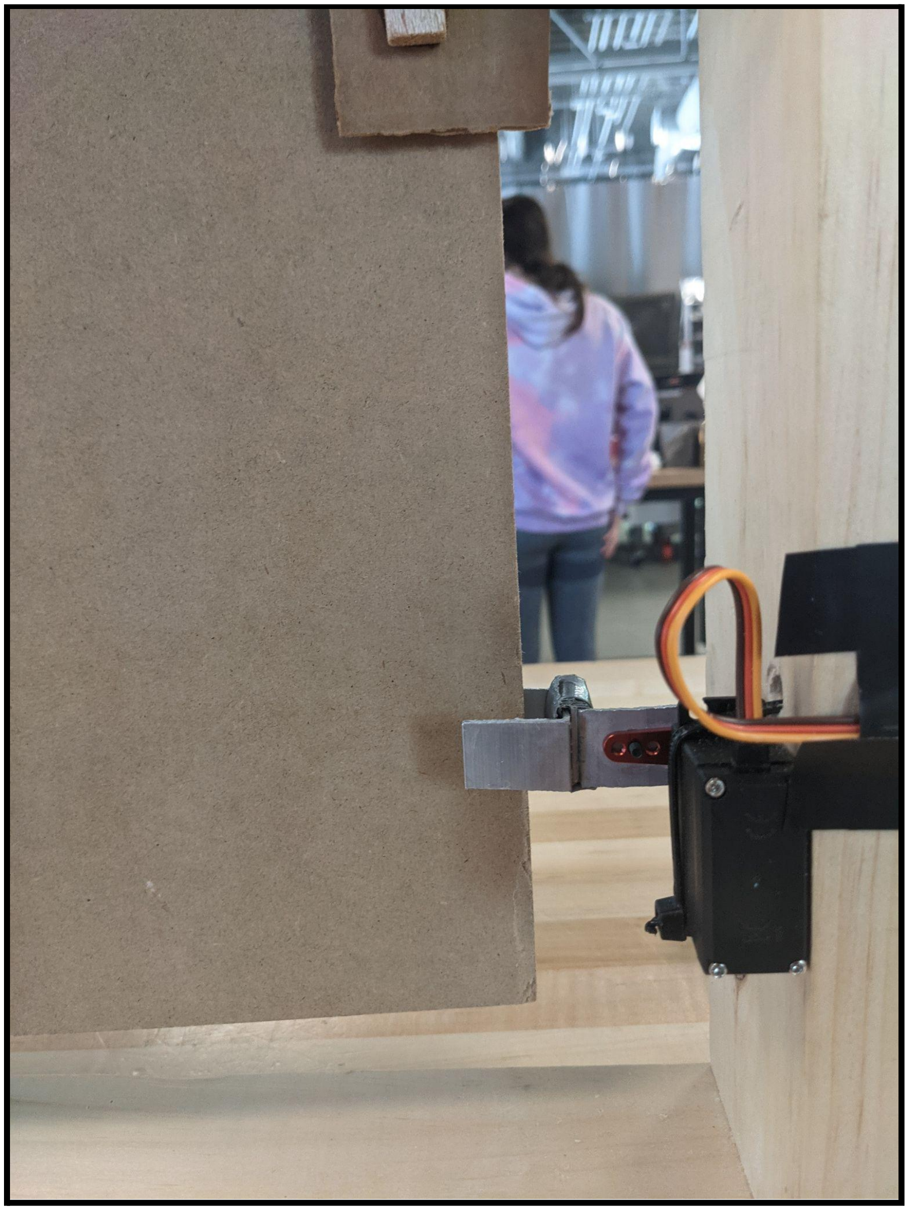

Figure 16: Door in a locked state

Figure 17 shows the potentiometer which is used to detect the movement of the door flap. As the door swings, the output voltage of the potentiometer changes. The picture below shows the range of movement of the potentiometer.

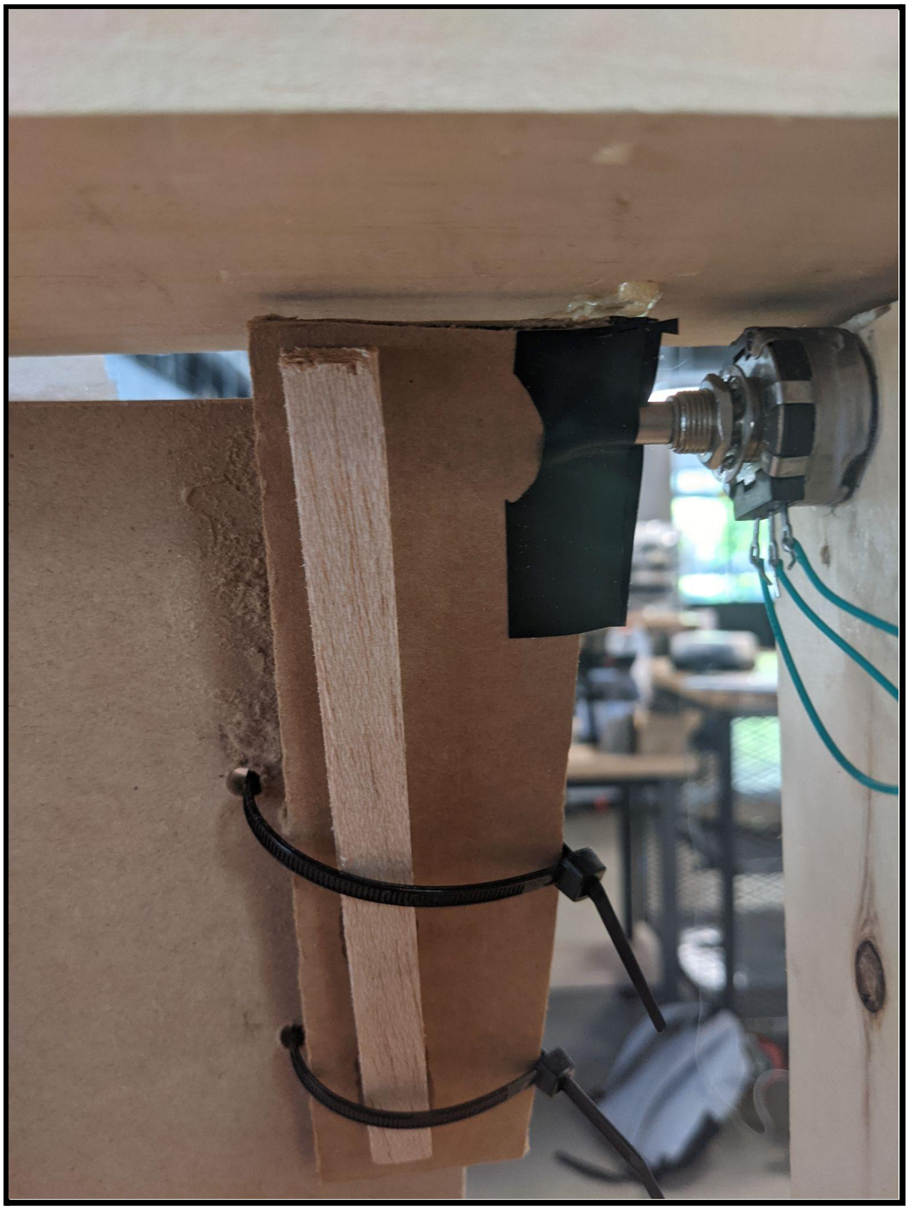

Figure 17: The Swing Detecting Potentiometer

Figure 18 shows the entire dog door. This is the prototype of our dog door.

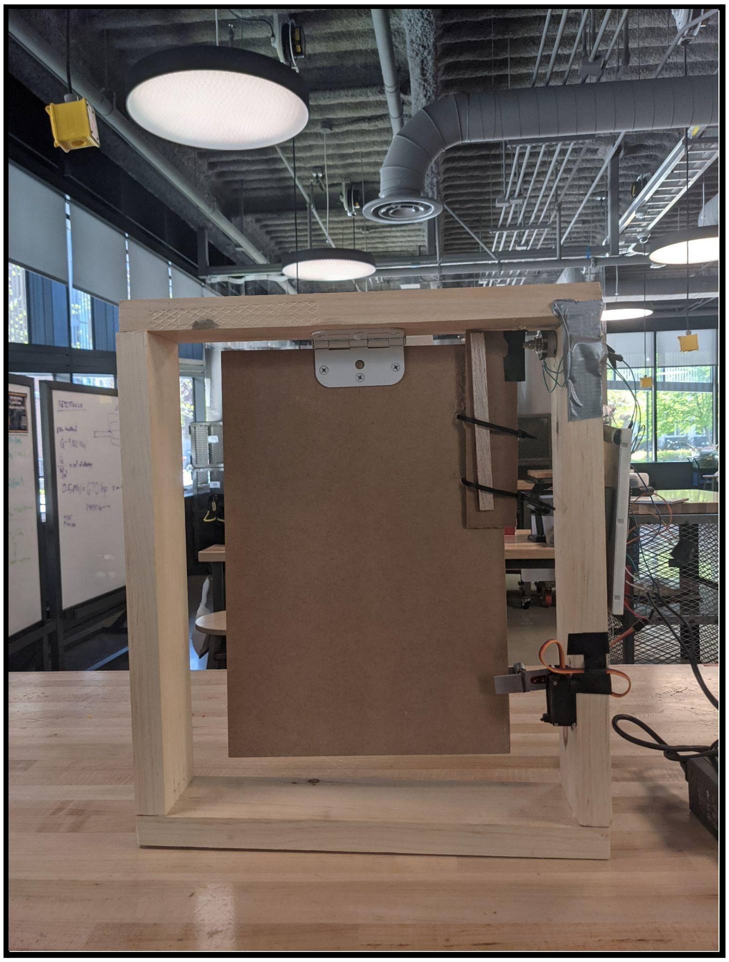

Figure 18: The Final Door Prototype

Cost Analysis

Initial Investment

For our product, we've decided to sell it on Amazon as it has a wide user base which will allow us to reach a wider audience.

RF Collar

Our RF collar circuit ended up being more expensive than we expected. For each collar, the cost of just the electronic components will be about $19 a unit. The bulk of the costs comes from the TXM-433-KH3 transmitter which retails for $17. Although this transmitter has a very large price tag, we still chose it as it outclassed all other transmitters in the 433 MHz range in terms of low current draw.

Dog Door

Our dog door has far more components than our collar so it also makes sense that it is more expensive to create as well. Our dog door cost a total of $66.25. This does not count the costs for assembly, just the parts. We are also not including parts like solder and wires as on a finished product, they will be included in the PCB. This is a relatively cheap price for our door as we are planning on selling the door for more than $100. We can make the price per door even cheaper when mass-producing.

Fixed Fees

- **Amazon Distribution Fee: $39.99/month**
- **Amazon Fulfillment Fee: $5.42/unit**
- **Assembly Fee: $1/unit**

Variable Fees

- **Amazon Referral Fee: 8% (minimum $0.30)**

Return on Investment (ROI)

In total, both the door and collar cost about $83.94 to produce. With a retail price of $129.99, we can make quite a sizable profit. We can also sell additional collars in order to further increase profits.

(Note: Five years was chosen as we had to estimate a set amount of time that we would have our item listed on Amazon)

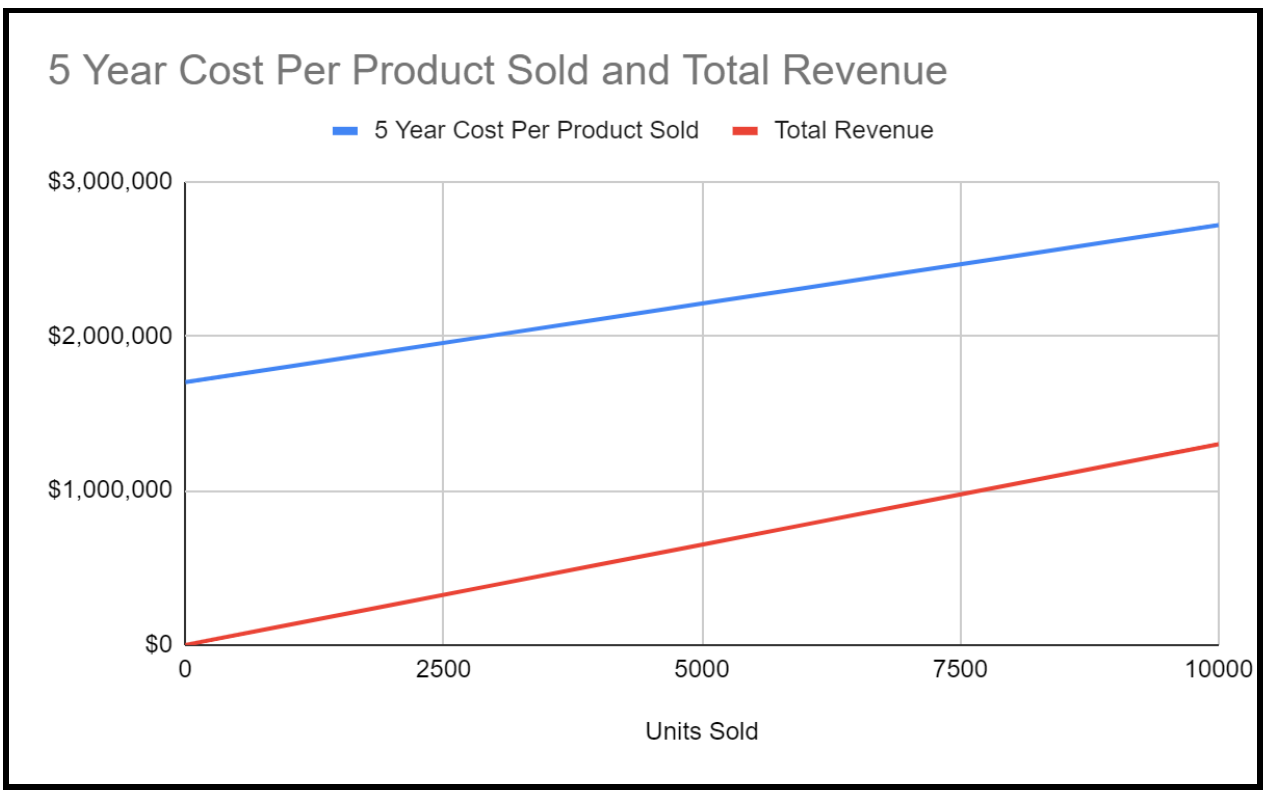

Figure 19: Return on investment graph

Units Sold	5 Year Cost Per Product Sold	Total Revenue	Profit
0	$1,701,200	$0	-$1,701,200
1000	$1,802,960	$130,000	-$1,672,960
2000	$1,904,720	$260,000	-$1,644,720
3000	$2,006,480	$390,000	-$1,616,480
4000	$2,108,240	$520,000	-$1,588,240
5000	$2,210,000	$650,000	-$1,560,000
6000	$2,311,760	$780,000	-$1,531,760
7000	$2,413,520	$910,000	-$1,503,520
8000	$2,515,280	$1,040,000	-$1,475,280
9000	$2,617,040	$1,170,000	-$1,447,040
10000	$2,718,800	$1,300,000	-$1,418,800
11000	$2,820,560	$1,430,000	-$1,390,560
12000	$2,922,320	$1,560,000	-$1,362,320
13000	$3,024,080	$1,690,000	-$1,334,080
14000	$3,125,840	$1,820,000	-$1,305,840
15000	$3,227,600	$1,950,000	-$1,277,600
16000	$3,329,360	$2,080,000	-$1,249,360
17000	$3,431,120	$2,210,000	-$1,221,120
18000	$3,532,880	$2,340,000	-$1,192,880
19000	$3,634,640	$2,470,000	-$1,164,640
20000	$3,736,400	$2,600,000	-$1,136,400

Figure 20: Specific analysis on profit

At the moment, this product is not profitable as the prototype parts we used were too expensive. However, when we perform the actual manufacturing process, we predict that we will get the price of the parts down to about $40 instead of $83.94. Here are the predicted graphs for when that happens.

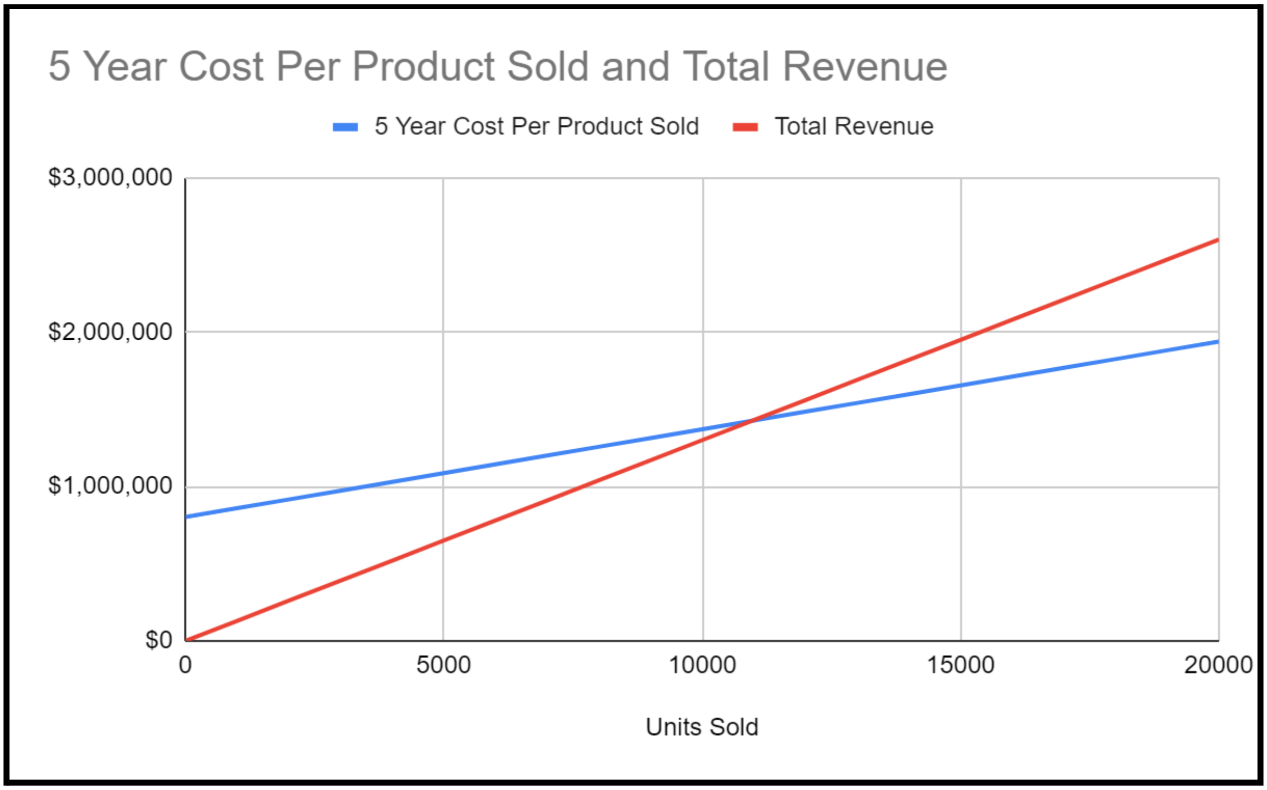

Figure 21: Predicted return on investment graph

Units Sold	5 Year Cost Per Product Sold	Total Revenue	Profit
0	$802,400	$0	-$802,400
1000	$859,220	$130,000	-$729,220
2000	$916,040	$260,000	-$656,040
3000	$972,860	$390,000	-$582,860
4000	$1,029,680	$520,000	-$509,680
5000	$1,086,500	$650,000	-$436,500
6000	$1,143,320	$780,000	-$363,320
7000	$1,200,140	$910,000	-$290,140
8000	$1,256,960	$1,040,000	-$216,960
9000	$1,313,780	$1,170,000	-$143,780
10000	$1,370,600	$1,300,000	-$70,600
11000	$1,427,420	$1,430,000	$2,580
12000	$1,484,240	$1,560,000	$75,760
13000	$1,541,060	$1,690,000	$148,940
14000	$1,597,880	$1,820,000	$222,120
15000	$1,654,700	$1,950,000	$295,300
16000	$1,711,520	$2,080,000	$368,480
17000	$1,768,340	$2,210,000	$441,660
18000	$1,825,160	$2,340,000	$514,840
19000	$1,881,980	$2,470,000	$588,020
20000	$1,938,800	$2,600,000	$661,200

Figure 22: Predicted analysis on profit

For our predicted analysis, we will break even at 10,965 units sold.

Failure and Hazard Analysis

RF Collar

Our RF collar runs only on 6V DC and none of the parts can bring electrical harm. However, the circuit is not waterproof and the encasing of the unit must be airtight as to not let any water in. For this prototype, we have not done any testing of temperature or water resistance which would need to be done before this product is marketable. We also would need to test the encasing of the collar for chew resistance and see how the casing affects the range and reliability of our transmitter.

Dog Door

Our door runs off the power from a wall outlet that is converted to 5V DC. None of the products on our door can bring electrical harm except for the power supply which is contained. We are, however, mindful of mechanical harm. If, for example, our servo were to receive a signal incorrectly or if something without a collar got close while the servo was moving. A few solutions to this might include adding an additional sensor to detect if something is in the path of the servo and/or adding warning labels to our product. Much like the collar we are also concerned about the door itself being water and temperature resistant. In our prototype, we were not concerned with weatherproofing but for our final product, this will need to be added and tested.

Conclusion

Over the past seven weeks, we have developed a functional prototype of our electronic dog door. We first conducted market research on the dog door industry in the United States and then translated this research into product requirements. We then created a block diagram for our dog door and designed its individual modules. Finally, we built and tested our final product, leaving us with a functional prototype.

If this project were to be continued in the future, we have several recommendations. First, we would need to find lower-cost components. We believe that we could find cheaper door materials, potentiometers, servos, power supplies, and receivers. Finding these cheaper components would be a major portion of a second prototype. Additionally, we recommend recruiting a mechanical engineer to assist in the mechanical aspect of our door. Our team only consists of electrical engineers, so our door's current mechanical design is not optimal. Finally, we suggest improving the swing detection of the door. Currently, the swing detector only detects if the door is swinging one way, and we would like to have it detect swings in both directions.

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Appendix A: Parts List

- **TXM-433-KH3 Transmitter: $17.60**
- **LM555 Timer Chip: $0.15**
- **AM-RX12E-433 Receiver: $6.58**
- **ESP32: $10.00**
- **PW118RA0503F02 AC/DC Adapter: $11.00**
- **MG996R High Torque motor $4.25**
- **Door Materials (Wood, screws, glue, ect): $20.00**
- **Misc.**
  - **Clarostat 53C3 Potentiometer: $12.94**
  - **LM393PE3 Comparator: $0.50**
  - **Switch: $0.58**
  - **Resistors/Capacitors: $0.34**

- **Total: $83.94**

Appendix B: System Code

```
#include <ESP32Servo.h>

Servo myservo;
int pos = 0;

int servoPin = 13;
int swingPin = 26;
int rxPin = 34;
int switchPin = 35;
int ledPin = 14;

int doorLock = 1;
int rx = 0;
int swing = 1;
int switch1 = 0;
unsigned long duration;
int count = 0;

int lastSwingState = LOW;

void setup() {
  myservo.setPeriodHertz(50);    // standard 50 hz servo
  myservo.attach(servoPin, 1000, 2000); // attaches the servo on pin 18 to the servo object
  pinMode(rxPin, INPUT);
  pinMode(swingPin, INPUT);
  pinMode(switchPin, INPUT);
  pinMode(ledPin, OUTPUT);
   Serial.begin(9600);
}
```

```
void IRAM_ATTR isr() {
    count = 0;
}

void loop() {

attachInterrupt(swingPin, isr, RISING);

duration = pulseIn(rxPin, HIGH);to
  int accumulate = 0;
  int average = 0;
    for(int i = 0; i < 36; i++){

      duration = pulseIn(rxPin, HIGH);
      accumulate = duration + accumulate;

      //Serial.println(duration);
      Serial.println(accumulate);
      delay(100);

      if(i == 35){
      average = accumulate/35;
      //Serial.println("THIS IS THE AVERAGE");
      //Serial.println(average);

      if(average > 425){
        Serial.println("LOGIC HIGH");
        rx = HIGH;
      }
      else{
        rx = LOW;
```

```
      }
      }
    }
Serial.println("RX: ");
Serial.println(rx);

switch1 = digitalRead(switchPin);
Serial.println("Switch: ");
Serial.println(switch1);

if(switch1){
   digitalWrite(ledPin, HIGH);
}
else{
   digitalWrite(ledPin, LOW);
}

if(rx == 1 && doorLock == 1 && switch1 == 1){
  doorLock = 0;
  // Move the Servo
  Serial.println("Door Unlocked");
  Serial.println("Wait a few seconds");
  for (pos = 0; pos <= 180; pos += 1) {
    myservo.write(pos);
    delay(5);
  }
}

if(doorLock == 0 && rx == 0){
  while(count <= 5){
    count++;
```

```
    delay(1000);
    Serial.println("count: ");
    Serial.println(count);
   }
   doorLock = 1;
   // Move the Servo
   Serial.println("Door Locked");
   for (pos = 180; pos >= 0; pos -= 1) {
    myservo.write(pos);
    delay(5);
   }
   delay(15);
  }
  }
```

Appendix C: Component Specifications

- Transmitter
- Receiver
- ESP32
- LM393
- LM555
- Servo Motor
- Potentiometer