Senior Design Report

IoT Smart Doggy Door

Figure 1: Doggy Door
Reprinted with permission pending, from [1]

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Executive Summary

The need to simplify everyday, repetitive activities is becoming more desirable as technology advances. All pet owners can attest to the fact that pets can take up a lot of time, especially in an already busy schedule. Reducing the time spent on simple activities, such as letting animals both inside and outside, can save pet owners a lot of time. This is now possible. Part of technology advancing is the introduction of the well-known and very popular architecture: Internet of Things (IoT). This architecture is meant to make everyday devices communicate to other devices via the internet or some other communication network. Using data acquisition in the form of sensors, actions can be performed to make the lives of everyday users more efficient and less repetitive.

While existing technologies aim to reduce the time spent on letting animals both in and out, these products leave a lot to be desired. To configure the settings for the system, the user must approach the system on the door itself, the problem that is trying to be reduced. This could be remedied by implementing the IoT architecture.

Our IoT Smart Lock Doggy Door is primarily intended to automate and remotely control the need to let animals both inside and outside. Users will have full control over their animal entry and exit habits through the use of a smartphone application. Our door is designed to remain secure with a collar that must first be registered to the system, an advanced locking mechanism, and a camera that captures movement outside the door. Many concerns regarding IoT involve the loss of power or internet. Our solution addresses these concerns by providing both an external power supply if the power goes out and a local storage to maintain key information to keep the system operating if the internet goes out.

This paper documented the design process of our IoT Smart Lock Doggy Door to ensure that safety, efficiency, and ease of use is maximized. First, the project's motivation and objectives are discussed with the required specifications following shortly after. An overview of the whole system is provided in the form of both a hardware and software block diagram. Research into existing products is performed to help determine which relevant, cutting edge technologies will be best for this application. With meticulous research, parts are discussed and compared to find the best part for the job. Related standards are discussed to keep our system aligned with existing technologies. After having discussed the project's constraints, initial designs are presented. After weighing several design considerations, a decision is made on the best implementation for the system. This implementation included a printed circuit board (PCB) as well as some way to communicate to the internet, while maintaining a low profile. Finally, the project's budget is discussed alongside the project's milestones. All referenced figures and materials can be found at the end, inside the appendixes, providing permission to use copyrighted material.

2 Project Description

In the project description, the motivations, objectives, and requirement specifications for this paper are discussed. The motivations included why this project is important and also included motivations behind some of the features that are used. The objective section explained what should be achieved once the project is complete. The requirement specifications discussed what the system is capable of to ensure that the objectives are reached. Further analysis of the requirement specifications will be found in the House of Quality diagram.

2.1 Project Motivation and Goals

Our motivation behind this project was to make a smart lock doggy door that is advanced and changes the way dog doors are currently being used. We have found that most “smart” systems are not truly smart as they lack a lot of features found in a lot of smart systems. Some missing features included remote control, customizability, and internet connectivity. To do this, we believe that by adding IoT to our system allowed us to revolutionize the approach that is already being taken to doggy doors. To incorporate IoT into our design, the system has both a database and a mobile application which will not only allow for the system to have more utility, but also remote control too. Our motivation behind radio frequency identification (RFID) was to create a responsive system that is scalable to many animals. With passive RFID, the consumer does not have to worry about the collar dying because it does not operate with any batteries. Finally, security can be a major pitfall for many door designs. Whether it be an intruder trying to force entry or even just a stray animal trying to sneak in, our motivation was to prevent any unwanted being from coming in. Our locking mechanism is accompanied by both an infrared sensor and a camera. If the sensor detects any movement, a picture is taken which can then be viewed on the smartphone application.

Technology is everywhere nowadays and it is here to make our lives better and more efficient. We were motivated to extend technology in areas that affect most people. Seeing that most people have at least one animal, we believe we can improve the quality of life with regards to pet maintenance.

We had many goals that we wanted to achieve with this project. Because the system is largely software oriented, there are always more goals to work towards and features to implement. To not overload our schedule, we broke down our goals into three separate categories. The first category was basic goals, the second was advanced goals, and the third was stretch goals.

The basic goals were the bare minimum goals that had to be achieved by the completion of the system. The first goal included the ability to detect and read a tag (or collar) from half a meter up to 1 meter away. This is important because the animal should not have to be touching the door for it to open. The second goal is that the user is able to change permissions for each animal on the mobile application. This was necessary because this allowed for both uniqueness among each animal and allowed more user control. For the last basic goal, the time it takes to detect a tag, process it, and unlock the door will happen in under 4.5 seconds. If this time is too long, there is a chance the animal may not be able to be adequately trained to use the door. The association the animal makes with initially approaching the door and the capability of being let outside after hearing a buzzer diminishes as time increases.

Our advanced goals were the goals that we aimed to achieve by the completion of the project. Our first advanced goal was being able to detect the presence of an animal that had been waiting at the door for an extended period of time. From there, the has the option to manually override the locks and let the animal in. This allowed the user to not have to change permissions temporarily to let the animal in. This would be useful for animals that are not registered in the system, but still wanted to enter or exit. The second goal was to be able to keep record if the animal is inside or outside. This could easily be solved by using two separate antennas or readers, however, to keep costs to a minimum, we only used one of each. Therefore, sensors had to be implemented in such a way that will be able to keep track of the state of the dog. The final advanced goal was to create a local storage for caching database results. This storage was used to record the latest permissions for each animal. This improved the speed of the system and allowed the system to still work if the internet went out.

Stretch goals were the goals we would have liked to achieve if we still had time after accomplishing all the basic and advanced goals. The first stretch goal was to allow the user to create custom permissions for each animal instead of choosing between a predefined set of permissions. This provided the user with even more control and flexibility over the system. The second goal was to have a user grant temporary access to a guest user without having to reveal the user's login credentials. If the user has someone babysitting their animal(s), the user can give the guest access to the system and allow the guest to change permissions for a certain period of time. The final stretch goal was to implement live video streaming with the camera. Currently, the camera is able to take snapshots when movement is detected with an infrared sensor for additional security, but with a live video, the user can always check the current state outside of the door.

2.2 Project Objectives

Our objective was to make an advanced doggy door system that worked with not only dogs, but similarly sized animals that can also be trained. Though there were many existing solutions on the market, they were not very innovative. We wanted to change that while still maintaining an easy to use, feature rich, and smart system. Other objectives included making the system have a small footprint and making it easy to install. Our team has a wide range of knowledge that can be applied to make the best of both the software and hardware required for this project.

2.3 Requirement Specifications

This section is dedicated to listing all the engineering requirements that must be met with the completion of the system. A list containing all of the quantitative specifications relevant to the project can be found within the contents of the table located below:

Description	Parameter	Specification
Door flap dimensions	Dimensions of the door flap	W: 0.25” L: 12” H: 19”
Door frame dimensions	Dimensions of the whole door setup	W: 8”, L: 12”, H: 22”
Durability of flap	How much force the door flap can withstand	63 N/mm^2
Tag/collar reading distance	How far the tag should be read from the door	0.5 m - 1 m
Infrared detection distance	How far the infrared sensor detects movement	0.5 m - 1.5 m
Tag process and door unlock time	The duration at which the tag should be read, processed, and the door unlocked	< 4.5 seconds
Door flap locking distance	How far the locks should be placed from the door flaps resting position	< 4”
Sound pressure level of buzzer	How loud the buzzer should be	70 dB - 90 dB
External battery life	Duration of the battery life	1 hour - 1.5 hour

Table 1: Requirement Specifications

By having met these specifications, the stated objectives for this project were met. Most of these specifications had a value that can be measured. If the value were met, the objectives should then be met as well. Should the values be positively exceeded, the system may be smaller in size or read tags at larger distances. However, in some cases, a reduced value will be better, like in the case of reducing a system's response time or hardware protrusion from the wall.

Other types of specifications also existed that did not rely solely on measurable values, but rather design and system configuration. A list of these specifications are found below.

2.3.1 Safety Specification

This system was carefully designed to prevent any risk of injury to either animal or human. This system was kept as low profile as possible with minimal protrusions. The fewer the parts that stuck out, the least likely that the system will be hit by someone or something. This also made the system less prone to taking any damage. The hardware, like the reader, antenna, and other electrical components, had to be carefully concealed. Doors are taller than they are wide, so most components can be safely tucked above or below the system itself. The closing part of the door was the biggest concern that most people would have. Implementing a sliding type of door was a consideration, however, object detection had to be taken into consideration. If an animal tried to walk through the door as it was closing, the door had to be able to detect if an animal was in the way. This type of setup also required more components and more work to open the door too. Therefore, the door adopted the traditional doggy door flap where the opening sequence is controlled by the push of a dog and the closing sequence is controlled by gravity. The material was light enough so that no damage was done to any animal passing through the door when the flap falls back to its original position. This reduced the amount of components that could cause injury and kept the door from becoming too complex.

Another safety specification was how far an organism could be from the antenna of the reader module. If the antenna had a gain of 8.15dBi and had an output power of 27dBm, the organism had to be more than 21cm away to not be exposed to the radiation beam being produced [2, p. 63]. Our antenna, however, had a gain of 5.5dBic and was operated at 27dBm. Therefore, the minimum spacing required was reduced from 21cm.

2.3.2 Power Specification

Our design was largely powered around a standard American wall outlet; that is, powered at 120 V with a frequency of 60 Hz. Our components, however, needed to be powered with a DC supply voltage, not an AC supply voltage, and at a much lower value. These values varied between 3.3 V up to 12 V. Some components, like the buzzer and passive infrared sensor required lower voltages, whereas components like the RFID reader and solenoids required higher voltages. If power was not supplied (like a power outage for example), our system would no longer work and may trap animals either inside or outside. Therefore, an external battery had to also be attached to the system. The ideal battery life of the battery was about an hour. The usefulness of this addition was seen when there was a power outage. If the power went out, the door would continue to operate like normal. In minor outages, this allowed enough time for power to be restored. To help with power consumption, the RFID reader could operate at low power modes. Though this was not a major selling point of the system, this would have allowed our system to be more environmentally friendly.

Our system required complex power operation, therefore, our printed circuit board (PCB) was dedicated for this operation. The PCB allowed for the conversions from AC to DC and at the correct voltages. Because high voltages were present, it was important to work with extreme caution. Some other constraints we had to look out for were heat generation, noise, overload, overcurrent, undervoltage, and overvoltage. After converting to DC from AC, a voltage regulator was required to step down the voltage. Either a linear or switching voltage regulator could be used, however, depending on which regulator is used, both heat and noise would be variable. Overload occurs when a system receives more current than it is rated for. This could then lead to overcurrent. Overcurrent is when a system has too much current flow, via a short or overload, which could lead to failure of components, fire, and more. Undervoltage is when the system operates at a lower voltage than expected. This behavior could lead to a Brownout, where voltage drops lower than required and the system continues to operate at this new voltage. This may produce unusual behavior, like components failing to operate as desired. While damage may occur with undervoltage, overvoltage is more likely to permanently harm components if the voltage is higher than a part's absolute maximum ratings.

The external battery was an electrical constituent of our PCB. With this necessity, we had to find a way to connect it to the rest of the power supply. More specifically, we needed to design some sort of circuit that would act as a switching circuit, where the external battery was electrically disconnected from the circuit until the 12 Volt rail produced from the AC/DC converter fell significantly beneath 12 Volts. Once this occured, we wished for the external battery to be the source of power. In order to achieve such a function, the switching design desired the functionality of a solid state relay. There were many types of relays that could be used, but ultimately we wanted to create two circuits that were electrically isolated from one another, but would always have one of them active at a time. The implementation of an optocoupler would be perfect for our design. Essentially, when one circuit is on, it will excite the presence of a diode within the IC. Once this LED is turned on, a photoreceptive material would then be activated, and with this IC configuration, electrical isolation is achievable, as well as the secured switching of two different circuits.

2.3.3 Design Specification

Design had to be taken into careful consideration when building the door. No matter if the door was installed into a pre-existing track for a sliding door or inside of a wall, the presence of this door had to be kept to a minimum. Along with a low profile, the system had to also be easy to install for maximum convenience. The door would be heavily used by animals and would need to have the endurance to support long time utility. Both the locking mechanism and electrical components had to be out of reach to prevent either human or animal interference. The electronics also needed to be protected in such a way to prevent tampering, damage by external forces, and weather related problems (such as shorting a circuit due to rain). Finally, the system needed to be designed with fewer components to not only keep both the cost and complexity down, but to also improve how efficiently the system responds to commands from the system controller.

2.3.4 Mobile Application Specification

The mobile application is how the user will access and control the settings of the door and each profile. Through the application, the user could generate requests to a database. From the database, results will be sent to and processed by the Raspberry Pi Zero W. Some of the features included adding (or pairing) a new tag, editing permissions for each tag, and viewing pictures taken by the door. The application had to be able to connect to the internet whether it be through Wi-Fi, mobile data, or some other form of communication.

2.3.5 Database Specification

The database played an important role as it would tie the whole system together. Both the Raspberry Pi and the mobile application would be in communication with the database, via an application programming interface (API). The database acted as a middle man and allowed the Raspberry Pi and the mobile application to communicate with each other. The database had to be flexible as it would support multiple systems, accounts, the creation and deletion of permissions, and be able to store photos for a short period of time. In order for the system to stay in communication with one another, an internet connection was required.

Querying the database every time a tag was read by the door would take too long to process. Therefore, a local storage (or onboard database) was also implemented on the door. Using a realtime database allowed results to be updated across the clients (or the registered systems) as soon as the database got updated. Accessing the database results that are cached not only reduced the system read times but also allowed the system to continue to function without the presence of an internet connection. This meant that the database had to be capable of updating the system whenever a change occurred on the database through the mobile application.

2.3.6 Environmental Specifications

When the reader was operated, several considerations had to be accounted for. Firstly, thermal considerations. The reader could operate between -40°C and +60°C [2, p. 15]. Though it was very unlikely for the door to be placed under such thermal stress, it was important to be mindful of those constraints to ensure that the device would operate as expected.

Duty cycles and heat-sinking considerations also had to be accounted for. As seen in [2, p.15], high duty cycles resulted in overheating if heat-sinking precautions were not properly managed. It was possible, however, to have a low enough duty cycle where heat-sinking would not be a concern. If high enough duty cycles were being used, a surface mount configuration had to be used where a ground plane would distribute and release the heat to a larger ground plane as necessary.

2.4 Hardware Block Diagram

The block diagram was a useful representation to get a quick understanding of how a project will be built, the flow of data between components, as well as getting an idea for the components that will be used. Before we created the block diagram, we had to have a general idea of what we wanted the project to do. Without any direction, the block diagram would constantly be revised. After discussing the features of the project, we were able to compartmentalize components into individual blocks. When we designed the block diagram, we wanted to reduce the number of components while maintaining functionality and speed. Our first system controller did the most work as it hosted the local storage, implemented WiFi, managed peripherals, and was at the center of almost all data transmission. Due to intense computations and processing images, we had to decide early on that our system controller required a lot of processing power. The second system controller was in charge of operating an actuation driver circuit the team designed.

While we designated roles for the block diagram, we wanted to be as fair as possible. We made a list of what people would prefer and assigned roles accordingly while playing into each member’s strength. In the block diagram, each part was split up into a primary and a secondary role. This was to ensure that each member would be accountable for a part in the project while being able to bounce ideas off another member. We made sure that everybody had a primary role first before assigning a secondary role. While some members had more primary roles, other members had more secondary roles. We all agreed that the distribution of work was fair before proceeding. Alexis Quintana and

Logan Waln focused mostly on software aspects to each of the blocks, while Hunter Herrold and Jordan Carraway mainly focused on electrical/hardware aspects to each of the blocks.

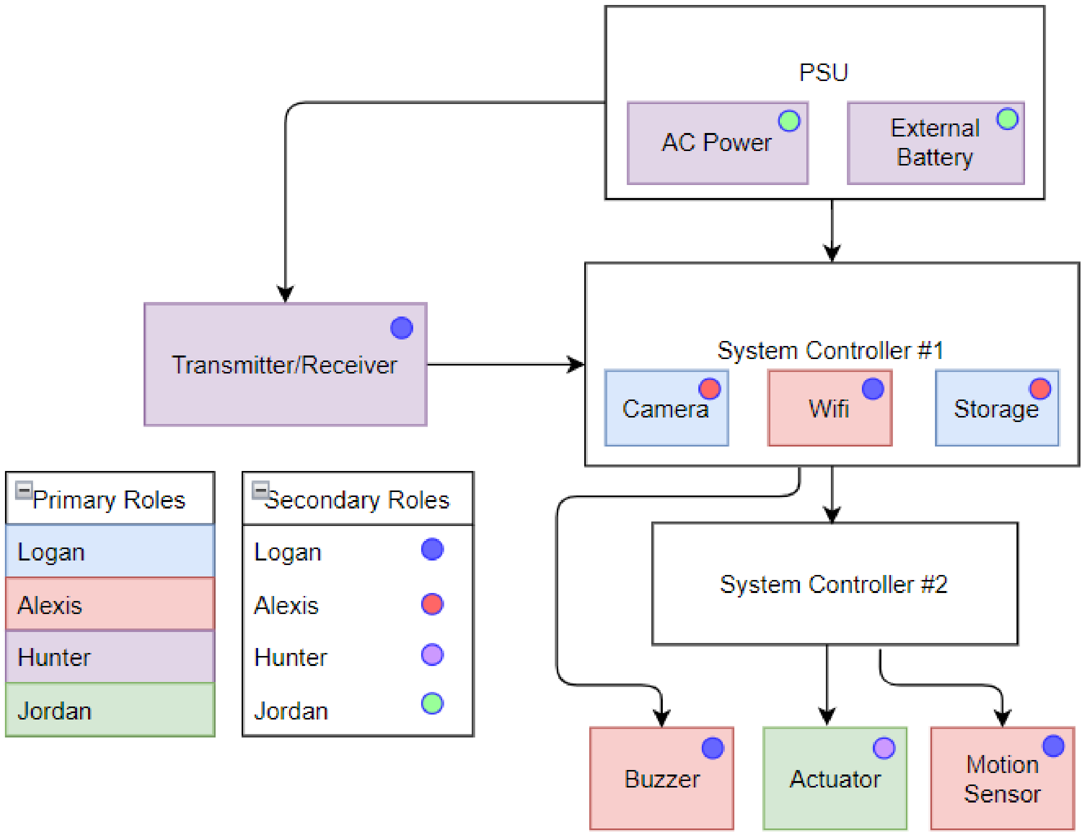


Figure 2: Hardware Block Diagram for Doggy Door

2.5 Software Block Diagram

While the software block diagram functioned similarly to the hardware block diagram (division of parts and structure of system), the diagram focused solely on higher level software for the project. Because our system was an IoT Smart Doggy Door, it had to be able to connect to the internet and the user had to be able to control the system. To control the system, a smartphone application was used to create an account, register the doggy door, add and remove animals, and allow the user to change permissions. Most actions performed on the application updated values in the database. The database would be the centerpiece between the application and the system controller.

The software block diagram was created in such a way to track the flow of logic and data. The logistical flow, represented by a black arrow, is how blocks will communicate with one another. The data trail, represented by a dotted line, showed at what points data will be collected and processed in the database. Logan Waln and Alexis Quintana divided the software aspects of the project between each other. Because there were only two members, one will have a primary role and the other member will be guaranteed to have the secondary role.

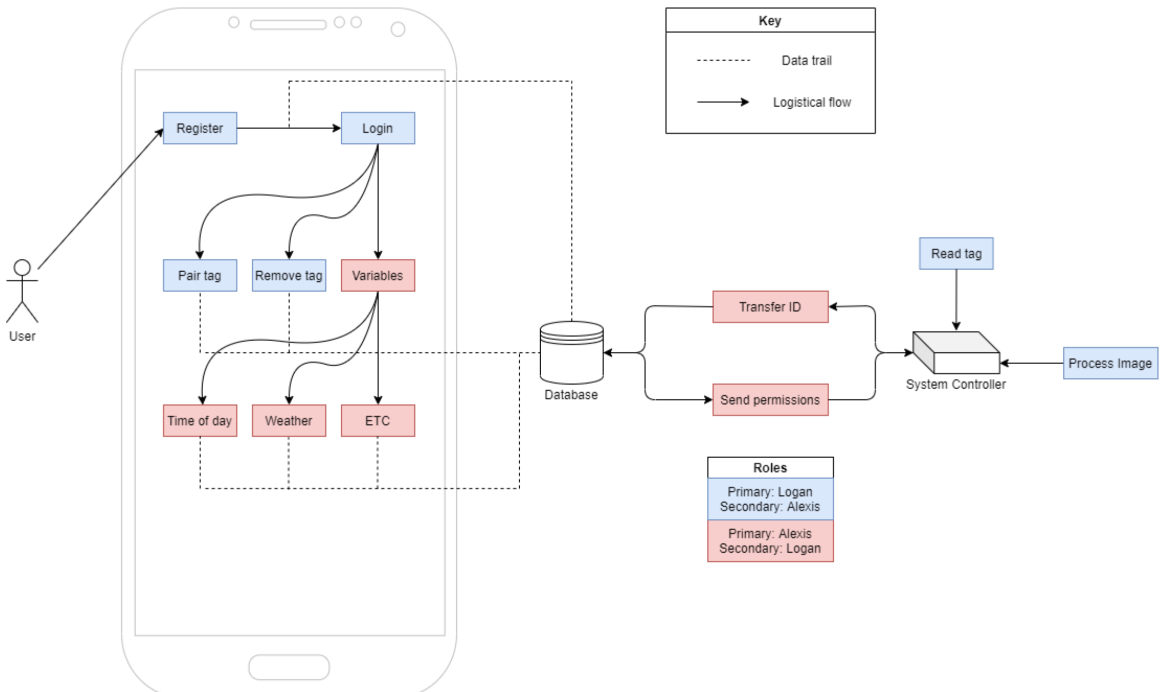


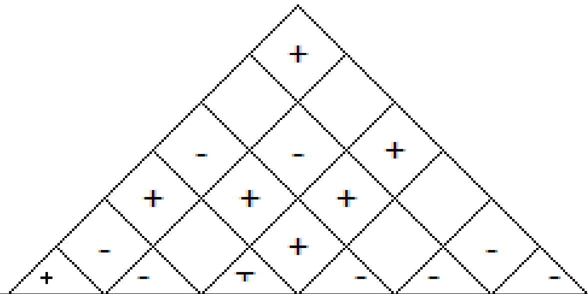
Figure 3: Software Block Diagram for Doggy Door

2.6 House of Quality Analysis

To provide this well thought out project that we strived for and to be able to implement those ideas, we examined the tradeoffs between the marketing and engineering requirements. This section gave a look into the house of quality diagram, depicting the correlations and relationships that each one will see.

Correlations	
Positive	+
Negative	-
No Correlations	

Relationships	
Strong Positive	▲
Positive	△
Neutral	○
Negative	▽
Strong Negative	▼



Column #	1	2	3	4	5	6
Customer Requirements (Explicit and Implicit) \ Engineering Requirements	Accuracy	Operation Time	Qualtiy	Smartphone Operations	Size	Cost of Production
Aesthetics	▲	○	○	○	▽	▽
Ease of Use	○	○	▲	▲	○	○
Reliability	○	○	△	△	○	▼
Range	○	▽	△	○	▽	▼
Security	▽	▽	△	△	○	▽
Cost	○	○	▼	○	▽	▼
Target	Beamwidth +/- 20°	< 4.5 seconds	Withstand for 1-2 years	Query database < 4 seconds	< H:22", W:4:, L:12"	< $700

Table 2: House of Quality Analysis

2.7 Facilities and Equipment

In order to accomplish everything we needed to do for our project, our group used the senior design lab as our primary facility to do work and all of our necessary tests. The senior design lab has four machines to conduct tests which consist of the digital multimeter, DC power supply, function generator, and oscilloscope. These machines were crucial for testing the hardware components of our project. For most of the testing, our group used the DC power supply and digital multimeter the most in order to test that our hardware equipment ran properly and to supply power to independent hardware components before the group integrated all the components together.

While these machines were very important, the senior design lab also included other things that made the process of testing and conducting our project easier. This includes the multiple soldering irons, wires for building circuits as well as a breadboard, resistors, capacitors, and additional tools as well.

2.8 Group Communication

In order for our group to be able to stay organized with our plan for tackling the project, we used various platforms to communicate with one another and keep all of our important files together in one location. To talk to one another, our group decided to use Discord to message one another. We were also able to create different subjects to distinguish different topics of communication such as meetings, ideas, resources, pictures, general communication, and a message tab to talk to the mentor professor that we had for the project. Another reason we chose to use Discord over other forms of communication is that we are also able to use voice chats with each other and share our screens to help explain different things that we need to go over.

To keep all our files together in one location, we decided to use Google Drive and make all of our files using Google Docs, Google Slide, and Google Sheets. This allowed each member to easily access these important files with ease and be able to edit documents all at the same time, which increases productivity.

3 Research

In section 3, the different technologies and similar existing products would be discussed. It was important to know the current solutions to justify and validate the choices made for the architecture of the IoT smart doggy door. The first topic discussed was the presence of products or projects that have been already realized or are currently on the market. Once this was discussed, an in-depth analysis of the technologies that were currently available would be done in order to weigh the pros and cons of each, eventually identifying what our design would benefit most from.

3.1 Similar Existing Products and Projects

A doggy door has many applications, and each different design has a uniqueness in its approach. The various techniques and applications on the market demanded a definition for our product. This section was included to address this definition by having first established a foundation of our design: the basic doggy door functionality.

3.1.1 Model PX-2 Large Standard Power Pet Door

The Model PX-2 Large Standard Power Pet Door by High Tech Pet was an automatic doggy door. A DC motor was used to vertically pull the sliding door open. Once the door closed, a steel bolt locked it in place. This system used ultrasonic sensing technology embedded into a smart collar in order to sense the dog's distance from the door. The door mainly checked for the sensor's path directly aimed at the door, preventing accidental/unwanted opening. The utilization of such a sensor keeps out stray animals, giving pets personal, direct access to the outside. The PX-2 model also ensured safety with an air-tight seal as well as bullet-proof polycarbonate panel.

This door also comes with a control panel that was used to customize or identify the status of four features: Power, sensors, battery, and range. The PX-2 Model allowed for the flexibility of using either an AC adaptor or a rechargeable battery, and allowed for the user to turn the door on, off, or to manually open the door. The sensors established a four-way access system, giving the user freedom to configure the pet's access to being only in, only out, in and out, or neither in nor out. If a battery was used, then green and red LEDs would indicate if the battery was low or not. The read range of the collar was able to be configured via knobs located on the control panel as well, which allowed for customization of indoor and outdoor read range, independently [3].

3.1.2 PetSafe Electronic Smart Door

The PetSafe Electronic Smart Door by PetSafe was also an automatic doggy door, with an electronic locking mechanism as well. This door consisted of a doggy flap made of plastic. Using radio frequency identification (RFID) in order to sense the dog's presence, the smart door required a tag. The RFID tag was located within the dog's collar, and was read by an antenna located within the door itself. This battery powered door had a maximum of 5 smart collars that were able to be programmed to one door. The control panel of this door had three options: locked, unlocked, and automatic. The user was able to change the settings manually at any time by pressing on the "mode" button, switching between the three modes. When the door was in locked mode, access to the other side of the door for the dog was denied. When it was in unlocked mode, the dog had the ability and freedom to go in and out as it pleased. In automatic mode, the RFID technology was utilized to unlock the door when the dog was in range. The door would then promptly lock when it was out of range. At 11 x 16 inches, this door was compatible with surfaces such as metal, wood, PVC, and other materials [4].

3.1.3 myQ Pet Portal

The myQ Pet Portal was an automatic doggy door developed by Smart Dog Door Technology. The opening mechanism to this door in particular was rather unique. As opposed to the traditional "flap" design or the vertically opening doors, this door employed a horizontal opening method that closely resembled an elevator door. This elevator-like door came with a few features of interest that bore a resemblance to the IoT Smart Doggy Door design as well. This door design included a smartphone mobile app as well that had many uses. The myQ Pet Portal included multiple sensors to ensure proper operation. Via bluetooth technology built within the collar, the door was able to sense when the dog had come within range and open the door. The door included sensors as well in order to detect when the dog had successfully traversed the length of the doggy door so as to avoid any potential harm to the animal. The application had a few customizable features for the door. It had the option to customize whether or not notifications will be sent to the smartphone when the dog was within range. Through the mobile app, using such features, the user was able to customize what "mode" the door was in. The door could either be set to automatic, where the dog had the freedom to come and go as they pleased, or it could be set to "By Request" mode, where notifications would be sent to the user in order to open the door or keep it closed. With cameras located on the inside and outside of the doggy door, the mobile app allowed for the user to visually check on their pets near the door as well as communicate with them via two-way communication audio [5].

3.1.4 POE Powered UHF Doggy Door

There were many independent projects that tackled the issue of an automatic doggy door. One such project that was particularly impressive was done by a youtuber named “Mack Tech.” This door design used a POE (powered over ethernet) powered doggy door that utilized RFID technology in order to achieve an automatic doggy door. The design consisted of a pneumatically driven door that would open vertically when a tag was within range of the antenna located underneath the molding of the door, where the tag was defined to be located within the collar. Once the door opens vertically, then the LED within the acrylic of the baseboard changes color. This color would change depending on the status of the door. The three statuses were open, searching for a tag, and closed. In order to ensure safety, the sides of the door have infrared sensors that would detect if a dog or other object was caught in the doorway while it was closing. On top of this, the opening/closing mechanism contained a muffler that slows the closing speed of the door, so as to avoid injury or potential damage to the door.

This independent project neatly packed all of its hardware components behind a clock located above the door. A solenoid valve was used to control the opening and locking mechanisms for the door. For the reader, a TR-65 reader module is used, coupled with an antenna that was not specified, and the tags operated on UHF. As far as the types of infrared sensor that were used, it was also not specified, but they were referred to as “infrared curtains.” An arduino nano was used to handle the logic and coordinate between the inputs and outputs, as well as the valves driving the door mechanism and the TR-65 reader. The TP Link module was used to power the circuitry facilitating the process via ethernet [6].

3.1.5 SureFlap Microchip Cat Door

Another product on the market that employed very similar technology and functionality of design was the SureFlap Microchip Cat Door by SureFlap. The main means of communication for this door was also RFID communication. Compatible with many microchips as well as tags, the reader would recognize up to 32 individual tags/microchips, allowing for use in a multi-pet house. This door was quite small, with dimensions of 5.75 x 4.75 inches. While this door was labeled as a cat door, it also proved to be useful for smaller dogs as well. Select models of this door included an LED screen at the top of the door in order to indicate the current status of a few parameters. The LED screen indicated which of the four modes that the door was in. There was one mode for the animal to go in and out as it pleased, one mode for “in-only” where the animal was only able to come inside but not go outside, another mode for fully locked, and the last mode was for out-only. These were all customizable via a button located on top of the door [7].

3.2 Relevant Technologies

This section provided a list of relevant technologies that may be used to design an advanced doggy door. While many of the technologies could have worked, some would have worked better than others. A background would be provided for each option as well as why we considered it. Lastly, the pros and cons would be discussed to explain why one path was better or worse.

3.2.1 Radio Frequency Identification

Radio-frequency identification (RFID) is a wireless tracking technology that uses electromagnetic waves in order to convey information. The main components of RFID are the reader, the tag, and the antenna. Common implementations of RFID can be found in car key fobs, where the fob is a tag and the reader module built within the car is a car. Another example is the chip on a debit card, where the card itself acts as a tag.

A reader (sometimes referred to as an interrogator) is the component of RFID that is the primary processing unit of RFID communication. A reader converts specific data into electromagnetic fields through the air via an antenna. A tag contains a chip with unique information on it, programmable by the user. Once the tag is in range of this electromagnetic field, it sends out its own electromagnetic field containing its unique information. This field is then received by the reader and converted into data that can be read through certain software. Once this data is read, any given task specified and programmed by the user can occur, ranging from physically moving parts to digital action [8]. The IoT Smart Doggy Door intended to use this technology; each dog would have their own unique ID, where customizable permissions would allow them to enter and exit the doggy door at specific ranges of times in the day. The collar would contain an RFID tag that would communicate to a reader located underneath the doggy door. Once information has been communicated, depending on the customized permissions, the door would unlock, allowing the dog entry/exit.

There were many different variables when it came to designing an RFID system. Careful research was required in order to make sure compatible components were selected. A very important parameter to consider was the polarization of the reader/antenna. There are two types of polarization: linear polarization and circular polarization. Linear polarization is when the electromagnetic fields are sent through the air in such a way that, in order for a tag to receive the signal and send one back to the reader, the orientation of the tag must be known. With circular polarization, the electromagnetic fields are sent in such a way that the orientation of the tag does not need to be strictly defined [9]. Given these two options, the ideal polarization was circular polarization. This was mainly due to the fact that as the dog moved, the collar's orientation would be unpredictable.

Every RFID antenna has a particular beamwidth. The beamwidth indicates the angle from the antenna where most of its power is being radiated outward. This means that an antenna with a particular beamwidth needs to be identified. Common angles range from 30 degrees to over 120 degrees. The higher the beamwidth, however, the power tends to decrease. This is because there is a larger volume that the power is being distributed across [10].The antenna was situated underneath the door. Due to the fact that a short dog could be very low to the ground, a beamwidth of 120 degrees is preferable as opposed to a smaller angle so that the tag has a greater likelihood of being read. However, we kept in mind the decrease in power that comes along with an increased bandwidth.

In addition to beamwidth, ensuring impedance compatibility is crucial. The antenna impedance had to match with the value required on the reader's datasheets. The top industry standard impedances were 50 Ω and 75 Ω. The specific reader module used in this project required an impedance of 50 Ω. This value would maximize the power that was being transferred between the source and the load as well as minimize the signal's possible reflection. Although most antennas operate with an impedance of 50 Ω already, this parameter still could not be ignored so as to avoid unnecessary complications and loss of energy.

When choosing a tag for any given application, there were two main types to consider: Passive tags and active tags. Both of these tags had their advantages and disadvantages. Having no internal source of power, passive tags send information only when they are in range of a reader whose electromagnetic fields incite power within the tag. Once this occurs, the tag sends back information for the reader to receive and interpret. In general, passive tags were far cheaper than active tags due to its ability to operate without a battery. Active tags, on the other hand, are tags that operate with an internal source of power. When it comes to active tags, there were two major types: transponders and beacons. Transponders are more battery efficient because they would wait for when they are in range of a reader to send out their signal, whereas beacons send out a signal every 3-5 seconds. Active tags are capable of much further read ranges in comparison to passive tags, but a downside with active tags was that their battery presents a lifetime to the device, requiring the user to change it out every so often. Due to the necessity of a battery, active tags were generally more expensive than passive tags, and they were often larger in size in comparison to passive tags [11]. These variables gave rise to important considerations for our application, such as whether or not we wanted to have a tag containing a lifetime, a large read distance, and so on. Passive tags had the benefit of affordability as well as convenience, given the fact that battery changes could be avoided.

Another variable considered was what operating frequency was best suited for the project. Passive tags and active tags had different frequencies of operation, and each range of frequencies determined certain characteristics of the tags themselves, such as read range. While active tags commonly operate at 433 MHz, passive tags have three different ranges of frequencies: Low Frequency (LF), High Frequency (HF), and Ultra High Frequency (UHF). Having the shortest read range of only about 1-10 centimeters, 125 - 134 KHz indicate a Low Frequency tag. Containing a subset of RFID technology known as Near Field Communication (NFC), High Frequency tags operate at a frequency range of 13.56 MHz, where the typical read range could be between 1 - 100 centimeters. Corresponding to the longest read range of potentially over 30 meters, 865 - 960 MHz is the frequency range for Ultra High Frequency. While a higher frequency indicates further read distances, there is a downside to higher frequency as well. The further the read distance, the more opportunity there is to have proper operation-threatening materials to interfere with the signal, such as water and metal.

In regards to the frequency range, the pros and cons of these different ranges needed to be weighed. The LF tags run into the issue of a slow data reading speed in comparison to the higher frequency tags. An advantage to this frequency range was their low vulnerability to certain electromagnetic interferences. They were also able to pass their signals through layers of metal that were relatively thin. Its short read range could be beneficial, but for the IoT Smart Doggy Door, it would pose a constraint. High Frequency tags had the advantage of a faster transmission rate for the data collected, but it was also limited to its short read range of a maximum distance of approximately 1 meter, where roughly 2 meters would be our ideal read range. In addition to this, HF tags also had higher vulnerabilities to noise and EM interference. Ultra High Frequency had the furthest read range capabilities between the three options, as well as the fastest data transmission rate. While a higher frequency indicates further read distances, there was a downside to this higher frequency as well. The further the read distance, the more opportunity there would be to have operation-threatening materials to interfere with the signal, such as water and metal. [12]

3.2.2 Wi-Fi

It was through the use of Wi-Fi, made possible by the Wi-Fi module built into the Raspberry Pi Zero W, that our doggy door could access the database that holds all users, tags, variables, etc. This specific system controller of ours used the wireless standard of 802.11 b/g/n wireless LAN. In doing so we kept the cost of our product down while still using a very reliable and common standard that is capable of giving us speeds that exceeded what is required for any of the communications the controller will be having with the database. This Wi-Fi standard utilized the 2.4 GHz frequency band so even though it was not as fast as the 5 GHz band, the data transfer rates that we could access through this band would be more than enough for the scope of our product. Not only this, but we actually benefited from using the 2.4 GHz band because this band is known to have a wider area coverage and have an easier time penetrating through solid objects to make a connection. In situations where a consumer with a larger house is using our product, this wider coverage can make all of the difference to making it work properly. While regardless of any factors that the consumer might present, the data being transferred between the door and the Internet will always be a fraction of things like multimedia streaming, downloads, etc.

Below we compare some of the main features that differentiated these two popular Wi-Fi frequency standards. We also have a column that noted whether we would reap the benefits of this feature, whether it would slightly negatively affect us, or whether there would not be a noticeable effect. Keep in mind, we used the 2.4 GHz band.

Features	**2.4 GHz**	**5 GHz**	**Effect for us**
Speed	Max of ~450-600 Mbps	Max of ~1300 Mbps	No effect
Area Coverage	Larger area	Smaller Area	Positive effect
Interference	Microwave ovens and other appliances	Cellphones, radars, sensors	No effect, both balance out
Wall Penetration	Waves are more capable of travelling through solid objects	Waves are less capable of travelling through solid objects	Positive effect, no worries about connection strength
Congestion	Old standard, high congestion	Newer standard, lower congestion	Slight negative effect, slowdowns aren't big issue

Table 3: Wi-Fi[13]

Our integration with the database was part of what makes our product an Internet of Things device. But the integrations actually go much deeper than just the system controller talking to the database. This system of ours included the locking mechanism of the solenoids, the addition of an outer camera, the sensing of our motion sensors, and so much more that all interacts with a mobile application and classifies as a Internet of Things system. For every door that is sold, the consumer gets to register however many animals they want based on how many tags they have. Each of these animals has a unique ID or UID. This UID is the foundation for how our system functioned. Every single animal registered under one of our doors had its own UID that lets the specific door recognize it. Each of these individual doors also had their own UID which is how the database keeps things organized. With the help of our RFID reader we hope to store each animal's UID on their RFID readable tag. When an animal approached their respective door, the RFID reader would pick up on the tag and grab its UID. Then the system controller will take note of this UID and pass it along to the Wi-Fi module on the board so it could be sent over the internet. It was very important that when it did this, it also took note of its own UID and sent that along with the tag UID. When the database received this information, it first used the door UID to access the correct subset of animals. From there it could search that subset for the animal UID that was picked up by the reader. Even though this seemed like a process with quite a few steps, we planned for this to all happen very quickly as it is near impossible to train a dog to wait around a specific amount of time for a system to finish its task. The only aspect that we could see slowing down the process would probably be the sending and receiving to the internet through the Wi-Fi module. Still, with network speeds adequate enough to browse the web, sending two IDs and receiving some variable values shouldn't take longer than a second at worst. An edge case that is addressed with our unique door system was not allowing just any animal with one of our IDs into any home. While this might be an edge case we found it would make the customer a lot more comfortable knowing that their door could only be unlocked by their animals. Not only that but the organization for the database would be a lot nicer and easier to follow for any sort of debugging.

3.2.3 Bluetooth

Bluetooth is an important protocol that could easily create a network of devices that can communicate with one another. It plays a large role in IoT as it provides many advantages that other protocols either cannot support or simply lack. While Bluetooth cannot fully operate on its own as an IoT device (due to the lack of internet connectivity), this protocol can be used to deliver information cheaply and effectively to devices that can broadcast information as needed.

One major selling point of using Bluetooth is how cheap it would be. To use it properly, two Bluetooth enabled devices needed to be available to allow for communication. Therefore, in most projects, two sources of Bluetooth must be provided. With that being said, costs could still be around a few dollars. If many devices are required, the price can be expensive, however, for projects that require only a few devices, Bluetooth becomes an attractive option. Other alternatives like Wi-Fi or LTE require some sort of network service provider where fees are charged based on bandwidth usage, speeds, and capacity. A desired feature that Bluetooth offers is the Received Signal Strength Indication (RSSI) which will allow for the detection of the strength of a received signal. Using simple math, a rough estimate can be provided about the distance between two connected devices.

Bluetooth is versatile and provides a wide range of use cases. When people talk about this protocol, they mostly refer to Bluetooth Classic. Bluetooth Classic operates at 2.4GHz using the point-to-point communication topology. It is used in many cases where data types, such as audio, text, images, or video, need to be transferred or streamed [14]. In order to get two Bluetooth Classic devices to communicate with one another, they must be paired. This process can sometimes only take a few seconds. Along with short pair times, security is taken into consideration with authentication, encryption, and authorization [15]. Four different modes of security are offered and there are more than one way to pair two devices. Classic also offers reliable and fast data transfer speeds. While Classic may appear to be a desirable solution, battery life may suffer depending on types of data transfer, speed, and broadcast range.

Another form of Bluetooth is Bluetooth Low Energy (BLE). BLE is another viable option that serves many purposes. BLE commonly gets confused with Bluetooth Classic. BLE not only has a much better battery life compared to that of Classic, but it also offers a better price point as well. Similar to Classic, BLE communicates at 2.4GHz and is able to do so over many channels. Several types of communication topologies are offered such as point-to-point, broadcast, and mesh. BLE offers just a couple of security modes with several levels each [15]. Another important feature is "...high accuracy indoor location services [16]." which is useful for proximity detection and product tracking. Other fields where BLE can be used is data broadcasting with beacons, quick data exchanges, and personalized marketing. Data types like audio, video, images, and more are not supported though. BLE is a strong option to consider due to its variety of uses, cheap price, and ease of use.

While BLE is a better solution than Classic, Bluetooth overall was overkill for our project. Our project did not require constant transmission of data. We only required proximity detection and a unique ID, which could be provided with other communication protocols. We also disliked the fact of having a battery powered collar. BLE does reduce the strain imposed by Classic, however, we did not want the user to worry about the collar dying or being impacted by environmental factors. While RSSI would be useful for our project, with a little bit of research, we quickly found that orientation and other external factors could greatly produce inaccurate results. Bluetooth had its time and place for its use, however, we believed better options exist.

3.2.4 Ultrasonic Sensing

When the project was relatively new and in development, many methods of technology were discussed and taken into consideration. One such technology was ultrasonic sensing. With the necessity of distance measuring, naturally ultrasonic sensing technology was heavily considered. With the use of sound waves, ultrasonic sensing technology uses frequency ranges that are undetectable to the human ear. Once these waves are sent out at a speed of approximately 344 meters per second, they are then reflected back to their transmitter. The hardware component then processes the time it took this wave to be sent back and yields a value for the distance. The average human can hear frequencies up to 20 kHz, hence it is very important to operate at a frequency range that is above 20 kHz. Consequently, the typical range of frequencies that is used is within the frequencies of ultrasonic sound, around 40 kHz - 75 kHz, although other frequencies can be used. The frequency used is a very important consideration when choosing a design for this technology. The lower the frequency, the less distance that is detectable through ultrasonic sensing. For example, at 40 kHz, a distance of about 10 meters is detectable. However, at higher frequencies, only a few centimeters may be achievable.

This technology is utilized in many applications. Ultrasonic sensing had the ability to detect objects regardless of their shape, orientation, and physical properties. They are commonly used in implementations that must have the ability to avoid physical objects or detect the presence of something. This can be seen in drive thrus. Many companies include these sensors in order to detect the presence of a large vehicle such as a car or a truck in order to notify a worker. They are also a vital component in collision avoidance systems. Certain quadcopters use ultrasonic sensing in order to detect the presence of a wall or incoming object, and promptly move out of the way with a particular protocol initiated by its detection.

With such an effective means of measuring, one might wonder why this method was ultimately not chosen. Originally, it was debated where this technology would have been placed in our design. The idea of inside the collar was entertained, as well as on the door frame. Once the ultrasonic sensor came within a particular distance to the door, then pneumatic actions would be taken to open the doggy door. The use of some transmitter/receiver would have to be used as well in order to distinguish the presence of a particular object/location. It is important to note as well that the range of frequencies a dog can hear is up to around 45 kHz, and a cat's detectable frequency range can be up to 85 kHz. While the sound coming from an ultrasonic sensor would not necessarily hurt an animal, nor cause them any discomfort, it is possible that this would distract the animal and result in unnecessary difficulty in training the animal. On top of this possible constraint, there was an additional issue: It would not be feasible to create unique identities for each individual pet. A defining characteristic of our IoT Smart Doggy Door design was the customizability of permissions of individual pets via a smartphone application. Using ultrasonic sensing technology, this would not be so easily implemented due to its lack of individuality. It would be difficult to distinguish one pet from the other, causing the idea of individual permissions to be unachievable [17].

3.2.5 Local Storage

On our system controller we will be using an SD card as a form of local onboard storage. There were two main reasons why we see it beneficial to our product to include and fully utilize this onboard local storage even with our product's main attribute being IoT. The first of these reasons was that we plan to keep a cache of certain variables for each tag stored for quicker access. If we stored these important, base level permissions locally we saved the system the time of having to communicate with the database each and every time a pet approaches the door. Instead our cache would be holding the basic information of all the tags associated with the specific door and would know whether or not any of these specific animals could use the door when they approach it. To keep the system updated with time and weather changes that could change if an animal could use the door, we will be polling the database often to see if any of these changes have come into play. This frequent polling of the database by the system also allowed it to accurately implement any direct overrides that the owner might've done on the mobile app.

Besides the overall quicker access, our local storage will keep our consumer at ease in the case of the system losing connection to the internet for whatever reason. As explained above, our system would be constantly polling the database for if each and every pet can currently use the door. In the situation where communication with the internet is lost, the local storage would still be holding the most recent data that the database contained before it lost communication with it. While unfortunately there was no way of us getting a change made in the database to the system when internet communication is lost, with our polling system, as soon as the connection has been re-established with the internet, the latest state for every single tag was sent straight to the cache and ready to be accessed. When making a smart doggy door, the last thing we wanted our consumer to worry about is down time. With such a product it is essential that it is working 24/7 as your pet does not know when the internet is down. Without local storage our IoT door would have the negative compared to regular smart doggy doors that it would be down with no connection.

To summarize, the importance of our local storage comes from:

1. Cache
    - Quick access
    - Only holds essential information
    - Latest updates made available by constant polling
2. Independence
    - No reliance on internet connection
    - Constant polling allows for the most recent data to be what is stored in an outage situation
    - When the connection is reestablished, data updated on both ends is communicated and merged

3.2.6 Security

Bringing up security when it comes to a doggy door design might seem a bit unnecessary to some, but one of our main goals with the project was the consumer's peace of mind. Thankfully, since this will be a regularly sized doggy door, users would not have to worry about a thief making their way into their house through the door. However, there were still concerns that could arise from a doggy door system with regards to security. The main one that came to our mind was having a thief taking our consumer's pet from inside the house.

Our solenoid locking mechanism would double as the locking mechanism for the main functionality of the door while also preventing any thief from accessing anything on the inside. The solenoids on both sides of the door would sit very close to the flap itself. This meant that the inner solenoids would prevent any thief from pushing the door in to get access to the immediate area by the door on the inside. Our flap would also reach the bottom of the frame, preventing the thief from sticking their fingers under it and pulling the flap towards them to access the inside, even and only if they manage to bypass the outer solenoids.

In the event that a thief is trying to open the door, not only will our preventative measures stop them from doing so, but we implemented our camera system setup so that anything that occurs outside without a tag's presence will be captured as an image and sent back to the database and subsequently the user's phone. We wanted to implement this with a high priority notification alert that will be sent to the user so that they are aware of the situation outside of their doggy door while it is happening. From the app the user could then take over control of the locking mechanism and they can also decide from there whether they would want to contact some sort of law enforcement or a neighbor/friend to check out the situation.

An important implementation of our system was to ensure this security measure works by overhauling the pet's access in these situations, only being able to be overwritten by the user in the app. This meant if the thief gets the pets attention and lures it towards the door in conditions where it would normally be let it out, the buzzer will play a sound alerting it that it cannot currently exit and the solenoids will stay in place as we will implement a top priority auto lock when the infrared sensor detects something outside. This also means that this system would also help keep unwanted animals from entering even if they grabbed the pets attention.

3.2.7 Databases

IoT integration became the most important aspect of our project. In this semi-new field of smart doggy doors, we saw the potential in innovating this product beyond what has been done on the market. We wanted to put the power of customizability into the users hands with a mobile application that lets them control their smart doggy door at any time from anywhere. At the core of this concept, database integration was our necessary foundation to allow for all of this to happen.

Very early on into our brainstorming, right around the time when we had started considering a doggy door, the option of storage of IDs with some sort of subset of different variables that could change the effect of the state of the system was considered. It didn't take us long to reach the thought of online databases as previous experience with them had shown us just how powerful they can be, but there were still several reasons why we didn't just stick to some local storage only system. The first situation that solidified our preference towards databases was taking into consideration when a pet owner is away from their residence for any amount of time. With a local setup system, even if a mobile app was integrated, we did not have a way to communicate with our door if the user was not in range of their home network. With our system, the user actually never communicates directly with the door on the mobile app. Instead, certain adjustments the user is making are sent to the database which the database then communicates to the door over the home network no matter where the user is.

Name	**Couchbase**	**Firebase**	**MongoDB**
Short Description	JSON-based database derived from CouchDB	Cloud-hosted realtime database. All clients share one realtime instance and auto receive updates	Database that works both as a cloud service or a deployed self-managed infrastructure
Cloud-based only?	No	Yes	No
Offline mode?	No	Yes	No
Server Operating System	Linux, OS X, Windows	Hosted	Linux, OS X, Solaris, Windows
APIs and other access methods	CRUD, Query, Search, Analytics API	Android, iOS, Javascript API, RESTful HTTP API	Proprietary protocol using JSON
Triggers	Not immediate	Immediate	Not immediate
MapReduce	Yes	No	Yes
Server-side scripts	Javascript	Potentially limiting Google 'rules'	Javascript

Table 4: Databases[18]

Above, we delved into some popular databases that were all considered for use in our project. Finding the perfect database platform for our software was crucial as the database serves as the foundation on which our whole project was built upon.

Another consideration was the flexibility and power that databases are capable of nowadays and how they could help this project on a larger scale. With a local setup of IDs and variables we are limited to local storage space, potential local storage issues that could leave a consumer with all their inputted data being lost as it is only stored in that one location, and things of the sort. Besides this, having our user data in databases, our team was able to help the customer debug certain issues much easier with direct access to their specific product's data. Our team was able to help them set up anything they might be struggling to set up and ensure that certain changes could be reflected in our database. Down the line, in the age of software updates, we would be able to make certain changes to our database, add new variables, fix any potential issue, all without having to go through each individual product one by one.

For our database, we used Firebase. Firebase is Google's database that had some amazing features that led to choosing it. Firebase is so much more than just a database, it is a service that provides its users with great ways to create projects like our own and helps with the integration of everything in the project. One of the features that would be of essential use to our team is their asynchronous listeners. These listeners could be attached to any of the variables we wish to create and act in such a way that when the variable is first initialized or when its value is changed, it would be able to trigger whatever event we see fit. This is how we plan to keep our local storage on the system up to date with anything happening in the database.

3.2.8 Programming Languages

As an Internet of Things project, our software is what sets us apart from other "smart" doggy doors on the market. Most, if not all, of these smart doggy doors just have to worry about programming their tags to the reader and be done with it. In comparison we will have to go through that process while also being sure it is communicated back to the database over the internet. After this it will have to add certain database entries that then have to use an API we would make to communicate it back. Finally, it must be able to access all of this on a mobile app that will be from the ground up allowing users to make changes to the database and use other features.

There was a lot that went into the decision on what programming language/languages to use for this project. Throughout their years at UCF our two computer engineers have learned quite a few different languages but most agree that they are most comfortable with Java. For this reason, Java was our first choice and with Javascript experience for API from previous classes we planned to use both of these languages to write all the software for our project. Java is an extremely powerful language, especially for people who know how to use it and have been taught some of its best utilities. In terms of Javascript, the experience was not as much as Java but it was being used in the exact same way we are looking to implement it.

However, as time passed and all factors were considered we ended up agreeing Python was best for our project. Python, while we may not have as much experience in it, is not only an extremely powerful language but it is easy to follow and understand. We were ready to be faced with some difficult software challenges and believe all the libraries and resources for python will be a big help in getting over the hurdles along the way. Python is the future of programming and with our innovative product that we hope to introduce to the market, we want to make sure we are not only with the times, but also future proof. Our Python software that will be made publicly available will make it much easier for our everyday user to try to follow if they would like to, while also being a breeze for most programmers to understand as Python is the most popular programming language in the world.

Even though we were mainly utilizing Python for this project, some Javascript was still considered for the database. But as mentioned, this will be no problem as we feel comfortable coding up APIs in Javascript. Javascript has many different objects and already existing APIs that it can easily access. Things like events, security features and authorization are all made simple through the use of Javascript. Because of our utilization of a REST API it is possible that we use Python.

3.2.9 Doggy Door Damping Mechanisms

One of the main concerns with the doggy door involves the swinging motion of the doggy flap door itself. When the door swings outward, we would like the door to move back to its starting position after being opened. This was to facilitate a predictable and consistent closing pattern so that it could be locked without any complications. When pondering the issues and comparing them to the desired function, there had to be solutions to this specific problem. Below are several types of relative technologies that were researched in order to solve this concern, which include rotary dampers, soft closing spring door closer, and door magnets.

3.2.9.1 Rotary Dampers

Rotary dampers slow down rotary movements and allow for controlled declaration. As seen in [19] , they come in two different styles, one having a gear component coming out that is often used in CD player lids that cause the lid to open slowly when the CD player is opened. The other style is called a disk damper. Instead of having a gear on the end of the damper, the disk damper has a small circular or square hole in the center that allows for a shaft to be inserted.

The disk dampers usually require more torque in order for the damper to work properly. The gear-shaper rotary dampers have a larger range of torques necessary to work properly. With both of these dampers, they can be used for movement in the clockwise and counterclockwise directions, as well be bi-directionally. For the purpose of the project, the bi-directional damper was the best option since a traditional in and out style doggy door was being used.

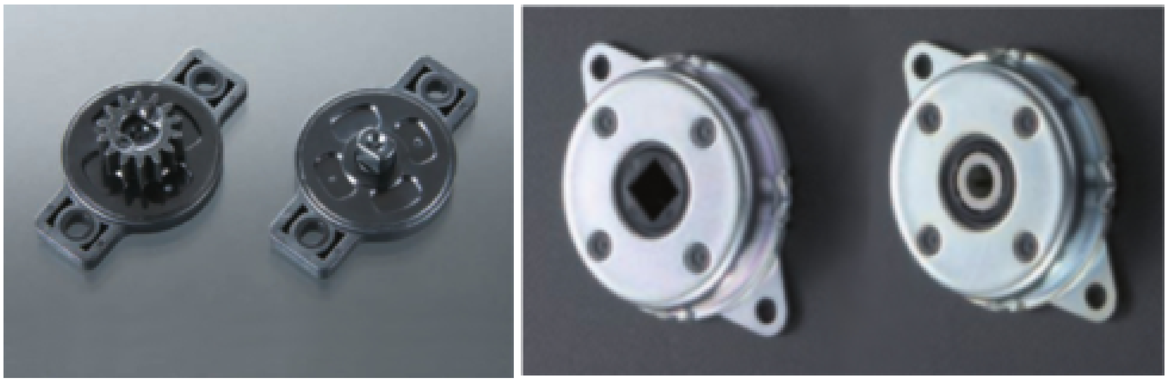


Figure 4: Rotary Dampers
Reprinted with permission pending, from [19]

3.2.9.2 Soft Closing Spring Door Closer

Another relevant technology is a soft closing spring door closer. These are very commonly placed on doors in schools, stores, and restaurants to close the door automatically once it is opened. These are usually large with respect to the door. The specific one in [20] that is pictured below is about 6 inches long and was the only spring door closer that scaled down to a doggy door size. The limitation of this design is that it only allows for movement in one direction. This would cause the design of the door to be adjusted and the door would have to only go out as opposed to in and out. If this mechanism was used then the door would have to be opened automatically for when the dog is outside and wants to come inside. This would cause an even bigger issue causing other technologies to be researched.

Figure 5: Soft Closing Spring Door Closer
Reprinted with permission pending, from [20]

3.2.9.3 Door Magnets

Door magnets were the first component thought of to get the door to settle back into its starting location after opening. This was arguably the most widely used device used to help the door close in doggy doors on the market. However, this project was using an RFID reader and the magnets could affect the electromagnetic fields that the reader gives off. This was something that needs to be further tested if it does affect it or if it would not be an issue if smaller magnets were to be used. This concern led to further research on how to keep the door in the starting location after opening in order to all together avoid any interferences in the electromagnetic fields coming off the RFID reader that could occur either right away or in the future.

3.2.9.4 Door Hinges

Different hinges were researched to be used for the doggy door to allow 180 degrees of rotation and work with the flap that was designed. As mentioned in section 3.2.9.1, rotary dampers were researched to eliminate the need for hinges so they could allow the door to rotate 180 degrees as well help allow the door to return to its starting position without having many swings back and forth. This idea would be the best but when prototyping, the rotary dampers started to not work exactly as planned and therefore door hinges were researched to see if they could work.

The first hinge looked at is just a basic door hinge that would be used for a small door. This was the first hinge that was prototyped due to being an inexpensive option. When it was prototyped, two hinges were used, and one part of the hinges were attached to the ceiling of the door frame while the other was attached directly to the door flap. For the initial prototype the door flap was made from plywood to just see how effective the hinge was. When the flap was open it was able to be fully opened to be perpendicular to its starting position when opening out, but when opening inward, the door was only able to open about halfway. The door flap had to be screwed too close to the ceiling of the door frame and when opened the top of the door would catch the ceiling of the door frame limiting its range of motion. Although this prototype did not fully get the range of motion that was expected, it could be adjusted to allow for a full range of motion but it would have to be done by adding another mechanism. The top of the door flap was already screwed as far down on the hinge as possible and could not be screwed any lower on the door or it runs the risk of not having a strong connection to the hinges and the screws breaking off from the door. Therefore a metal piece would have to be attached to the hinge and the door flap would then have to be attached to the new metal piece. This would allow for the door flap to be lowered from the top of the ceiling and allow a full range of motion. The downside of this fix is that it could leave a small gap from the ceiling to the top of the door that could allow bugs and the outside elements to enter the house, which would not be ideal.

The second hinge researched was a pivot hinge. These hinges are usually placed on the top and bottom of a door on either the right or left side, and this allows the door to rotate on the pivot. This was an alternative to normal door hinges. To use these pivot hinges for the purposes of the doggy door, they would be attached to the top left and right side of the door frame and the door flap itself. This was a promising idea but the main concern of this method is that most of these pivot hinges are designed to be attached from top to bottom as opposed from right to left, and this could lead to an unsecure connection between the door frame and door flap.

3.2.9.5 Solenoids

Solenoids were researched as a potential mechanism to be used as a way to lock the door and this information came from [21]. Another design of the solenoids is to dampen the flap when it starts to swing back after opening. Two solenoids would be placed on the inside of the flap and two would be placed on the outside of the flap. When the dog is inside and wants to exit to the outside, the exterior locks will retract to allow the dog to open the flap, but the interior locks will remain extended. The purpose of this is to allow the flap to be able to bounce off the interior locks once the flap begins to close. This will allow the solenoids to dampen the singing of the flap and allow for the door to need a smaller number of swings before returning to its stationary position.

Relevant Technology	Cost/Unit	# of Units for Implementation	Difficulty of Implementation (1-10)	Constraints
Rotary Dampers	$8.64	2	9	- High Torque
Door Closer	$17.98	1	2	-Unidirectional
Door Magnets	$9.99	2	6	- Interfere with RFID
Door Hinges	$3.18	2	3.5	- Limited range of motion as is
Solenoids	$10.67	4	7	- High current draw

Table 5: Damping Mechanisms

The main concern of this design was that the motion of the flap would potentially damage the solenoid, or the flap could be damaged by hitting the solenoid. To get around this, a material that could absorb more of the force would be placed either on the solenoids or on the bottom of the flap to dampen the force of the swinging door more, while also reducing the chance for the door flap and the solenoid being damaged.

3.3 Core Components and Part Selection

Months of research was needed in order to choose the proper technology that would fit our design. Once the appropriate technology was determined, fitting hardware components that were compatible with one another also needed to be identified. The following section outlines the reason why certain technologies and specific hardware were chosen.

3.3.1 System Controllers

After extensive research into the perfect system controller for our project, we arrived at the Raspberry Pi Zero W. When we initially as a group came to an agreement on the doggy door idea out of the other projects we had in mind, the scope of this smart door was quite different.

One of the first additions made to the idea back in the early stages of brainstorming was the IoT functionality. We all agreed that at this current point in time, just differentiating ourselves with the fact that our project was a doggy door instead of a regular door didn’t bring something necessarily new to the table as these have been done before, even if they are still a fresh new addition to the market. With some of us having just recently finished a class where we worked extensively with databases and got introduced to the endless possibilities of the IoT, we knew integrating it with our door was the creative step up we were looking for.

This is where our first real thought of the system controller came to us. After agreeing on making our product an IoT product and making it the main selling point to have it stand out from the current smart doggy doors, we knew a system controller with the ability to communicate over the internet was a must. This didn’t necessarily mean we needed a system controller with a Wi-Fi module built in as we were aware that there are separate add-on modules that provide Wi-Fi capabilities to a system controller that doesn’t have it on its own. Still, this is when the idea of a Raspberry Pi first came across the table for us as we knew it was a powerful, cheap, compact device that could communicate over the internet on its own or with an add-on depending on the model we went with.

As our research progressed and our idea became more solidified, there were a few minor components that would be added onto the vision we had for our product along the way. Starting off with the motion sensor, the idea to include it was brought up at a time when we already knew we needed the Wi-Fi capabilities and needed to make connections to actuators, a buzzer, and things of the sort. At this stage we were thinking of a system controller that would be along the lines of a MSP 430 as we knew the Raspberry Pi could've been considered a bit of overkill for what we were going to include and something under performing an MSP 430 could struggle handling something like the Wi-Fi module on top of everything else.

The last piece we would decide to include would end up being the most demanding one, the camera. After hoping to still get by with something that had comparable processing power to the MSP 430, research found that MSP 430s' were known to struggle with capturing images even if it was the only thing they were tasked with. This is when we returned to what once might've been considered overkill for our scope as the addition to the camera now needed this extra processing power. Further researching into Raspberry Pis, with an understanding that we still didn't need their most powerful controller, we found the Raspberry Pi Zero W to be the perfect device for our product as it had just the right of processing power to use a add-on camera perfectly, store these pictures locally when need be, and came with Wi-Fi capabilities already built in.

Around this point in our research is when the comparisons had to be made and used to determine which board would be best. Regardless of whether the other option would be some sort of MSP board from TI or an Adruino isn't really important to this comparison. We wanted to compare these microcontrollers to the microprocessor which is the brain of the Raspberry Pi Zero.

	Microcontroller	**Microprocessor**
Clock speeds	Usually well below 1 GHz, especially for the small scale board we are looking for	1 GHz for the Raspberry Pi Zero W
Memory (RAM)	Usually in the KB range	512 MB for the Pi Zero
GPIO pins	Usually less than 20 for smaller sized boards	40 for the Pi Zero
Operating system	None	Linux-based Raspbian software
Programming Languages supported	Usually lower level languages	All sorts of languages up to high level languages like Python

Table 6: Microcontroller vs Microprocessor[22]

As shown in the table above, Microprocessors were found to be the best type of system controller to go with for our project. In terms of the processing, the demands of the locking mechanism, the image-capturing from the camera, the communication to the internet and back, along with other things; we found it crucial that we have a capable processor running everything. As you can also see from the previous sentence, there are not only tasks that can eat up a bit of processing power, but they are all working at the same time. Because of this, the higher RAM capacity was a big help for running concurrent tasks. Finally, the presence of an operating system along with the ability to program in most high level languages made our job easier and allowed for us to innovate further without being held back.

Raspberry Pis are compact single board computers that started off as teaching devices and have become so much more than that. Being categorized as computers these mini devices can have a keyboard, mouse, and monitor connected to them to use just like you use any other computer. Granted, simple tasks that we take for granted such as web browsing struggle to keep up with the speeds of computers that most would even consider slow. This also means things like some of the simplest video games or programs also struggle to run on the Pi and even the slightest step up in complexity renders the Pi useless.

Our final decision to go with the Pi Zero, while it may have not been difficult, was still run through a proper comparison to ensure that this system controller was indeed the correct and ideal device for what our project was to entail. Below we have laid out a table of different Raspberry Pi models and compared them to narrow down on our final choice.

Thankfully these uses are not what we are trying to get out of our Pi. In fact, we did not plan on connecting a keyboard, mouse, or monitor to our Pi at all. This mode that we plan to run our Pi in is referred to as “headless mode”. This allows for us to embed our Pi within our project. In our headless mode we still had the Pi communicating with the internet, and all of this requires a very specific set up.

So as the table below shows, the Pi Zero W is our perfect system controller. To first off compare it with the Pico, let’s start with what makes the Pico look desirable. The first difference we can see is the lower price, which at the end of the day may just be a few dollars we are talking about, but it is over 50% cheaper. This along with the slightly smaller factor are both not enough to put it over the Zero. One area where looks can be deceiving and almost convince someone who’s not paying attention that the Pico performs better is the number of cores. With a quick, full glance, it was abundantly clear though that the Pico, while having one more core, also runs these cores at a significantly lower rate and has much less RAM. Getting into where the Zero W puts the nail in the coffin for the Pico is when observing the built in Wi-Fi capability on the Zero W and the already discussed advantages of a microprocessor vs a microcontroller for our project.

	Raspberry Pi Zero W	**Raspberry Pi Pico**	**Raspberry Pi 4 B**
Description	The iconic, cheap, small Pi Zero with wifi and bluetooth	Raspberry Pi microcontroller	Fourth edition of the mainline Raspberry Pi devices
Price	$10	$4	$35
Dimensions (HxWxD) in inches	1.18 x 2.55 x 0.197	0.83 x 2 x 0.154	2.22 x 3.37 x 0.433
Weight in grams	9	3	46
Number of cores	1	2	4
Clock speed	1 GHz	133 MHz	1.5 GHz
RAM	512 MB	264 KB	1, 2, 4, or 8 GB
Ethernet	No	No	Yes
GPIO pins	40	26	40
Storage/Operating System	Yes, microSD/Raspbian	No	Yes, microSD/Raspbian
Wi-Fi	802.11n (only 2.4GHz)	No	802.11 b/g/n/ac (2.4 and 5 GHz)
Bluetooth	4.1 BLE	No	5.0

Table 7: Raspberry Pi Models[23]

When comparing the Zero W to the Pi 4 B is where things got a little more difficult when deciding on the correct system controller for us. One of the first things that strayed us away from the mainline Pi is the fact that it is significantly more expensive and now the difference is not only ~$5. It was not the deciding factor for us, but it definitely started it out lower than the Zero W. Next the quite bigger form factor is another thing that was be a negative for our use. We wanted to keep our system compact as this was all stored inside a door frame. Everything else from the power of the system controller to the capabilities with its wireless standards goes above and beyond on the Pi 4 B. After much consideration into this, we determined just how much power we needed, saw that the mainline Pi might be a little overkill, and sided with all of the advantages that the Pi Zero W gave us in terms of our project.

Our Raspberry Pi operated as our central hub. We used its GPIO pins to connect all our different modules to it. The reader sends all its information that it obtains from tags in its surrounding area to the Pi so that it can be processed. This data is then both stored temporarily on the local storage while also being sent from the Pi's Wi-Fi module to the database.

	ATmega382P	**MSP430**
Architecture	Advanced RISC architecture	Older, von-Neumann architecture
Power Consumption	Low & Efficient	Low
Performance	Medium, suitable for decently complex projects	Low, suitable for simple projects
Ease of Use	Easy to use	Complex

Table 8: Microcontroller Comparisons

To communicate with the solenoid driver circuit, we needed a microcontroller that would bridge the gap between the solenoids and our main system controller. As seen in the table above we ended up deciding on the ATmega382P for multiple reasons that perfectly fit the needs of our project. Overall the arduino chip is more advanced while also not only remaining simple, but actually being simpler than the MSP430. That combined with the better performance and more efficient power consumption makes the Arduino a perfect candidate for the microcontroller. This microcontroller was used to further fulfill our significant PCB Design.

3.3.2 RFID Technology

As discussed in section 3.2.1, there were many variables to consider when choosing specific hardware components for a particular design. Extensive research was done to identify the components with the desired characteristics for the functionality of our project. RFID readers, tags, and antennas must be compatible with one another, requiring careful selection of each component, ensuring that one can accept the others.

3.3.2.1 RFID Reader

With the system we envisioned for this project, we needed some sort of reader that interacts with some sort of tag. As we've discussed throughout the paper, there was a lot of research done on this topic and we believe it led us to the perfect solution for our project. We went with the RFID reader as we believe it provides some of the most accurate and efficient results we can get as RFID as a technology has become very advanced over the past years.

As mentioned early, there are a few very important parameters to consider when choosing an RFID reader. One such crucial variable is the type of polarization of the electromagnetic signals that would be communicated and processed. When considering this parameter for the IoT Smart Doggy Door, we determined that circular polarization would be the best fit for the application. This is due to the fact that the orientation of the collar is variable at the moment of reading, given that the behaviors of animals are quite unpredictable.

The Sparkfun Simultaneous RFID Reader - M6E Nano was chosen to be our RFID reader. This interrogator has compatibility with circular polarized antennas as well as linearly polarized antennas, but in this design it was used for the former. It also adheres to the EPCglobal Gen 2 ISO 18000-6c standard. This reader was a bit more costly at $235.95, but was deemed necessary given all of its desirable qualities. This was definitely the most expensive piece of hardware used in our project. Because of this we had to do everything in our power to make sure that we handled the reader very carefully in order to maintain the integrity of any onboard circuitry, as it would have been very expensive to replace and would have set back our progress significantly.

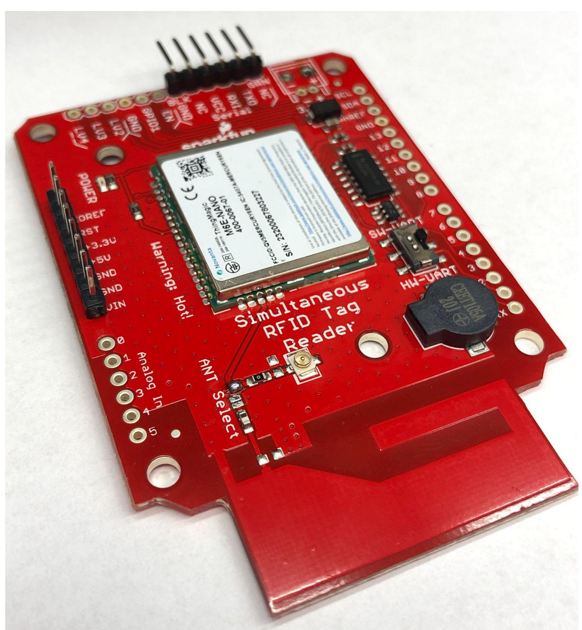


Figure 6: Sparkfun Simultaneous RFID Reader - M6E Nano

The M6E Nano has an onboard antenna in addition to its integrated circuit reader. The onboard antenna has a relatively small reading distance on its own, promising a maximum of only 1 - 2 feet. After testing the onboard antenna with five UHF RFID tags, only one and a half feet was achievable as the furthest distance. Even with the one and a half feet, the reading capabilities are not reliable. For this reason, the reader has the option to connect an external antenna as well to achieve reading ranges according to the specifications of the external antenna. This external antenna can be connected in one of two ways: up to four antennas can be connected to a series of four GPIO pins on the reader module, where the antennas in use can be multiplexed to change which antenna is to be active. The second method of connecting an external antenna is via the u.fl connector located towards the top of the reader, and to solder the board in such a way that the trace antenna is disconnected. In regards to the operation of the reader, exposure of less than 21 cm while the reader is at maximum operation power for an extended period of time is considered to be unsafe. Our design needed to consider the limitations of the onboard antenna, as well as weigh the necessity of a certain read distance in accordance with the price, application, etc.

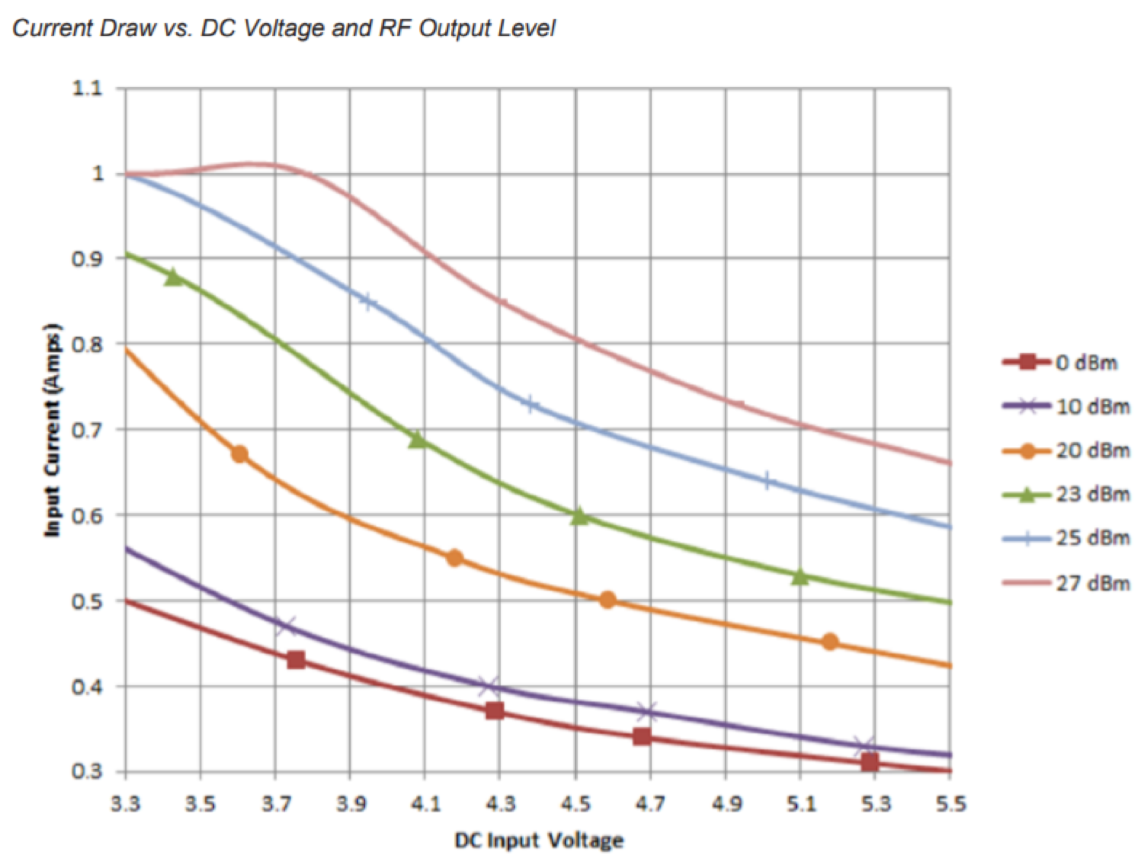


Figure 7: Current Draw vs. DC Voltage and RF Output Level of onboard antenna [2]

Before considering an external antenna, the team first needed to test the onboard antenna's capabilities. The chart above shows the relationship between current and voltage to yield a particular dBm for the onboard antenna, found within the datasheet provided. In order to ensure that the reading module is not damaged and that the device runs properly according to specifications, certain criteria must be met. The input voltage must be between 3.3V to 5V DC for most cases. In order to achieve 27 dBm, the reader must have an input voltage of at least 3.7 VDC. In addition to this, the total input current must also be below 1A. The maximum RF power that this reader is able to manage is 27 dBm; however, as seen in the graph, less current may be supplied at a particular voltage range in order to lower the RF power. For example, in order to operate at 25 dBm RF power, about 4.1 VDC is sufficient for 0.7 A of current. Such details were considered in order to address certain issues. For example, the higher the output power, the larger the read distance. While our design may want to avoid the potential danger of a 21 cm exposure by decreasing the RF power from the maximum output power of 27 dBm to 25 dBm, for example, the group needed to decide if the lesser read distance was a worthy tradeoff. Measurements needed to be done as well in order to determine the significance of this decrease. Another element to consider is power consumption. In regards to RF power, every 3 dBm increase/decrease in power indicates a doubled/halved output power, respectively.

In summary, the Sparkfun Simultaneous RFID Reader - M6E Nano was an excellent choice for the team's design. The reader is compatible with a circularly polarized antenna, which is crucial for the unknown orientation of the tag. Adhering to the EPCglobal Gen 2 ISO 18000-6c standard, this reader meets the standards established for RFID technology. While the price of 235 dollars for a reader is not ideal, it was ultimately unavoidable, and is considerably reasonable compared to many RFID reading modules on the market. The reader does have an antenna included on the board itself, however, rigorous testing of this antenna proved that the distance achievable was too small for its application, reaching a little over 1 foot. This led to the decision to seek out an external antenna. Another important thing to consider is the long-term exposure limit of the antenna. Long-term exposure safety is discussed in section 4.2.4, labeled “safety constraints.” This reader also operates on the frequency band for North America, 902-928 MHz. Overall, this reader provides the functionality the design needs and was essential for the success of the project.

3.3.2.2 Tag

To use RFID, there are some core components that have to be utilized. Firsty, there is the reader which is able to process data. Secondly, an antenna is used to send and receive data. Finally, the tag is the component that is able to store data. Using a combination of the three items, a comprehensive system of data transfer can be created.

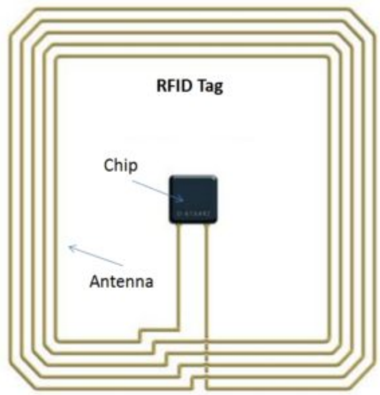


Figure 8: Anatomy of an RFID Tag
Reprinted with permission pending, from [24]

The anatomy of the tag consists of an antenna, an integrated circuit and a memory bank. To power the integrated circuit and receive the data, the tag utilizes the antenna. When the reader sends a request, the antenna attached to the reader sends out a signal. Tags within range of the electromagnetic fields produced by the antenna attached to the reader use the fields to induce a current to power the integrated circuit located inside the tag. Once the integrated circuit is powered, data is retrieved from the memory banks and a signal propagates back out by the antenna on the tag. This is known as backscattering. When the tag backscatters a signal, the antenna attached to the reader is able to pick up the signals and send it to the reader. The reader is then able to process the data that was stored on the tag.

RFID has many applications, therefore, many types of tags can be utilized. Different types of tags can operate under different frequencies. The common frequencies and the ranges at which they operate are as follows: low frequency (LF) which operates between 125kHz and 134kHz, high frequency (HF) which operates at 13.56MHz, and ultra high frequency (UHF) which operates at 433MHz or between 860MHz and 960MHz. It is important to note that most frequency ranges are region specific, therefore, the whole band may not be available in every location.

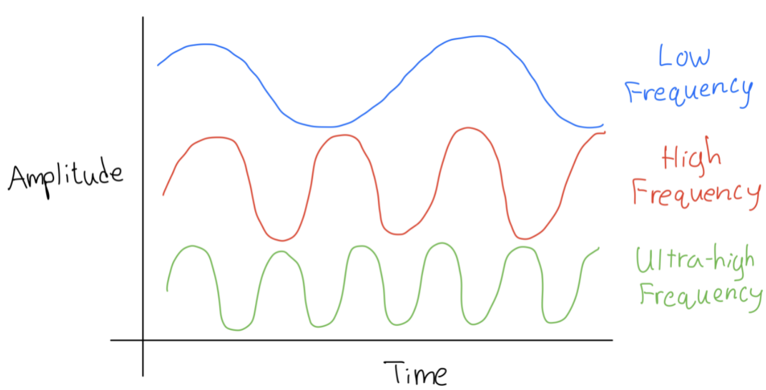


Figure 9: Visualization of different frequencies

LF has a very short read range of about 10cm. The benefit to using LF is that signals are much less susceptible to noise produced by the environment. Some examples of applications that LF excel in are animal tracking, access control, or where liquids or metals are present. HF has a faster data transmission rate than that of LF, but it is still on the slower side. While HF does have an improved read range of around 10cm to 1m, which is ideal for most hobbyists or small distance applications. Applications where HF performs well are in small item tracking (like books or in a store), payments, and ticketing. UHF has the greatest read range of anywhere between near field communication (NFC) to more than 100m. Not only does UHF have fast transmission speeds, but it also has larger memory as well. UHF is most beneficial in cases where accuracy or long range is required such as asset tracking, manufacturing, and electronic tolling.

Different types of tags also exist. There are passive, semi-passive (also known as semi-active or battery assisted-passive), and active tags. Passive tags have the lowest read ranges, but do not require any battery and are the cheapest. Semi-passive tags have a battery on the tag itself to help power the circuitry when a current is induced by an external signal. Lastly, active tags have the greatest read ranges but are less replaceable due to these tags having the highest costs. Active tags have several functions. The first function is that the active tag can act as a transponder and send out its data when in range of an antenna. This type of operation conserves the battery usage which increases the lifespan of the tag. The battery on the tag is used to amplify the signal to achieve greater read ranges. Secondly, the tag can act as a beacon. When acting like a beacon, the tag uses the battery to send out its data periodically for any antenna to pick up. This behaves differently from all other cases where the tag only responds when communicated with by a reader's antenna. Due to the periodic transmission of data, the battery life is greatly reduced. Because the battery is difficult to replace, it is usually better to buy new tags instead of repairing old tags.

Tags come in different form factors as well. Some tags are round in nature like keyfobs or sailboat tags, some are rectangular like business cards or for wristbands, and some are even cylindrical in nature for implants. The larger the tag, the better the read performance because larger antennas can be accommodated. However, large tags may not always be possible in some applications like animal tracking. Orientation of tags is also important. If tags are not aligned appropriately to an antenna, the read range can be greatly hindered.

Figure 10: Different Tag Form Factors
Reprinted with permission pending, from [25]

Of all the different frequencies, we decided to use UHF due to its nature of having better read ranges. To get higher read ranges with LF or HF, prices increase exponentially. We also decided that our tag should be passive instead of semi-passive or active because not only is it cheaper, but we did want our collar to operate with any batteries. If something were to damage the tag, the tag can be easily replaced. Finally, the ideal solution would be to go with a round tag that would be encased inside of some plastic or epoxy to weather-proof it. By attaching a split ring, the tag can be added or removed to any collar. Alternatively, we could have used a rectangular tag (that is paper thin) for better read ranges, however, the tag must be embedded in the collar itself. The round tag hangs perpendicularly from the animal's neck and the dog faces the door when wanting to exit. This allowed for the best possible orientation of the tag to improve the system's reading performance.

3.3.2.3 Antenna

It is important to ensure that our external antenna is compatible with the reader chosen as well as the project at hand. While there were many antennas that were analyzed, the Times-7 SlimLine A5020 Circular Polarized Antenna proved to be the best fit for our design, meeting most of the requirements of our desired antenna parameters that was outlined in section 3.2.1. This antenna was thus chosen as our external antenna.

The Times-7 SlimLine antenna is priced at $119.00. Its polarization type is circular polarization, which is our desired polarization type, as mentioned earlier. As specified in 3.2.1, the beamwidth that was desired for our project was around 120 degrees. The Times-7 SlimLine antenna has a beamwidth of about 115 degrees, which is sufficiently close to the desired beamwidth. Pictured below is a diagram of the beamwidth given in the datasheet:

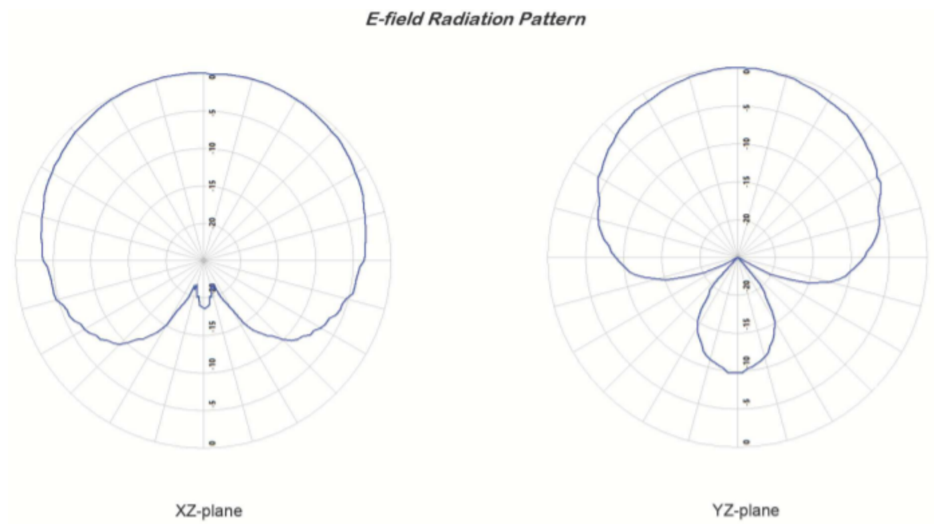


Figure 11: Beamwidth for Times-7 SlimLine A5020 Circularly Polarized Antenna [26]

The two graphs show the power that is emanated from the antenna, where the radial axis describes the amount of power radiated from the antenna at a particular location. The beamwidth corresponds to the angle that captures the majority of the power emanated. This angle is defined between the -3dB (half power) points on either side of the central axis, where the power that is emanated significantly decreases. For this antenna in particular, the input power in the datasheet was specified to be 6 Watts.

The Times-7 SlimLine A5020 Circular Polarized Antenna adheres to the FCC standard for the operating frequency in North America is 902-928 MHz. The max read distance for this antenna is 4.3 meters, which is around 14 feet. This read distance is more than acceptable for our application, where the desired read distance is around 3-4 feet. The gain of this antenna is 5.5 dBic. In order to achieve a particular read distance that is less than the maximum, this power through the antenna can simply be adjusted accordingly. The dimensions of this hardware component are 5.9 x 5.9 x 0.55 inches, providing a relatively small area. Considering that the antenna is situated beneath the door, the smaller the dimensions of each hardware component, the better off our design was. Pictured below is the Times-7 SlimLine A5020 Circular Polarized Antenna, the component that was ultimately chosen as our external antenna for the project.

Figure 12: Times-7 SlimLine A5020 Circularly Polarized Antenna

Even after our search was refined to the parameters discussed earlier, there were still many antennas that were considered during our research. Many of the antennas that were found satisfied a fraction of the requirements that were made, but could not quite satisfy certain areas enough. One such example is the Laird Bistatic PRL90209 RFID Antenna. This antenna met quite a few of the required specifications for our design. The first parameter to be considered was polarization. The PRL90209 was circularly polarized, which is exactly what we were looking for. The next most important characteristic was the beamwidth. This antenna was labeled as having a beamwidth of 70 degrees, which was significantly lower than the desired beamwidth of roughly 120 degrees. This value for the beamwidth coincides with its higher gain of 9 dBic. The max read distance for this particular antenna was not specified. The input impedance of this antenna is 50 ohms, which matches our design. The PRL 90209 operates on the frequency range of 902 - 928 MHz, and its maximum input power is 10 Watts. The dimensions of the antenna in question are 10.1 x 22.6 x 1.3 inches, and it was priced at $214.00. Overall, this antenna was not fitting to our design due to its relatively small beamwidth angle, as well as the fact that it was considerably more expensive than other options. In addition to this, the antenna was rather big, and a smaller size is preferable in order to fit underneath the door frame.

Another antenna that was considered was the Laird S9025PL Outdoor RFID Antenna. This specific component was very strongly considered. This antenna was specified to be circularly polarized, which is what the design required. The gain is given as 5.5 dBi. This indicates a much larger beamwidth than the previous antenna due to a smaller gain. This angle turned out to be 100 degrees, which is a few degrees shy of the preferred 120 degrees. The input impedance for this antenna satisfies the 50 ohm requirement, as well as the operating frequency required by the FCC, 902 - 928 MHz. Unfortunately, the max read distance for this antenna was not included. Its maximum power is also 10 Watts, much like the previous antenna discussed. Priced at $134.00, this antenna has very small, desirable dimensions of 5.2 x 5.2 x 0.71 inches. In the end, however, this antenna was nearly the same as the antenna that was ultimately chosen, except it was a few dollars more expensive with a smaller beamwidth. Its beamwidth shortcomings could have potentially been overlooked if the antenna compromised the issue with a decently lower price, for example.

The Vulcan RFID UHF RFID Antenna was also an antenna that was considered. Much like the previous few antennas, the Vulcan antenna is circularly polarized. With a gain of 3.4 dBi, the beamwidth for this component is listed as 100 degrees, which is decently smaller than the desired angle. The read range is specified to a value of around 3 meters at the maximum, which is certainly sufficient for our design. The input impedance of this antenna satisfies the 50 Ω requirement as well as the 902 - 928 MHz operating frequency necessitated by the FCC. With a price of $64.00, the antenna proves to be financially affordable compared to others. It is 5.4 x 5.4 x 0.13 inches, which is significantly smaller than the other antennas which is also another desirable characteristic. Despite the affordable cost, however, the Vulcan RFID UHF RFID Antenna was not chosen due to its detrimentally insufficient beamwidth.

	Times-7 SlimLine Antenna	**Laird Bistatic PRL90209 Antenna**	**Laird S9025PL Outdoor RFID Antenna**	**Vulcan UHF Antenna**
Gain	5.5 dBic	9 dBic	5.5 dBic	3.4 dBi
Beamwidth	115	70	100	100
Read distance	4.3 meters	unspecified	unspecified	3 meters
Dimensions	5.9 x 5.9 x 0.55 inches	10.1 x 22.6 x 1.3 inches	5.2 x 5.2 x 0.71 inches	5.4 x 5.4 x 0.13 inches
Cost	$119.00	$214.00	$134.00	$64.00
Input Power	6 Watts	10 Watts	10 Watts	unspecified

Table 9: Antenna Comparisons

3.3.3 Camera

Well into our brainstorming, we realized that adding a camera to our system would give the consumer a good amount of benefits. A camera provides the user with an extra layer of customization. Using it in conjunction with the mobile app the user can set up preferences on what they would like to be captured when motion is detected outside the door. We all agreed that going with two cameras would be redundant. Going with one on the outside gave us the added benefit of capturing any animal without a tag in our image.

This security feature was a big factor as to why we wanted to incorporate this camera. While the infrared sensor scans for any unidentified animal, at most it is capable of sending a signal back to the system which then can be transferred back to the database and therefore accessed on the mobile application warning of an unknown presence outside the door. However, this would not give the user any idea of what it might be outside the door and that was worrisome. With the camera implemented, when the motion detector is set off and the RFID reader is not, an image is captured and sent to our database storage. This image is then accessible to the user through their mobile app.

Besides this use we considered that some users of our system, while being away from their home for an extended period of time, might want to set up the camera to capture their pet everytime it goes out and comes back in for a peace of mind. This can be comforting for the user while also giving them the ability to see if any sneaky animal tried to make their way in along with their pet.

When first looking into the camera for our project we came across ArduCAM which is an affordable option that connects to many different types of system controllers and provides a decent quality image. After realizing we needed the Raspberry Pi for its processing power, we then had the option to also use the options provided by the company themselves, even though these seem to be pricier. For our project in specific we aren’t trying to capture images that need to be posted on social media or framed inside a consumer's home, so we just needed a camera that produces images that are good enough in order to recognize your pet, but not much more than that. After an image is taken it is transferred to the database as mentioned but we also included an SD card with our Raspberry Pi to store images locally for 24 hours.

	Arducam OV5647	Raspberry Pi Camera Mod 1	Raspberry Pi Camera Mod 2
Price	$14	$25	$25
Size	25 x 24 mm	25 x 24 x 9 mm	
Weight		3g	3g
Still Resolution	5 MP	5 MP	8 MP
Sensor Resolution	2592 x 1944 Pixels	2592 x 1944 Pixels	3280 x 2464 Pixels
Full-frame SLR lens equivalent	35 mm	35 mm	
Angle of view	64 x 48 °	53.5 x 41.4 °	62.2 x 48.8 °

Table 10: Camera Module Comparisons [27]

To compare some of the options we had for the camera we listed out some of the most appealing options in terms of our project scope in the table above. When searching for our options, the list automatically got narrowed down quite a bit because of the fact that we decided to work with a Raspberry Pi Zero and not just a regular Pi.

As can be observed above, these cameras did not end up being too different from one another. The biggest difference is between the lower two and the Pi Camera Module v2 which is above the others. This v2 of the camera module basically outdated the v1 and almost completely rules it out in any case as they are the exact same price. Price is the real area where our final decision was made. We know for the scope of our project, the higher resolution is not really necessary as we are more concerned with loosely identifying what is in front of the camera rather than obtaining a perfect image of it. Due to this, the Arducam with the lower resolution, lower price and same angle of view as the v2 was our best option out of the 3.

3.3.4 Infrared Sensor

We decided we wanted to use some sort of motion/distance detection for our project when we first started thinking of the risks associated with security and potentially having some animal outside the doggy door that was a wild animal that would obviously not be registered in the system. First, an ultrasonic sensor came to mind as it can not only detect something at the door but it could also provide us with decently accurate information on just how far this thing was from the door. It was pretty quick for us to see the issues with using an ultrasonic sensor. In the event that the consumer was receiving a package at the door and it was left on the ground, the ultrasonic sensor would have no way of knowing that this wasn't some wild animal and instead just some inanimate, non-moving object.

To combat this issue we looked elsewhere for our motion detecting and very quickly came across PIR sensors. PIR sensors use infrared technology to not only detect something that has moved into its range, but it uses the technology to detect higher or lower levels of radiation given off by hotter or colder subjects. This allows it to differentiate a living thing from a box and saves the consumer the hassle of receiving multiple pictures of boxes while away from their residence.

PIR motion sensors are not extremely complex devices. Not only that but they also only really need to execute one main task which is motion sensing. Besides that we preferred a sensor that allows us to change the delay and sensitivity. In the table below we compare different sensors we found online that seemed suitable for our project's needs.

	HC-SR501	**LEDENET**	**LPIR-8A**
Price	Varies, usually around $4 per sensor	$10	$8
Size (mm)	32 x 24	86 x 51	89 x 60
Field of View	<120 degrees	60 degrees	
Range (ft)	21	16-26	15

Table 11: Infrared Sensor Comparisons

This motion sensor is how we planned to alert the camera to take a picture, with a few conditions. First, we wanted to make sure it is not an object so instead of immediately taking a picture when motion was detected, we waited. Second, even if in the process we lose a few quick sneaky animals passing by, we wanted to wait a small amount of time before capturing the image to avoid getting images of people's feet and things of the sort. Lastly, we would by default only capture any image in the situation that the RFID reader is not detecting anything within range, unless otherwise selected by the user in the mobile app.

We also planned on having an interior sensor facing straight down towards the floor. Animals are very unpredictable in nature and can often change their train of thought second to second. Not only this but with all the technological tools we currently have at our disposal, we have no accurate way of reading an animal's thought process or even fully accurately predicting its behavior. The problem with this arose when we saw how this could potentially lead to our product not always being used in the way in which we desired. With humans, most of the time if they open a door, they immediately enter the room, or at the very least within the next few minutes. Only in a very specific case where they might remember something as they are opening the door could they potentially open and not go through. However, thanks to our intelligence, we are aware that we have opened a door and didn't go through and are able to take the appropriate steps to make corrections. With an animal they have the ability, for whatever reason, to try and go through the door and halfway through while sticking their head out, decide they would rather stay inside. While doing so they also don't understand the problem they are presenting us with, obviously.

In order to address this potential problem that came up, we decided to add this second sensor on the inside. It detects when something gets close enough to the door that there is a 90% chance it has opened the door. But just knowing this information was not enough to determine if any animal had actually gone completely through the door or not. To do that we had to use both of the sensors that we planned on including in our product simultaneously, communicating with the board about certain data they are collecting. This small system comes into play when a tag has been detected by the reader. When a tag is picked up we want to start taking note of any values we are picking up from both sensors. If we receive a signal from the one sensor on the inside but never from the other, we know that the animal probably just stuck its head outside and didn't leave. A small issue that arises with this is depending on how big the animal and their head is, the outside sensor might pick up some motion and relay that back to our system when in reality the animal might've not gone outside fully. To counter this we placed the exterior sensor on the top of the door frame at such an angle that completely avoided these mishaps. With this implemented correctly, once a tag is detected we have the system check to see if anything is picked up on both sensors. If the system indeed registers movement from both sensors, this means that the animal has successfully left through the door and we can register it as a proper exit and take note of the specific animal being outside with almost 100% certainty.

3.3.5 Switching circuit

The doggy door will be powered through a wall adapter AC/12VDC converter. However, as discussed earlier, this wall adapter power supply does not account for the event of a power outage. Therefore, a 12V rechargeable battery pack was necessary for the practicality of this IoT project, whose specs will be analyzed in further detail in section 3.3.8. In order to incorporate such an important function in our project, we needed to find a way to switch the power quickly. For this reason, we decided to include a switching circuit. This module receives two inputs. Once the device receives power from both terminals, the output of this component, by default, chooses the power from input one. Once the power from the first input drops below a certain threshold voltage, then the output terminal switches to the power supplied from input two. Before purchasing this component, the team researched its power specifications. This module is able to switch voltages of up to 12V with 150 Watts of power, which is more than enough power needed for the project.

Figure 13: Switching Circuit

3.3.6 Locks

When researching what mechanism would be used to lock the door, several different ideas were thought of. Some of them could only work with specific door designs while others could be used for any door designs. One idea that was thought of that would only work a specific door design, is to use a linear actuator. For this design, the linear actuator would be placed at the top of the door frame and be used to open and close the door vertically. The linear actuator would then have enough force when fully extended to lock the door in place. This method was able to automatically open the door while also being used as a locking mechanism. One issue with this method is that it was costly for our project. With a lot of the budget going into the RFID reader and the antenna, which was the focal point of the project, other methods were researched to lock the door. This design also made the entire structure of the doggy door close to four and a half feet tall. A door this size would not have been as marketable and other designs were taken into consideration after these issues were brought up.

The next two locks work very similarly but the locking mechanisms themselves are different. For this locking design, two locks are placed on the inside of the door near the bottom of the frame and two locks are placed on the outside of the door. This design is used for a door flap that opens and closes inward and outward. Both locks extend upwards, out towards the sky and block the door from being able to swing back and forth when the door is not being used. When the dog wants to exit to the outside, the locks on the outside of the door flap retract while the locks on the inside remain extended. This design allows the dog to only be able to exit one way and not allow for any wild animal or outside elements to be allowed to enter the house. When the dog finishes exiting the door, the flap swings back and bounces off the inside locks in order to dampen the motion of the flap and reduce the number of swings necessary to cause the flap to return to its stationary position. Once the flap is back to its stationary position, the outside locks extend again, locking the door from both sides. Another possibility from the lock design that more research has been conducted on, is to extend the locks on the outside once the flap has passed these locks and before it has been dampened from the inside lock. This would allow for all four locks to catch the door in place before it has time to swing, ultimately reducing the time the door is unlocked. This is the goal for the final locking mechanism, but more research into making this possible had to be conducted.

One of the two mechanisms that could have been implemented into the locking design stated in the previous paragraph is a push-pull solenoid actuator. These solenoids would be placed about an inch from the door frame on the left and right sides of the door and on both the inside and outside. The main component of the solenoid being used is 56x25 mm and has a stroke length of 8mm and can be seen in article [21]. It has a max force of 20N and requires 12v and 1A, as specified within the datasheets found on the website. The location of these solenoids are located underneath the door flap on both sides and block the path of the flap from being moved when locked. When the door is unlocked, the solenoids retract underneath the bottom of the door frame, allowing a full range of motion to the flap.

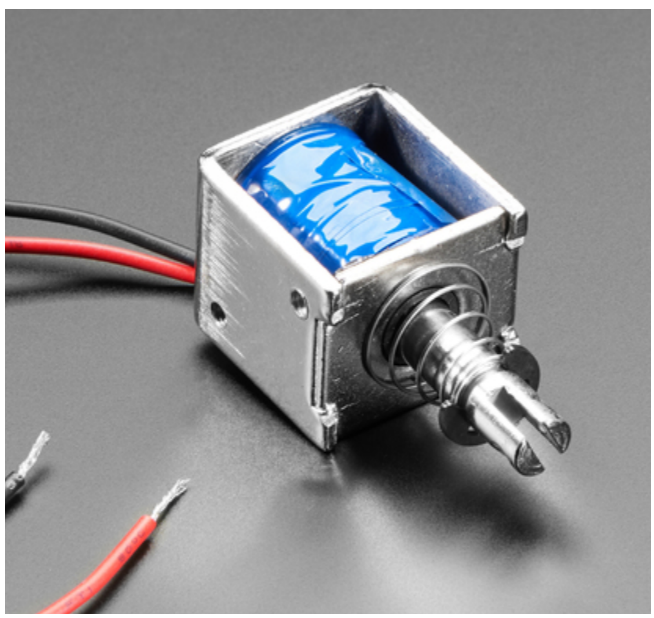


Figure 14: Push Pull Solenoid
Reprinted with Permission, [21]

The second mechanism that could have been implemented into this current locking design, is a mechanism that would require 3D printing and does not have a true name. It is a rectangular piece that would be connected to a rotary motor. The rectangular part of the locking mechanism would be used to lock the door in place and the rotary motor is used to lower the rectangular part from blocking the flap. Once lowered, it allows the door to have a full range of motion. This design was found by researching other smart doggy doors to see what was effective for other versions. Since this part has to be 3D printed, and there is not a lot of research on this style of mechanism, more research was put towards the solenoid design. Another concern was that the 3D plastic would not be able to withstand the forces that could be placed on this mechanism from the dog or outside factors.

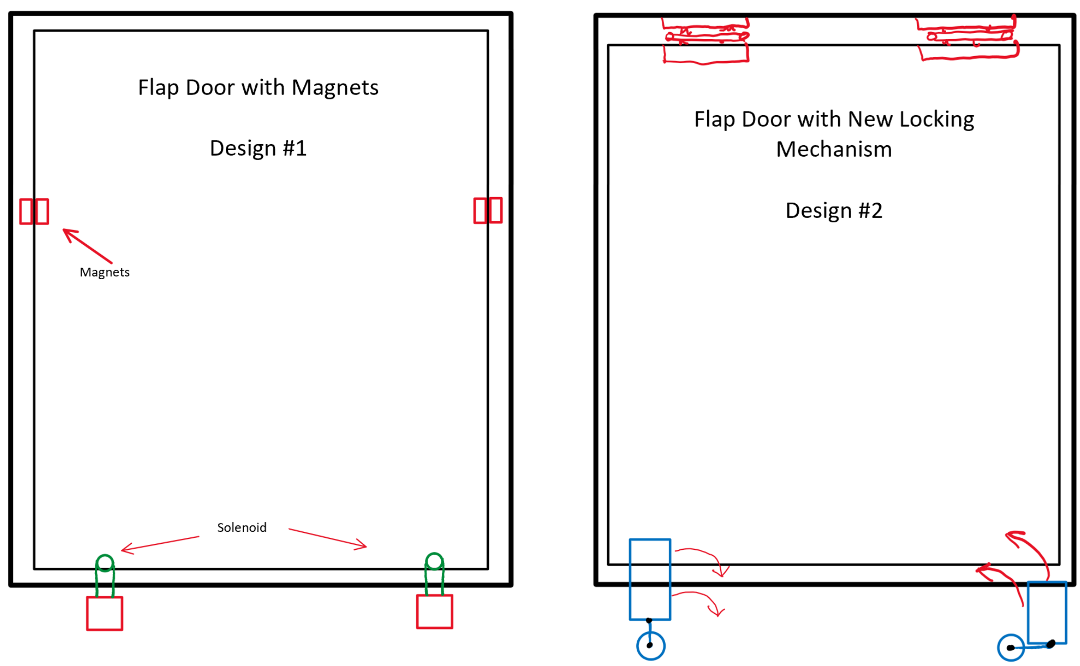


Figure 15: Sketch of the how the solenoid and rectangular locking mechanism would be implemented

A lot of designs had been taken into consideration. While other designs were more than capable of working, they may have been overkill and we believed a more simple solution existed. The previous designs require a lot of components. Some of the components included ways to reduce the momentum of the door (using rotary dampers) so that we can catch the door (with a reed sensor that detects proximity of the door flap) as it returns to its original closing position for the first time. This is important because we did not want other animals running out after only one animal gets permission to pass through. Therefore, locking the door as soon as possible is very important for our design.

After more thought and discussion, a new approach arose. This new idea allowed the door to be locked every time, as long as it had enough momentum (though much was not required). The components for this design are less electrical and more mechanical than some of the other designs. There are four specially engineered locking pins as well as a “knob” (or a protrusion of sorts) that are locked into place by the four pins. Also, some component was required to lift the pins from the locked position. In the door flap’s default position, the flap is stuck in between the four locking pins. Two pins are on the inside of the flap and two pins are on the outside of the flap. These pins are also specially designed so that the door could only open the locking pins in one particular direction (unless some external force is applied). This allowed the locking pins to be configured in such a way that one way entry is allowed from both sides. This behaves much like a normal door. For example, a door can be closed without twisting the handle, however, if a door needs to be opened, the handle needs to be twisted, and a force needs to be applied. If the door needs to be released from the four pins, a minimum of two pins have to be raised (either both pins on the inside or outside of the door flap). This is where an external force has to be applied. Other designs include a push pull solenoid; however, this solenoid is less desirable because by default, the solenoids are turned on. With our research, the smallest current draw that we found with a solenoid is about 600mA. Having four solenoids requires 2.4A at a voltage of 12V. That is a minimum of 28.8W. Other solenoids we have seen can go up to 1A per solenoid. Needless to say, having the solenoids on almost all the time is very inefficient. Additionally, if the system ever loses complete power (both from the wall power source and the external battery), the door remains unlocked which is unacceptable. Finally, the solenoids create an electromagnetic field which may have possibly interfered with the reading performance of the antenna. This information has led us to research other components, such as electromagnets.

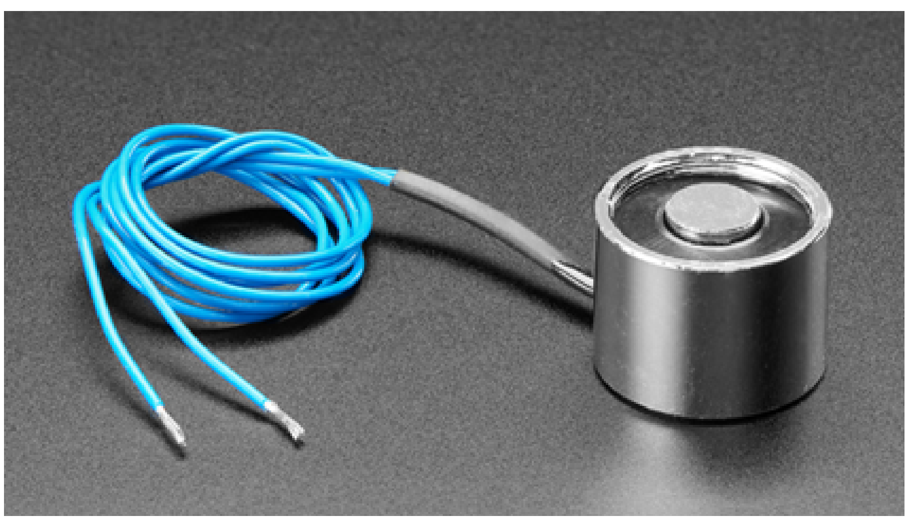


Figure 16: Electromagnet
Reprinted with permission, from [28]

In the place of solenoids, this new design that the team thought of would instead incorporate four electromagnets. These electromagnets would be implemented to effectively replace the presence of the solenoids, each situated on either side of the door on both the inside and the outside. Electromagnets are essentially magnets that can be turned on or off. Much like the solenoids, when these magnets are not “active,” they are in such a position that keeps the door locked. Once activated, these electromagnets sufficiently retract, clearing the way for the doggy door to open. For our new design, the electromagnets, by default, are turned off. What had to be discussed is the driving force behind their actuation. Remaining purely electrical, the only time at which these electromagnets are turned on is after the antenna has already read and processed a tag. Therefore, the electromagnetic fields do not interfere with the antenna’s reading performance, mitigating the concern for electromagnetic interferences. This realization in particular was especially promising, considering the delicacy of RFID technology’s adverse reaction to electromagnetic interferences. Another fortunate characteristic of these electromagnets was realized, and its benefits would significantly be reflected in our finance budget. The magnets are much smaller and vastly cheaper than the push-pull solenoids that were discussed for the previous design. This change in price becomes glaringly obvious when the required quantity of four actuators is taken into consideration. Overall, these magnets would perform much better and would be more efficient.

While electromagnets would be ideal for this use case, electromagnets are not as strong as some permanent magnets. Therefore, we first had to do some math to see if electromagnets were a possibility. Ideally, we wanted an electromagnet that was no taller and no wider than one inch. We found an electromagnet that had 12V DC input and around 80mA current draw. A chart was also provided to find the Gauss of the electromagnet at varying distances. Due to precise mechanical engineering, we did not want the distance of the locking pin to be any shorter than a quarter of an inch. At this point, we had enough information to determine if using electromagnets were feasible. To solve for the force of the electromagnet at a quarter of an inch, we needed the following variables: number of turns in solenoid, current draw, magnetic constant, area of ferrous material, and the distance between the magnet and ferrous material. We had to solve for both the magnetic constant as well as the number of turns in the solenoid. To find the constant, we only needed to plug in two numbers. To find the number of turns in the solenoid, we needed to solve for the magnetic field intensity from the flux density. From the magnetic field intensity, we were able to rework the magnetomotive force and solve for the number of turns. After finding all the variables, the force could be found. Unfortunately, the force of the electromagnet was weaker than the force exerted by gravity on the locking pin. Therefore, without relying on bigger electromagnets, more current draw, and more money, this implementation would not work. The math described can be found in the figure below.

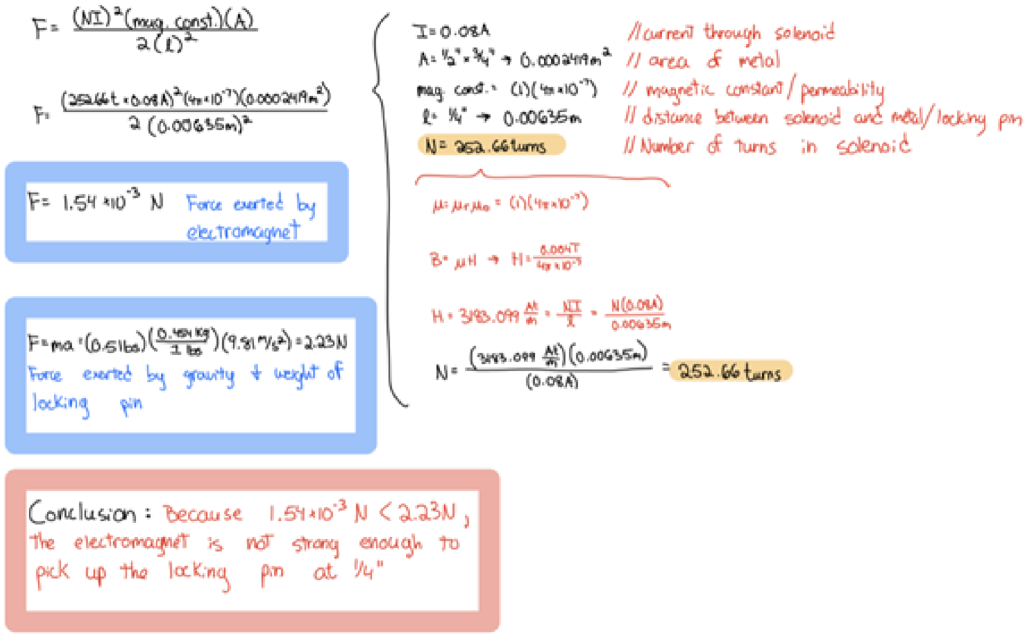


Figure 17: Electromagnet Force

While electromagnets would not work, push pull solenoids were still a viable option. By setting up the solenoids in a particular manner, the default state of the solenoids are off. The solenoids are positioned on either side of the door, one on the inside and one on the outside, for both edges of the doggy flap door. This design was implemented by placing a solenoid above each of the 3D printed locking pins. The locking pins were specially printed to match certain dimensions that are needed. These pins needed to attach to the shaft of the solenoid in a very specific way, whose design specifications were rectified by the 3D printing technology. Once the Raspberry Pi processes a tag and the door is ready to be unlocked, the corresponding solenoids activate, which lifts the locking pins for a few seconds. This gives whichever pet has activated the door a sufficient amount of time to exit. Once the solenoids are turned off, however, the locking pins are then pushed back into place. This is because of the spring that is attached to the shaft of the solenoid. As the door returns to its original position, the “knobs” on the door flap raise the locking pins (due to the design allowing for one way entry from either side) and lock the flap into place. Because the knobs constantly collide with the locking pins, the pins have to be durable. The pins needed to be lightweight, and the spring had to be relatively weak to allow the locking pins to be raised with the force of the closing door. Below are several drawings that help visualize the idea of the door. For this design to work with the knobs, a groove (or cutout) was made to allow the knobs to pass through. Without the latter, the knobs would constantly collide with the frame and prevent the frame from closing any further.

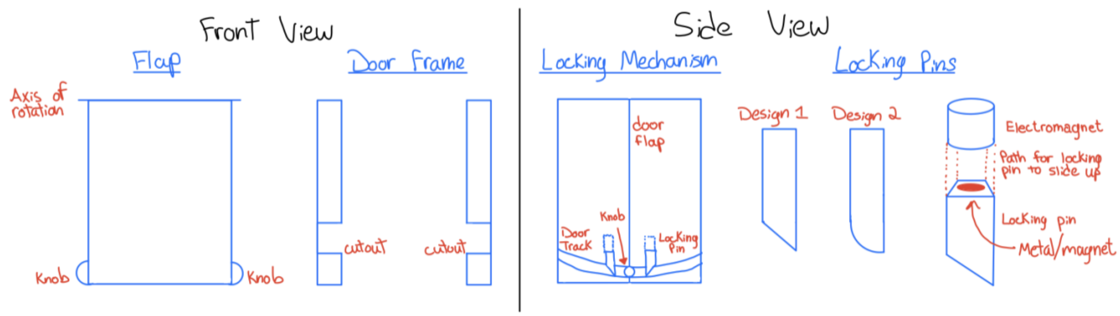


Figure 18: Locking Pin Mechanism

In order to use this lock, it had to be designed in AutoCAD first and then 3D printed. This method was chosen over making the pieces out of wood to ensure all the pieces were identical as well as being light and sturdy. This also allowed for small designs or holes to be designed on the lock in the AutoCAD that are very precise and reduce the chance of errors occurring. This method was also better over making the locks by hand because if the project were to be mass-produced it would be easier to recopy each locking mechanism rather than make each one by hand and have a chance of not working properly due to human error. The locking system is designed in three parts: the pin, the knob that attaches to the door, and the shaft that the pins stabilize to only move up and down. The locking mechanism can be created by using one of two different types of filament, which is ABS or PLA filament. Both of the advantages and disadvantages of these two types are further discussed in section 3.3.8 but both do have a constraint that needs to be taken into account. This is that types of filaments deteriorate after thirty days and can no longer be used without potentially damaging the 3D printed objects as well as the 3D printer. This puts more emphasis on getting all the precise measurements correct the first time so only minor adjustments need to be made to get all the necessary locking pieces created within the thirty day window.

The first piece designed is the pin that is used to lock and unlock the door. The length is 0.65 inches, the width is 0.5 inches and the height is 1.75 inches tall. The print also has a 25 degree slant at the bottom of the pin to allow for the knob to push up the pin. Four of these were 3D printed with two on each side of the door. The pair on each side has the slant side facing away from each other to allow for the knob to push up the pin and then get trapped inside the pair of pins. A possible design that may be added in the future is that each pin will have a small cylindrical piece extending off the side of it on one side. This is used to prevent the pin from falling too far down from the shaft and causing the motion from the knob to not work as it is supposed to.

The second piece that was 3D printed was the knob. This piece is attached to the door and pushes the pin up. This piece consists of a rectangular prism with the dimension of 0.75” x 0.75” x 0.5” as well as a cylindrical prism on the top of it with a diameter of 0.3125 inches and a length of 0.75 inches. The rectangular piece is used to connect the knob to the door while the cylindrical piece extends out and pushes the pin up. The rectangular bottom has an opening for the door to slide in to be attached. This opening is 0.27 inches wide and 0.5 inches deep. Small holes are inserted to the side of the rectangular prism to allow for screws to connect the knob to the door to allow for a sturdy connection. The cylindrical piece was attached to the top of the rectangular prism on the opposite side of the opening.

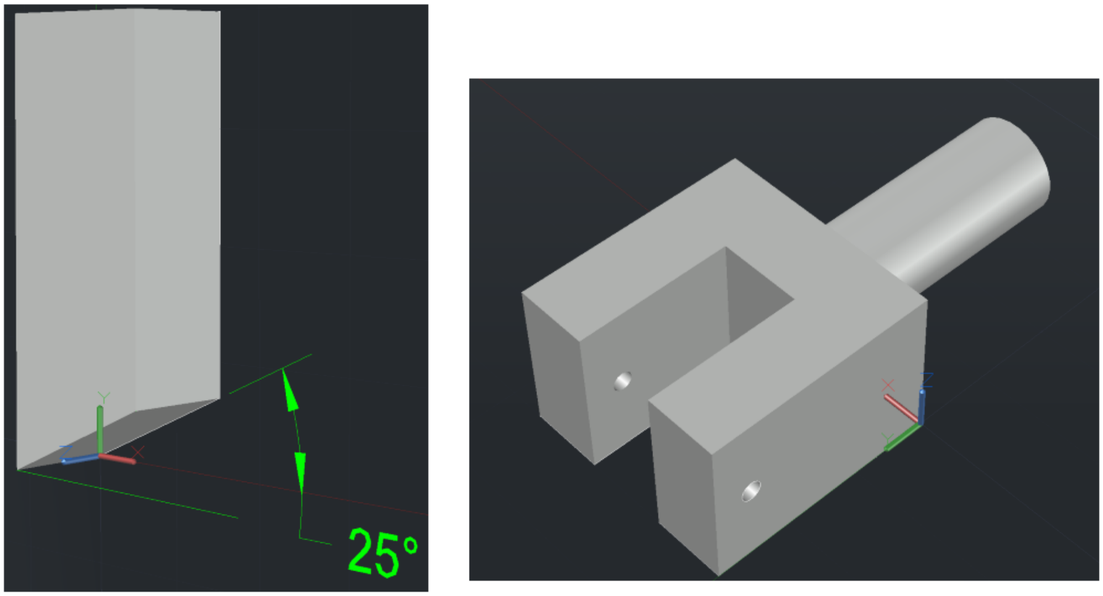


Figure 19: 3D Design of the Locking Pin (Left) and Knob Mechanisms (Right)

The third piece that was 3D printed was the shaft for the pins that allowed them to move up and down without them moving side to side. Unlike the pins, where all four were printed individually, the shaft for each pair of pins were connected to each other in one piece. This allows for a specific distance that the pins are separated to make sure the spacing on each side is the same to help reduce any error when used. The shafts were connected with two horizontal bars that are on the back side of the shafts. These bars also have drill holes on them to allow for the shafts to be attached to the side wall of the door structure. The size of the drill holes were referenced with [29]. This allowed for an easy assembly and eliminated the need to try to find the best way to attach the shafts to the door after printing them. A possible design that may be added is that each pin could have a small knob on one of the faces that reduce the range of motion of them and prevent them from falling too low on the shafts. If this is the case, the front of the shafts would also have a small slit on them which allows for the cylindrical prism on the pin to enter and act as a guide for the pin to go up and down without it falling too far below the shaft.

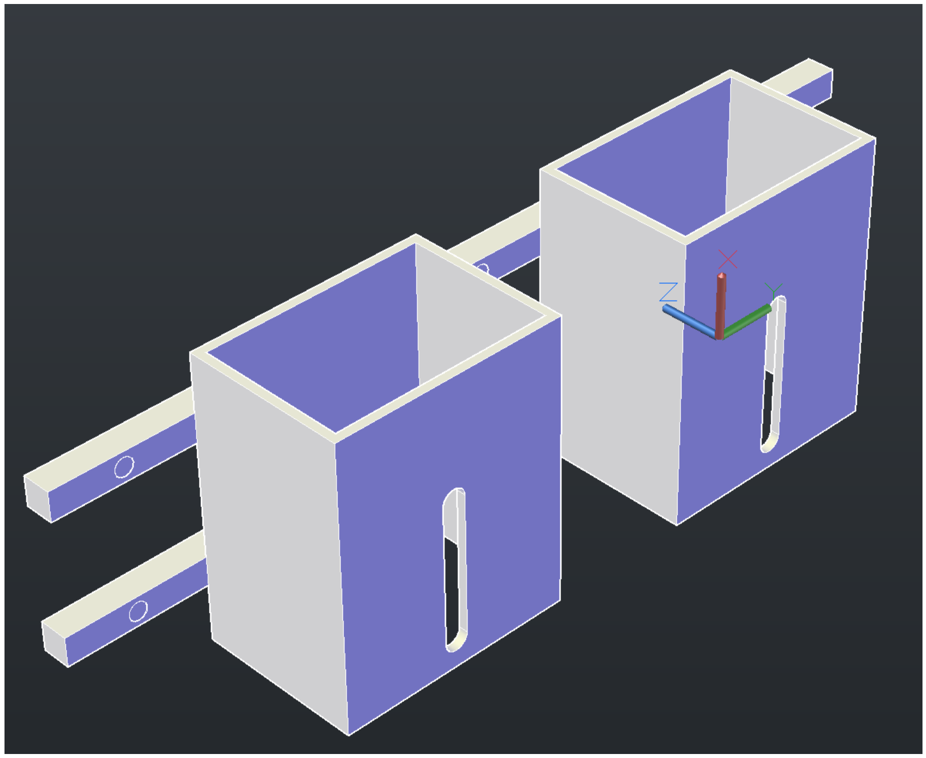
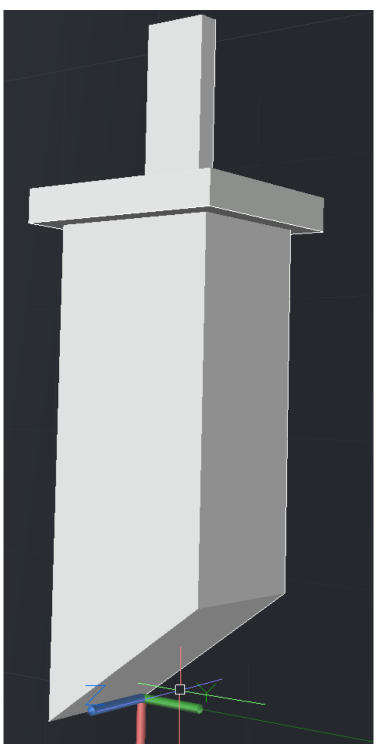


Figure 20: 3D Design of the Shaft Mechanisms (Above)
Figure 21: 3D Design Prototype 2 of Locking Pin (Below)



After initially designing and then later printing the pieces of the locking mechanism, alterations to the design had to be made. One issue that kept occuring was getting the size of the shaft right for the size of the locking pin. The shaft for the first prototype was too small and the locking pin could not fit through the shaft. The shaft for the second prototype was too large and the pin moved around and rotated too much. On the third prototype there was a better idea of what to make the measurement to allow for little friction between the locking pin and shaft while also reducing the amount of side movement from the pin. A square top was also added to the design of the locking pin. This square has the same dimensions as the outer square of the shaft and was used to prevent the locking pin from falling through the shaft. This eliminated the need for a piece of wood to be attached underneath the locking mechanism to keep the locking pins up. The angle of the pin was also increased to thirty-five degrees as opposed to twenty-five degrees. This helped the knob of the locking mechanism to have an easier time lifting up the pin. For the locking mechanism, two pieces of equipment were thought of to pull the pin up to unlock the door. For this design of the locking pin, it utilizes a push pull solenoid that pulls the pin up when a voltage is applied to it. In order to connect the locking pin to the solenoid, a rectangular piece was added to the top of the square piece. The shaft at the end of the solenoid splits into two smaller pieces that have a gap between them. It has two holes that a screw can fit. This allows the rectangular part of the solenoid to fit between this gap and make a sturdy connection between the locking pin and the solenoid. After printing, the option to create a drill hole in this rectangular piece was decided rather than designing them into the 3D printed design. This was done to ensure that the drill holes on the locking pin match up with the drill holes of the solenoid. The drill holes on the locking pin were created by using a drill bit to create the holes and this process gives more the option for a precise alignment between the two sets of drill holes. This is something that can be changed in the future with more precise measurements between the rectangular top piece of the locking pin and the solenoid. Then the drill holes can be implemented into the design to eliminate the need for the drill holes to be made manually using a drill bit. This will also speed up the production time if the locking mechanism needs to be mass produced in the future.

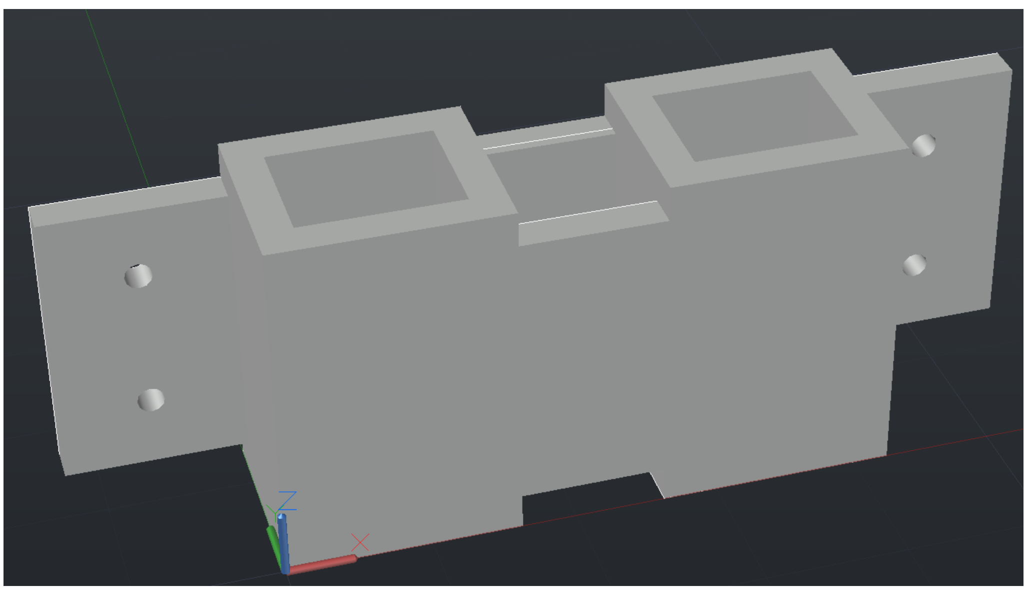


Figure 22: 3D Design of the Prototype 2 of the Shaft Mechanism

The two original shaft pieces had two bars run behind the two shafts to allow for drill holes to be connected to the door frame of the smart doggy door. However, this method made the bars to be very flimsy and decreased the durability of the locking mechanism. Instead the third design uses one bar that has a larger height. The drill holes between the two shafts were also removed and instead an additional bar was placed in between the two shafts. With both of these changes the durability of the shaft mechanism was greatly increased.

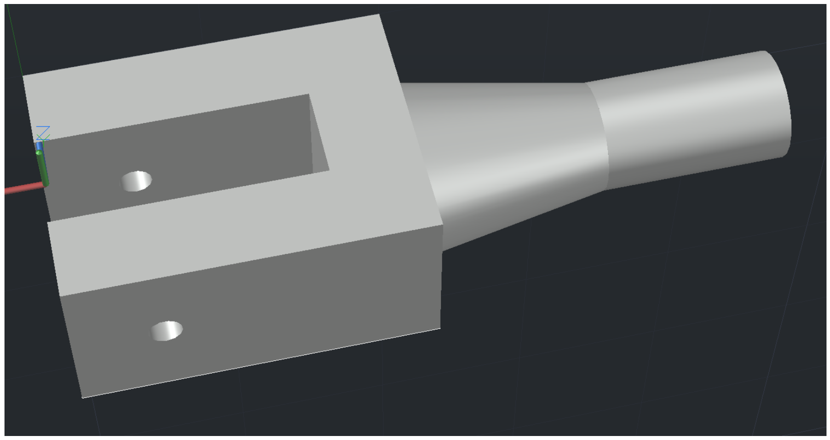


Figure 23: 3D Design of the Prototype 2 of the Knob Mechanism

The knob had a small amount of changes. The circular shaft of the knob was increased from 0.75 inches to one inch to allow for a longer reach from the side of the door to the bottom of the locking pins. The base of the knob that connects to the side of the door increased from 0.75 inches to one inch to allow for a sturdier connection, giving more room for the drill holes as well and the drill holes were changed to allow for #6 screws. The only aspect unchanged that may need fixing in the future is to increase the size of the circular shaft at the base to ensure its sturdy connection to the base. With this, the knob can withstand the force exerted from the swinging of the door that pushes the locking pin up.

Locking Mechanism	**Operating Voltage**	**Current Draw**	**Force**	**Operating Speed**	**Price**	**Size**
Solenoids	12V DC	1A	20N	Instant	$11.59	2.2"x1"
Linear Actuator	12V DC	2.3 A	4000N	4.5mm/s	$59.95	Extended Length: 44.3”
Printed Pin	None	None	N/A	N/A	$21.00	0.75”x0.5”x2”
Printed Shaft	None	None	N/A	N/A	Free	1.3”x3.375”x 0.8125”
Printed Knob	None	None	N/A	N/A	Free	0.75”x0.5”x1.5”
Electromagnet	12V DC	80mA	6N	Instant	$29.24	0.75”x0.75”x 0.62”

Table 12: Comparisons of the Different Locking Mechanisms

The table above goes into more details about the measures and other specifications of the different mechanisms that are used to lock the smart doggy door. It starts at a diameter of 0.5 inches and gradually becomes more narrow for 17/32 inches until it reaches a diameter of 0.3125 inches. After this distance, the width of the cylinder remains the same for another 17/32 inches. This increase in the width of the knob is done to create a sturdier piece that reduces the risk of the piece breaking after further use.

3.3.7 Buzzer

When researching for our project we put a bit of our resources into researching how animals react to sounds. Through past experiences and prior knowledge we as a group knew that sounds could be used as indicators for certain animals and that these animals could pick up on them. We also knew that an animal with the ability to isolate certain sounds in its brain also gives it the ability to associate certain sounds with whatever is happening around them when they hear the certain sound. This is how dogs can be trained to sit or stay. However, further research into this subject found that many dogs can very well be sitting because of the pointing gesture their owner is doing at them rather than their ears hearing the sounds produced by the owner saying the word ‘sit’. Cats, we thought, were also just generally less responsive to hearing these commands, but it actually just has to do with the fact that cats are a bit harder to boss around and they do whatever they please at any given moment. With proper training, a cat can learn the sounds made by the owner saying “sit” and react to it properly if it wants to.

While a buzzer was the first item that produced a consistent sound that came to mind for us, initial research first went more towards bell training. Upon getting a better understanding of bell training we saw that this wasn’t exactly what we were aiming for with our project but we could still get some useful knowledge out of it to apply it in our own application. Bell training is a training that teaches an animal to ring a bell that is accessible to them whenever they want to do a certain thing, like go outside for example. In fact the training for the dog getting used to the buzzer probably has to be approached in a similar way with the only difference being that in our case the buzzer is activated independent of the dogs actions. The dog needs to be trained to learn that the buzzer's sound indicates he can go outside and we then use the buzzer to reproduce that sound. If the dog is properly trained, it would approach the door in order to exit, thus being incited by the buzzer.

Unfortunately the buzzer only has one frequency it outputs at, meaning we cannot set up different pitches for different things. This put us in a position where we had to decide on either setting up the buzzer as it was mentioned in the last paragraph to alert the dog when it could come in or setting it up to warn the dog away from trying to use the door for whatever reason. There could be several different reasons why you might not want your pet exiting the doggy door even if it approaches. The main reason for this has to do with the permissions we planned on giving the pet through the database, accessible to the user through the mobile app. Besides this, as mentioned in the security section, if there is something outside that is not identified by a tag.

Dogs are smart but at the end of the day there is only so much we can ask of them. In a situation where a dog is given a door to exit/enter their respective home through, there is no full-proof way of informing the dog that it can only go out under certain conditions and even if just one of those conditions is not met, they are not able to use the door. The last thing that we wanted for our consumers' pets, was for them to run full force into a door that isn't going to budge for them. Not only is this super dangerous and problematic for the pet's health but it can also severely damage our project's components. To counter all of this we introduced the buzzer and hoped its use would prevent such an accident. The pet has to be trained to understand it, and that training is slightly different depending on if the buzzer alerts them of their ability to enter/exit, but this system provided us with a reliable sound to alert the pets of something.

3.3.8 Power

If you look at percentages for the average daily consumer, their chances of losing power day to day are quite low. Low to the point where the percentage might fall within the range of percentages that are attributed to edge cases. Yet with our product we find it of utmost importance that we do not treat such a scenario as an edge case. Even with the low chances of a power outage, it is still something that everyone probably goes through at least once a year. That one day of the year our customer could be away on a business trip, relying on our system to let his dog out when certain conditions are met. He might try to check up on the system and be alerted on the mobile app that, unfortunately, the system is down due to a power outage. Fortunately for him, we have thought of this exact scenario that can, and most likely will, happen to any of our consumers.

This is where our battery bank comes into play. The battery we chose to use for our project is the TalentCell rechargeable battery (whose specifications are discussed in section 6.1.1). We set up a system that has the battery always powering the system. Without our battery bank we would just get the necessary input power from a wall outlet. With our system, power is still extracted from a wall outlet at all times. But instead of sending this power straight into the system controller, we send it to the battery to keep it at its full capacity. In the situation where there is a power outage, the system is now able to stay up and running for as long as the battery power lasts.

Another possible approach is having a system that takes in the power from the wall and then reaches a crossroad in its set up. Depending on certain factors we determined if our doggy door is currently running off of straight wall power or off of the battery. This solution does not potentially overload and expand the battery which can decrease its efficiency slowly over time while also potentially becoming a very dangerous hazard. With this set up we were required to have a way of sensing whether the battery is fully charged or if it is in need of charge. This is because if we never end up charging the battery it is never ready for its use. In application, on initial setup our product takes the wall power and splits it evenly between the door itself and charging the battery. Once it has been detected that the battery is fully charged, the wall power is no longer directed to it and it is all sent directly to the unit. Batteries can hold a charge for an extended period of time, but power outages are not a very common event. Due to this the battery might drop to a percentage that is not preferable for keeping the system up and running. To counter this, the system we use to determine if the battery is fully charged also detects if it has fallen under 90% and provides it with power if that becomes the case.

3.3.9 3D Printing Filament Material

The locking mechanism is designed on autoCAD and then 3D printed. When it comes to 3D printed different filaments can be used that each have their own properties and prices. The filament that would provide the best for the smart doggy door is a filament that can make precise prints with fine measurements as well as being durable. While these are the main properties desired for the locking mechanism of the smart doggy door, the price of the filament also provided a major factor in the decision on what filament to use. The 3D printers that are used are one of two printers provided to the student at the University of Central Florida. These printers are only able to print ABS or PLA printer filament so the decision between what filament to use is between those two options. The University of Central Florida gives each group ten cubic inches of free prints and therefore both types of filaments were tested in printing out early models of the printing mechanism. The information below was gathered from [30].

The first filament that was tested was the ABS filament. Each piece of the locking mechanism was printed very precisely and the quality of the print turned out very good as well. The pieces were very sturdy and lightweight. The overall quality of the print and filament used was very positive after receiving the pieces.

The second filament tested was the PLA filament. After receiving the printed pieces, it was clear that the quality of the print did not turn out as well as the print using the PLA filament. Around many of the drill holes for the shaft of the locking mechanism, was a clump of extra burnt plastic that blocked some of the holes. The PLA filament was also denser and heavier than the ABS prints.

After receiving the 3D prints that used each of the two filament types, the ABS filament seemed to be the better choice. That being said, more research between the two types was conducted to make sure the PLA filament pieces were not just a poor print and would come out better if redone. After researching more into the two types, it was clear each had its advantages and disadvantages. The main drawback of both filaments is that they start to deteriorate after thirty days and this puts a constraint on the team to get all the necessary locking components created before the thirty day window is up. If all the locking mechanism pieces were not created in this window, additional 3D printing filament eeded to be ordered, and this would increase the cost of the overall design of the smart doggy door project.

	ABS	PLA
Price	($14 - $60)/kg	($19 - $75)/kg
Nozzle Temperature	210℃ - 250℃	180℃ - 220℃
Properties	- Durable - Flexible - Strong / Hard - Heat Resistant - Longer Lifespan - Creates Harmful Fumes - Needs heated surface	- Strong - Less Durable - Can deform with heat - High Printing Speeds - No Fumes - Can print on colder surfaces

Table 13: Comparisons of the Different Printing Filaments [30]

3.4 Part Selection Summary

When deciding parts for our system, a lot of considerations had to be taken into place. Some of the considerations taken for the components were as follows: price, weight, responsiveness, dependability, current draw, required operating voltage, footprint of the components, and more. While we desired to achieve a system that is easy to use and has a lot of features, we wanted to keep costs down when we can. Ultimately, we wanted to prototype a functional system that demonstrated our vision for this project. However, being college students greatly limited our budget. Dividing the prices among each of the members and paying for parts across the span of two semesters made the overall price more reasonable. Another important factor to keep cost as low as possible was the footprint of components. Due to the design of our system, we have some space allocated to house all of our components such as the antenna, reader, battery, Raspberry Pi, and more. To prevent the design from becoming too large and obtrusive, the footprint must be contained by opting in for smaller components if the option was available. Some examples where this was necessary was the decision between antennas. While the specs for one antenna may offer more range or a better beamwidth, our decision was to go with the antenna that had a smaller area but nearly identical characteristics. Sometimes, when deciding factors, an inverse relationship existed with other factors. For example, if we wanted a component to be more dependable or have more desirable features, the price must also increase. When deciding between using either Bluetooth or RFID, Bluetooth would have been proven to be cheaper, but the RSSI was inconsistent, and it also operated on batteries. The table below discusses additional considerations when deciding which technology to use on the collar for communication between the collar and the system.

	Wi-Fi	**Bluetooth Low Energy (BLE)**	**RFID**	**Ultrasonic Sensing**
Range (m)	50+	< 100	< 5	< 7
Frequency (MHz)	2400	2400	902 - 928	0.025 - 0.05
Battery consumption	High	Low	None	Low
Price	< $6	< $3	< $ 1	< $30
Responsiveness	Varies	Varies	Fast	Fast
Connection Type	TCP/IP	BLE Protocol	Radio frequency	Ultrasonic

Table 14: Communication Comparisons

Some of these rows may vary depending on antennas used, network providers, features included, and more. From our research, this was the general consensus of the parts we found. Realistically, RFID is much more expensive once both the reader and antenna are included. However, to implement RFID into a collar, it is very cheap by itself. The other communication protocols do not take into consideration the other parts required to make the system on the collar work. The collar may also require regulators, a power supply, a development board or some combination of all three. Wi-Fi and BLE may vary a lot with regards to range and responsiveness. This can be largely affected by environmental conditions (such as noise or obstructions) and the orientation of the device itself.

3.5 Weatherproofing and Enclosure Design

Due to the door being partially on the outside, a weatherproof design was implemented to ensure that the smart doggy door can withstand the harsh weather from outside and be durable enough to last many years after installation.

It was also important to create a design that will not damage the inside walls of the house since a small hole in the wall must be made in order to insert the doggy door for the home. In order to create the best design that takes weatherproofing into consideration, the design of the door frame as well as the materials that go into making it were carefully selected in order to make that most durable and weatherproofing design while also keeping the overall cost of the door frame reasonably low.

3.5.1 Door Materials

The door itself was split into three major components, the door frame, the door, and the hinges that connect the two. To save on cost, the door frame was constructed using wood boards. The boards were positioned into a 4”x12”x22” rectangular shape, leaving the front and back open. The size of this frame allows for large dogs to easily and comfortably go in and out of the door frame. The door needed to be able to withstand outside factors such as wild animals, burglaries, and the dogs pushing the door daily. A feature of the door that was wanted but not necessary, was for the door to be considerably clear to allow for sunlight while also allowing the homeowners and pets to be able to see what was on the other side of the door. To accommodate these door features, the door was made using a polycarbonate sheet because it is lightweight and durable as well as clear.

Two materials were thought of to allow the door to swing back and forth, normal door hinges and rotary dampers. We first tried to use rotary dampers to allow the door to swing since they could provide some resistance when the door is swinging back. This would allow for the door to not swing back and forth constantly and shut nicely. This was especially important to the design of the project because ideally, the door would lock once the swings back to the starting location, to eliminate the chances of unwanted things entering the house once the dog exits through the door. After testing the rotary dampers, it became clear that using rotary dampers may not be the best solution due to a lack of knowledge that could be found on them and difficulty in trying to attach the rotary dampers to the door. The one style of rotary damper that had the appropriate level of torque only had an end with a gear (this is pictured in Fig. 3).

After testing the rotary dampers, the design went back to using normal door hinges. One half of the hinge would be connected to the ceiling of the door frame and the other half would be connected to one side of the door. After prototyping this design, it became clear that the side of the door that did not have the hinge connected to it could not fully open ninety degrees. This was due to the width of the door being pushed to one side of the hinge and the top part of the door would hit the ceiling of the door frame limiting the door from opening more than thirty degrees. While this is the case, it is a problem that can be fixed by using a piece to extend the door lower from the ceiling and allow for the correct degree of motion from the door flap. This will allow for a full range of motion of the door and allow for the desired motion that the smart doggy door would need in order to operate properly with the project. The group believes this method would work but could provide some issues such as leaving a gap between the ceiling of the smart doggy door and top of the door flap. To fix this issue, a piece of foam would be placed in between the door flap and the ceiling to make sure there are no more gaps.

3.5.2 Weather Resilience

The polycarbonate sheet is shatter resistant, has UV protection for long-term weatherability, and impact resistance. As stated in [31], this material can be used for storm-window replacement which adds to the protection from outside elements. The door is as flush with the door frame as possible, while not reducing the range of motion of the door, to help reduce cool air from inside the house escaping and to help keep the natural eliminates from getting inside each home. Part of the door frame comes out from the installation hole and is screwed onto the wall parallelly to prevent any outside elements from getting inside the wall from the installation hole. These door frames, that are made out of wood, are coated in a waterproofing spray to reduce the risk of the wood becoming damaged while being outside.

Another potential design that was thought of is to place a waterproof material around the wooden door frame. As seen in [32], this material would be a water repellent canvas that could easily be surrounded by the wooden components of the door and provide a most durable weatherproofing design. This fabric is an onyx black color and is used similarly to a tarp but with better water repelling capabilities. This would also provide the most aesthetic design which would lead to most customers wanting to use our product. This is a more costly idea, but it could be worth it if the durability increases the number of years that the IoT Smart Doggy Door could be used by several years increasing the overall lifespan of the product.

Another method to add resistance to the weather for the smart doggy door, coming from [33], is to apply a rain guard water sealer spray to the wood of the doggy door. This approach is an inexpensive option and would provide immediate results once the spray is fully dried. This option would also be one of the easiest to implement and can be used in addition to the polycarbonate sheet to add extra weather resilience. This sealer protects against wind-driven rain, helps prevent mold and mildew, and also protects against salt, dirt, UV light, and freezing temperatures. While this is the case, it may not be as effective as providing a water-resistant coating as the water repellent canvas and could be something that needs to be reapplied every so often to ensure a strong resistant coat. This could cause the customers to either buy this wood water sealer on their own or else the smart doggy door could start to experience water damage after a couple of years of use and is a potential constraint that needs to be addressed.

One potential option to increase the weather resilience and overall durability of the smart doggy door would be to create the overall structure of the doggy door out of metal as opposed to wood. While this would provide many benefits to the weather resistance and durability, it could create even more complications to the production of the smart doggy door. Making the door structure out of metal would be very expensive not only to get the necessary materials but to also cut the metal into the necessary pieces needed to put the door structure together. This would drive the production cost up and would end up causing the price of the door to increase and with the smart doggy door using an RFID reader and needing an antenna already, the price for the smart doggy door would potentially be too large for customers to be willing to buy the product. Another potential concern of using a metal structure for the door would be that it would be partially outside and could have the chance to be the target of a lightning strike, which would inevitably lead to even larger issues. For these issues, using metal for the structure of the smart doggy door was not used even though it makes the overall product look more professional and be more durable.

After leaning away from the structure being made out of metal, the next option that was thought of was to make the structure out of hard plastic. This would make the overall quality to be very professional and aesthetically pleasing to the customers and it would allow for the smart doggy door to be able to be mass-produced. While these are all great reasons to use a plastic material for the structure of the door, it has similar concerns to that of using metal for the door structure. The cost of producing it would be very high, and unless we were able to make hundreds of smart doggy doors to make the production cost lower, this method would not make much sense to use. The initial cost would also be too large to afford without the use of a loan to pay for it. That being said, the plastic structure adds a lot of benefits that were worth looking into.

Product	**Cost**	**Weather Protection**	**Ease of use (1-easy, 10-hard)**
Polycarbonate Sheet	$16.84	Impact resistant, UV light, water resistant	4
Water Repellent Canvas	$14.00	Water repellent	8
Water Sealer	$12.53	Water, dirt, salt, UV light	2
Metal Structure	No Quote	Water Repellent	10
Plastic Structure	No Quote	Water Repellent	9

Table 15: Compares the Different Weather Resilient Products

It would be naturally resistant to rain and create a better weather-resistant smart doggy door as opposed to using wood without the need of using any additional products. This option will not be used for the initial project but could be something that can be used in the future if the smart doggy door has a lot of success and customers would want a more durable, weather-resistant, and professional product.

3.5.3 House Installation

The doggy door is set up to be installed into a wall leading outside and [34] helps explain the best way to do this. Most doggy doors are installed into an outside door, but the next most common way is to install it in a wall and this is the approach with the IoT smart doggy door. This approach was taken to allow for the hardware inside the door frame to be able to fit without having any components exposed. The average thickness of a door is about 2 inches while the average thickness of an exterior wall is approximately 9-12 inches thick. This allows about 8-9 inches to store all the necessary hardware components needed and have them protected from external factors. The door comes in three parts, the main structure of the door that includes the doggy flap as well as the locks and electrical components. The other two parts are a pair of identical door frames that cover any remaining gaps from the insertion hole as well as provide a means of screwing all three parts together and providing a sturdy connection.

3.6 Mobile Application

There were several ways to develop the mobile application. Some options included an app builder, developing an application for each operating system, or using some framework to make adjustments for each system. App builders tend to be easy to use, but offer the least amount of control by the developer. An application can also be made for each operating system (mainly iOS and Android) which will offer the best speed. The issue with this route is that an app must be created for each operating system, which requires a lot of extra work. Frameworks can be user friendly while providing the developer with many tools to use at their disposal. Frameworks can also be slightly adjusted to allow for the creation of an app on different operating systems. While many options exist for the creation of a mobile application, some options provide better support, speed, and control.

The developers had no previous experience with using Swift or App builders. Due to the platform dependent usage of Swift and low control of App builders, these two options would not be used. While the developers do have experience when it comes to using Java, development is once again platform dependent and would also not be used. Finally, while both Flutter and React Native have a lot to offer, React Native is the framework used to create the mobile application. The developers have had exposure to React Native and are more familiar with JavaScript than they are Dart. The usage of 3rd party libraries was also a selling point when it comes to using React Native over Flutter.

Our mobile app is the bread and butter of our project. In conjunction with the database, everything is interconnected with the hardware components on the door. We have a few screens we planned on implementing for the user to navigate through, and they were able to manage the tags and permissions on the app.

	Flutter	**React Native**	**App Builder**	**Java**	**Swift**
Language	Dart	JavaScript	Varies	Java	Swift
Ease of Use	Easy	Medium	Easy	Medium	Hard
Environment Setup	Text editor	Text editor	Web application	Android studio, IntelliJ Idea	Xcode, Atom, Appcode
Speed	Fast	Fast	Slow	Fast	Fast
Support/ Documentation	Yes	Yes	No	Yes	Yes
Portability	Yes	Yes	Varies	No	No
3rd Party Libraries	No	Yes	No	Yes	Yes
Learning Curve	Medium	Medium	Easy	Large	Large

Table 16: Application Development

3.7 Database Design

As mentioned previously, we would be using Firebase to create the database for our project. Firebase is much more than just a database service and has many uses past it. For our purposes we will be using it mainly as a database but Firebase is a Backend as a service (Baas) meaning it is actually capable of much more than just database hosting. With our use we dug into its core to make use of its realtime database that is a multi-node key-value database optimized for synchronizing data and storing it centrally in the cloud. All the data gets stored in a JSON and gets synchronized in real time to each client.

Firebase works best with systems that can store a cache of the latest data somewhere and it is integrated beautifully with our local storage. Even if the internet goes out, Firebase still continues working its magic in the background, executing any timed based or user called actions. Firebase is able to actively track all of this while it's happening, regardless of connection to the door, it’s able to keep note of every single change. Once the device comes back online, this allows for a smooth and quick refresh of the entire system. It’s even capable of taking note of changes that have happened locally and merge them with the latest information from the regained connection.

As stated above, the data from Firebase gets stored in a JSON. JSONs are JavaScript objects and are the foundation of how our API worked and communicated with the database. Firebase utilizes something referred to as a REST API. REST APIs are APIs that follow the REST architecture. REST stands for representational state transfer. An API is considered RESTful if it has a client-server architecture that consists of clients, servers, and resources with all of its requests managed through HTTP. It requires stateless client-server communication and cacheable data which allows the streamlining of the client-server communications. Our API consists of all these constraints and therefore is considered a REST API. Our realtime database is the REST endpoint. Using an API testing client like ARC we were able to send whichever HTTP requests we wanted to our endpoint and observe to see if the correct changes were made, assuring us that our software setup worked as intended.

When it comes to how we actually laid out the database, there were a few layers to it. At the base we wanted there to be all the user accounts, creating an account was the first step for any user that wants to use our product. There are tons of inexpensive, dumb doggy doors out there. Therefore we are not looking to provide that service, even if we allow it to function without things like internet and power in emergency situations, an account is required. After creating the account we looked to have the next level under that be the door/doors. Under that layer was where the owner can start adding all of his different pets to the door one by one based on the tag they give them. Finally at the deepest layer was all the permissions each individual animal has.

As the developers, we see every single account that is created for our service. We will encrypt every password for the safety and peace of mind of our consumers, not only knowing that we will not do anything malicious with the information, but in an unfortunate situation where our database gets hacked, their sensitive information is safe behind encryption. From this level of access that we will have as the developers we will be able to send out over the air updates to our consumers if we implement a new feature, bug fixes if we are getting lots of complaints pertaining to a specific issue, and we will also be able to easily assist a customer who might be struggling with the setup or certain configuration of their account.

4 Related Standards and Design Constraints

A very important goal our team had to meet was to adhere to certain standards established, as well as the natural design constraints given the design's integration process. It is important to adhere to the standards set on any given technology in order to guarantee optimal operation as well as safety for the users and developers. The IoT Smart Doggy Door strived to meet the related standards for all technology involved in the making of this product in order to have the most advantageous design possible. Knowledge of the design constraints was also crucial in communicating and applying necessary safety information to all parties that are involved.

4.1 Related Standards

Before we tackled such a massive project, acknowledging the industry standards was crucial. In this section, several electronic and RF standards are discussed. These standards serve as guidelines as well as beacons of success for the project. From the beginning, the team was aware of the many intricacies and details that were involved with RFID related products. In addition to this, electronic standards alone were very extensive, and use of such components without a deep knowledge, understanding, and reference to important industrial guidelines could most likely lead to devastating repercussions. In order to ensure success and safety, the following related standards were acknowledged and followed.

4.1.1 ISO 18000-6C:

The RFID reader and tags had to adhere to a particular standard. EPC global and the International Standards Organization coordinated these standards to ensure that RFID technology was safe and operated properly. The readers and tags that are used in this project follow the ISO 18000 standard. This standard specifies certain qualifications and characteristics for RFID related products, such as what type of operation the system will follow. An example of this is an ITF (Interrogator-talks-first) system, which describes the communication relationship of the reader and the tag. In this example, the reader would be the initiator. Another example would be TOTAL (tag-only-talks-after-listening), where, as the name suggests, the tag would not independently send out signals, but would rather wait for an initiation in order to communicate.

EPCglobal Gen2 consists of 6 different tag classes, each adhering to the ISO 18000 protocol, labeled as classes from 0 to 5. "Gen" refers to the RFID system's physical architecture in regards to how the system was set up to operate. The class refers to what type of functionality the RFID employs. Some of these classes offer features that are not necessary or required for the scope of this project. In addition to this, some of these classes' tag requirements did not even fit this project. Each class has slightly different features, each with a unique amount of customizability or read/write capabilities. The scope of this project only requires a passive tag with short read range. For this reason, the tags that we decided to implement fall under the class 1 category, fully described as EPCglobal Class 1 Gen2 tags: ISO 18000-6C protocol.

Class 0:

This class specifies a “read-only” interrogator-tag RFID system that is specified to be used in the ultra high frequency (UHF) range. The tags would be preprogrammed, and must be of the passive type. Tags falling into this class category could achieve our overall goal. However, this class does introduce an additional step to the process with the preprogram configuration required. While the frequency of operation does match the frequency of our implementation, a main aspect of the design we strive for would be ease of use, where the tag is capable of being written as well, storing multiple unique identities.

Class 1:

This class is meant for RFID systems that operate in the ultra high frequency or high frequency (UHF or HF) range. An appealing characteristic of this class is its ability to write-once, and read-many (WORM). This means that the tag will be written once, and then read an indefinite amount of times. This fits perfectly into the design of our project. We wish to create an RFID system that can give a unique identity to each individual animal/pet, and then to read that tag indefinitely. This class also operates at the UHF range, which is what our project employs as well.

Class 2:

Any frequency range from low frequency, near field communication, high frequency, all the way to ultra high frequency are able to fall under this class given its unique functionality. RFID systems of class 2 consist of passive tags that are able to be read or written on, but the amount of times that it can be written is not just once, but as many times as desired. Considering the fact that our project only requires a one-time write in order to establish an animal's unique ID, this class simply was unnecessary given the context.

Class 3:

RFID systems that fall under class three are able to perform many useful operations. This class allows for read-write operations for sensors capable of measuring phenomena such as temperature, acceleration, or pressure. An RFID system falling under this category would be very useful for projects involving such parameters, however, this class was not useful to us, considering our design only requires the sensing of the dog's presence. Ultimately, the number of features for this class simply exceeds the scope of this project.

Class 4:

This class of tags describes quite powerful operations that could get complicated very quickly. It consists of only active tags that can be either read or written. The identifying characteristic of this category is the tags ability to communicate with other tags and other readers. Its integrated transmitter allows it to perform such complicated operations. Considering the fact alone that this category requires an RFID system with an active tag, it was not applicable to our design. In addition to this, communicating with more than one reader as well as other tags simply had no place in this group's project.

Class 5:

This class is very similar to class four, except it has a few more features offered. Like class four, category five comprises purely active tags that are capable of communicating to other readers and tags. However, RFID systems falling under this category describe an active tag that has the ability to supply power to other tags. In addition to this, the tags from class five are also characterized by their communication compatibility with other devices aside from readers as well. The same conclusion that was drawn for class four can be drawn for class 5 as well: In addition to the active-only tags, the amount of features offered to this class was simply unnecessary.

4.1.2 IPC-2221

PCBs also had certain standards to meet. The Institute of Printed Circuits has issued a set of standards for printed circuit boards. There are many standards that IPC has created for PCB design. One of these standards is IPC-2221, which is the standard that addresses the physical properties of a PCB, such as the layout of its design, as well as how materials used perform electrically and mechanically. There are three classes of requirements for PCBs: The first class focuses on commercial products for everyday users, where the reliability of the application is is not of primary importance; the second class is required for applications where its functionality should be uninterrupted, but intermittent failures are acceptable; the third class is for products that need constant operation, when any error could prove detrimental.

4.1.3 Serial Peripheral Interface (SPI)

Serial Peripheral Interface (SPI) describes the relationship of communication for an embedded system of components. It consists of a master device that takes charge of multiple peripherals. This synchronous communication protocol was not developed by global institutes such as IEEE, but was developed by Motorola, a multinational telecommunications company, around the 1980s. SPI became so common that it became accepted as a standard as any other industry standard. In SPI, there is only one master device that is able to communicate to all other peripherals. In our project, the master device is the raspberry pi zero W, which was essential in the embedded communication required for our design.

4.1.4 Universal Serial Bus (USB)

Universal Serial Bus (USB) describes the communication between a PC and a peripheral. The USB standard allows for proper and safe communication between PC's and other devices. It grants the ability to not only connect and communicate with a device, but also to give it power to operate. This standard offers a multitude of benefits to a user. For example, USB provides self-configuring, eliminating the need to configure settings to optimize operation. A very important benefit is the ability to power small peripherals, which negates the need for external power supplies. This simplicity was obviously very attractive to our design. Therefore, in our project, USB was definitely used for extensive testing of the RFID reader and RFID antenna, displaying the results of their performance on a program on the computer. These results can be seen in section 7, where the prototyping process and results are outlined.

4.1.5 Doggy Door Standards

When it comes to doggy door standards there are not a lot of standards. One of them however is the size of the doors when it comes to dog size. As seen in [35], depending on the size dog you have, you need a specific door size or else it could be too small and potentially too big if the dog is too small to be able to push open the door flap. The large door design was used due to it being able to accommodate smaller dogs as well as working with the most common larger size dogs such as Labs, German Shepherds, Golden Retrievers and other similar sized dogs. Unfortunately, this project will not be able to accommodate the largest of dog breeds such as St. Bernard, Great Dane, and Rottweilers.

Pet Size	Door Dimensions	Dog Weight
Small	6"x7"	0 - 10 lbs
Medium	8"x15"	10 - 30 lbs
Large	10"x19"	30 - 60 lbs
Extra Large	12"x23"	60 - 110 lbs

Table 17: Common Door Sizes [35]

4.2 Design Constraints

Throughout our research and prototyping, there were many boundaries that had to be watched out for. Both real world and system design constraints limited our ability to implement the design as envisioned.

For our system to work as intended, the design constraints were taken into consideration. By not adhering to the constraints, the system may not work or may produce unexpected results.

4.2.1 RFID Constraints

One simple, yet very important constraint is that this system will only work with a special type of tag. That was, EPCglobal Gen2 tags that follow the ISO 18000-6C protocol. Realistically, the owner will be able to use any collar they desire, however, if the tag is not present, the system will not work. With that being said, the tags are cheap, easily replaceable, and can be bought from many vendors.

4.2.2 Internet Constraints

The Internet plays a large role in this project. Because it is an IoT door, the internet was a must for this system to operate. Therefore, when utilizing this doggy door, the Raspberry Pi Zero W must have had a way to access the internet via Wi-Fi, hotspot, or some other communication protocol. The system is able to work without the internet so long as it has maintained at least one internet connection before. When the internet is present, a local storage will be updated to reflect the information found on the database. After the internet is disconnected, the information stored on the local storage will then be used as the new database until a connection is made to the internet once again.

The Raspberry Pi Zero W that we chose for this project utilizes the Wi-Fi standard of 802.11 b/g/n. Back in 1997 IEEE created the first WLAN standard, 802.11. 802.11 is a very slow and incapable standard but as devices started to outpace it, IEEE saw it as a perfect foundation to just build off of. The first of these updates to the standard to come was 802.11b which uses the 2.4 GHz frequency just like the original. It also supports a maximum theoretical rate of 11 Mbps and a range of 150 feet. 802.11g increased this to 54 Mbps.

Both of these standards were available to be accessed by our Pi, as the b/g/n means that any of those were supported. The last, and newest of these was the 802.11n which took things to a whole new level as the speeds jumped from the measly 50 Mbps range to the 300 Mbps maximum theoretical. 802.11 also supports both 2.4 GHz and 5 GHz, however our Pi does not support the 5

GHz band. As can be seen, our Pi does not necessarily support the latest and greatest in Wi-Fi technology but for our use, we didn't have to. [36]

4.2.3 Time Constraints

With the implementation of a full-scale product design into a college class, there was a natural limitation on the amount of time available. The University of Central Florida splits the Senior Design course into the span of two semesters (roughly a 10-month span of time), with occasional deadlines to keep the students on track. Failure to ultimately accomplish a working product has serious consequences. The most glaring of any possible repercussions was the delay of the members' graduation date. Furthermore, the GPA of each team member would unfortunately reflect this failure. In addition to this, months of research and work would ultimately be nullified, considering the fact that the team would need to pick an entirely new project on the second attempt of the class. Each member of this group is planning to be in a full-time engineering position after receiving their bachelor's degree in their respective engineering college. The failure of this class could affect the future of each individual's career, proving potentially irreversible side effects.

The team was very aware of all the above concerns prior to enrolling in the class. The team needed to prevent any disastrous outcomes whatsoever. Firstly, the requirement of a 120 page paper, as well as the integration of multiple hardware/software components, proved to be quite daunting. The team decided to create a project milestone that detailed a week-by-week plan. This plan took into account a very important consideration: The practical case will never perfectly reflect the ideal case. Nearly all project milestones were set by the team to be accomplished before the due dates mandated by the Senior Design class. Ideally, there would be a substantial amount of time after the team's project milestone to refine and finalize any given aspect of the project. This would also ease the integration process, given that our hardware components were ordered and tested early on, diminishing the risk of significant setback due to sudden or unexpected hardware complications. To complement this practice, the team began the research and design process several months before the class started. Secondly, as a team, we were aware of our lack of experience regarding such a wide-ranging embedded project. Our team knew we needed guidance. This led us to seek out the counsel of one of the professors at the University of Central Florida; namely, Dr. Chung Yong Chan accepted the role of a mentor for our group. Dr. Chan helped the team to stay on track with the project by frequently stressing the importance of certain tasks as well as make our project milestones realistic. Each week, Dr. Chan met with our group to discuss the scope of the project and provided insight as to the direction of the project. He also helped us to realize the third important factor in managing our time constraints, which was to have a deep knowledge of the hardware components under consideration. Requiring an in-depth look into datasheets, it was essential to ensure that all components were compatible with one another. A situation of concern was realizing that the hardware elements we had ordered and implemented were not compatible. Intimately knowing the components led to careful selection of each hardware integrant, which reduced the possibility of this.

4.2.4 Safety Constraints

For this system to operate without batteries and have a reading distance of about one meter, RFID must be used. To increase the read range, a larger antenna or more power had to be used. If more power was used, the safety of an animal can become at risk. Depending on the gain of the antenna and the output power, an organism would not be within 21cm of the antenna [2, p. 63]. If one was within a range less than the previously stated value, either the output power of the reader had to be reduced or a lower gain antenna must be used, otherwise, the organism is exposed to safety concerns. Because our reader had to be either above or below the door, careful design considerations were taken to keep both people and animals safe while using this application.

The onboard antenna located on the Sparkfun Simultaneous RFID Reader requires maintaining a minimum distance of 21cm to avoid any negative side effects of long-term exposure. It is important to note that this distance was required for the onboard antenna. Keeping in mind the importance of safety, the team needed to see what this warning meant for different gains. The datasheets had an antenna gain of 8.15. With this gain and an input power of 27 dBm for 21 cm away, the RF output power had to be calculated. The RF output power turns out to be 5.89e+0. Next, we had to find an input power for our antenna that would yield an RF output power that is below this value. This input power was found by fixing the distance of 21 cm, plugging in the 5.5 dBi gain for the Times-7 antenna, and varying the input power until the output power yields the desired result.

Times-7 SlimLine Antenna Input Power	Distance from the antenna	RF output power
6 W (max)	21 cm	3.84e+1
5 W	21 cm	3.20e+1
4 W	21 cm	2.56e+1
3 W	21 cm	1.92e+1
2 W	21 cm	1.28e+1
1 W	21 cm	6.40e+0
0.9 W	21 cm	5.76e+0

Table 18: Times-7 SlimLine Antenna Input Power vs RF Output Power

As seen in the table, the antenna achieves an RF output power below 5.89e+0 when it has an input power of roughly 0.9 Watts. This corresponds to about 29.5 dBm. One concern of this distance restraint was the potential threat of a lowered read range. Fortunately, the input power for the antenna was actually able to achieve larger values due its smaller gain in reference to the onboard antenna. With this realization, reduced read range was no longer of concern.

4.2.5 Physical Constraints

While the door was designed to fit most animals, not every animal could fit. Animals that are too large, like Great Danes, will not fit. Animals that are too small, like puppies, are not intended to use this door either. The animal must be not too big or too small and strong enough to climb over the frame while pushing the door open.

While the system was easy to set up and start using right away, it does not necessarily mean animals will use it instantly. It will require some time and training before the animal starts to recognize the cues of the door. If the buzzer is played, the animal will understand it can either enter or exit. If the animal approaches the door and no buzzer is played, then the animal cannot proceed through. The buzzer had to be a frequency that animals can understand. It had to also be loud enough to be heard on both sides of the door.

Finally, the door is intended to be used one animal at a time. Most doggy doors will allow animals to run out one after another. If that happens with this door, the purpose of creating unique profiles for every animal would be defeated. Therefore, to protect against the latter as much as possible, we caught the door as it returned to its closing position instead of the door remaining inside its transient state. Ultimately, however, the door was designed for one animal to go through at a time.

4.2.6 Doggy Door Constraints

The design needed to work fluidly and have no issues when the doors opened and closed. One of the main design constraints with respect to the design of the door, was the door returning to its starting position after being opened so it will be locked without having any complications. The first idea to solve this constraint was to add magnets to the side of the door in order to attract the door to the starting position. The concern with this method was that the magnets would interfere with the RFID reader and would disrupt the connection between the reader and the tag to unlock the door. After this concern, other ideas were thought of to solve this constraint. The next idea was to use a two-way door hinge that is used for saloon style doors. The main problem with this idea was that these two-way door hinges are only made for the thickness of normal sized doors and the doggy doors were too thin to use this hinge. The next idea was to use a soft closing spring door closer. The spring can be adjusted to meet the appropriate amount of force for when the door closes. The main concern with this idea was that this soft closing door hinge only works one way and since the door was designed to be opened and closed both in and out, this method did not work. At this point in trying to find a solution to dampen the door once opened to have the door come back to the starting position, a new design was thought of that would work bi-directionally. After further research, the new idea was thought of to use rotary dampers. To test if this method worked, two dampers were purchased. After further testing, the rotary dampers that were bought had too strong of torque and it would make it very difficult if not impossible for the dog to push the door open. To try to solve this solution, meetings with mechanical engineers that design the rotary dampers were contacted to find one that would be more appropriate for our design.

After testing the new rotary damper that the engineers recommended, it was discovered that the torque was still too great for the application of a doggy door. The torque might not be too much for a dog to open the door flap, but it would cause more force by the dog, and a concern would be that the door would not have enough weight to rotate the rotary damper and the door would remain open after a dog exits the door. The rotary damper also had a gear attached to the end of it that is used for most applications, but this would be difficult to implement into the door design created for this project. Further research into gears and similar mechanical parts would be needed to use the rotary damper, and for all these reasons, the rotary dampers were no longer considered for this project.

After the rotary dampers were no longer considered for the project, the next mechanism that was tested was normal door hinges. This was something that was going to be the alternative design idea if the rotary dampers did not work. The main concern of using a door hinge would be that it would not get the full range of motion needed for a doggy door flap and that the door would continue to swing back and forth several times before returning its starting position, leaving time for unwanted things to enter the house. This design was used for the first prototype of the doggy door, this concern occurred exactly how it was envisioned. The top of the door would hit the top of the ceiling and limit the range of motion on one side of the door while the other side worked exactly as planned. While this is the case, the hinges used on the prototype were promising and could work how they are designed with an added mechanism that lowers the door from the ceiling. A small piece of metal with a set screw holes on the left and right sides will be placed in between the hinge and door connection and would lower the door from the ceiling and allow for a full range of motion.

The new lock design that was used also allows for the door to lock shut once the door returns to the starting position on the first swing back. This lock will be a solution to the door constraint and be used to lock the door as well. The lock works similarly to a normal door lock where when the door is shut, a bolt with a slant on one side will be forced in the door from the door frame and will pop back out once the door is fully open and a slot for the bolt to extend is available. The lock uses the force of the door swinging backward and pushes this bolt (placed vertically instead of horizontally for this case) upwards. Both sides of the door have a piece on the bottom of the door sticking out on the left and right of the door. This piece goes through the door frame to meet the locking mechanism on the other side of the door frame wall. When these pieces swing back it lifts the bolt up and moves past it and gets blocked by an identical bolt facing the opposite direction, causing the door to be locked and become stationary after one swing.

The limitations to this idea was that it had to be 3D printed in order to get the necessary components to get the locking mechanism to work. Due to this the lock would not be as strong as if it was created using some kind of metal. Using metal would be ideal and would not cause any concerns of durability but because it could not be done the next best option was to 3D print it. The good thing about 3D printing it, is that it could be customized to meet specific requirements and sizes and it was adjusted to make the locking mechanism as durable as possible. This included building built-in drill holes into the structures as well as making everything a little thicker. With it being 3D printed, it allows for this locking mechanism to be mass produced if the product is pushed to the market. This being the case, the push for making the materials using a metal and mass producing it that way would be something that would benefit the quality, durability, and overall safety of the product design.

Another limitation of this new 3D printed locking mechanism was that it had to be designed using the AutoCAD software and then printed. Due to this, a lot of trial and error needed to be done in order to get the correct dimensions of all three parts. This led to printing and redesigning the parts multiple times until the precise measurements for these parts were met. Thisl led to an increase in cost for the necessary materials to create the 3D prints. This constraint was evident after the initial design of these three parts were printed. The shaft hole was too small, and the pins would not be able to fit in the shaft without excessive force and the shaft would need to be redesigned. The pins were also slightly larger than desired and needed to be redesigned with smaller dimensions but overall, this piece needed the least amount of work needed on it. The last piece that needed to be redesigned was the knob that pushes up the pins. After the initial design, it was evident that the knob diameter was too large, and had a hard time pushing the pin up. Instead, the force from the knob wanted to push the pina in the horizontal direction as opposed to the vertical direction. Due to all of this, the 3D printed locking design was designed to meet specific specifications but also caused the project to have an increase in time and cost to create the locking mechanism.

When it comes to 3D printing and the size of the smart doggy door and the components that were needed to create it, several fine measurements had to be used. For the locking mechanism, each piece was relatively small and the smallest error in measuring the correct sizes needed could have made all the pieces not fit with each other and cause the designs to be redesigned. This was evident in the first prototype of the locking mechanism. The shaft for the locking mechanism did not leave enough room for the locking pin to move up and down. This piece then had to be redesigned, reprinted, and retested. The University of Central FLorida gives each group ten cubic inches of free 3D prints and then after that the filament used to print the 3D pieces must be purchased on the groups own to print it. Due to the measurements needing to be precise and not fitting or working exactly as planned, ten cubic inches of prints was used in prototyping before the final locking mechanism was created. This increased the price to make the 3D prints. A spool of filament was not too expensive and would be able to be used for any additional prototyping of the locking mechanism. While this was the case, the biggest constraint with 3D printing on campus was the policy that the University of Central Florida has on the 3D printer after you use up the free ten cubic inches. The policy states that a group can bring in its own spool of filament to be printed and it can be used for 30 days. After the 30 days, the policy says that the filament can no longer be used because it loses its quality to be printed and will either be thrown out or given back to the group who bought it. This is due to the filament being exposed to the humidity in the air causing it to start to deteriorate and this can cause the quality of the prints to be poor but it can also clog the 3D printer which can cause it to be damaged. While this was understandable, it was the second part of the policy where the true constraints of creating 3D printed objects at the University of Central Florida came into effect. Once a group brought in their own spool for the first time and the 30 days has past, the group can no longer have any free prints and can no longer provide their own filament to be printed. This policy makes it where a group only has a 30 day window to use the campus 3D printer and after that they cannot be used by that group any longer. This dramatically reduces the amount of testing and redesigning that could be done and potentially became a major issue if a piece of the locking mechanism broke after the 30 days have ended. Due to this issue, the group had to be more precise and think of all potential issues that could come from the locking mechanism before testing any additional prototype designs. One of the best ways to see if an idea would work was to fail fast and fail often until the best solution arised. This limits the failure that was very beneficial to design the best locking mechanism for the smart doggy door and caused issues later in the design process. If something were to break or need to be redesigned after the 30 day period, another 3D printer that is off the campus of the University of Central Florida would have to be used. This was a difficult task to find someone or a company that was willing to allow us to print on their 3D printer without charging a high cost to do so. The best solution to this constraint was to think of the best designs that may solve the problems with the locking mechanism ahead of time and then print all of the prototypes the first day of the 30 day period. This allowed for the most amount of testing to be done while also leaving the most amount of time possible to redesign any of the parts of the locking mechanism from there.

One possible piece of equipment that could have been used to raise the locking pin in order to unlock the door was to use an electromagnet. Four electromagnets would be used and each one would be placed above one of the four locking pins. When current is applied to the electromagnet, the magnet would attract a piece of metal that will be placed on the top of the locking pins, raising the locking pin and unlocking the smart doggy door. Once the applied current is turned off, the locking pin would be released and the smart doggy door would be locked once again. After further research into electromagnets, it was discovered that the strength of the magnet and the distance between the magnet and the pin are inversely proportional and exponentially decrease the farther the distance becomes. After conducting calculations on the maximum distance that the electromagnet would have to be to attract the 3D printed locking pin, this distance came out to be less than a quarter of an inch. For the 3D printed locking mechanism, the minimum distance needed was a quarter of an inch and therefore the specific electromagnet that was looked at would not work for the smart doggy door. After figuring this out, further research went into looking at other electromagnets that provided a stronger attraction from a further distance. The one way to get the electromagnets to work was to get a bigger magnet and this was not ideal because it must fit in the side of the door and may create an issue fitting along with the other components. The more significant issue with using a larger electromagnet, however, was that the larger electromagnets were either too costly or would need too large of an amount of current for the project and made the electromagnets unable to be used for the smart doggy door.

After realizing that the electromagnets would not work to raise the locking pin and ultimately unlock the door, the next piece of equipment that was researched to see if it would work was solenoids. Four solenoids would be used and each one would be attached to the top of each pin. When a current is applied to the solenoid, the shaft of the solenoid would move in the opposite direction, ultimately raising the locking pin to unlock the smart doggy door. When the door closes the force of the door moving back to the center would also be enough force to push the solenoid shaft up, allowing the smart doggy door to be locked once again. The issue with using the solenoids to unlock the smart doggy door was that each solenoid needed up to one amp of current and this could create some issues with the power source that was used for the smart doggy door. Another constraint with using solenoids in the design was that the maximum stroke length would be very small in order to stay below the one amp current draw. For the current solenoid that was researched, the maximum stroke length of the solenoid is only 10mm. This does however give a distance greater than a quarter of an inch that is desired, which the electromagnet did not achieve. The main concern with the solenoid is that it can only be turned on for a couple of seconds before it will begin to overheat and possibly damage the solenoid and potentially other components in the design of the smart doggy door. Two seconds could be all that is needed to fully unlock the smart doggy door and give the dog enough time to exit through the door, but this is something that had to be monitored to eliminate any potential damage to any components used in the design. With all these constraints with respect to the solenoid, the group believed these constraints can be manageable and could be overcome while also taking them into account.

An equally important factor to the door design other than the materials to build it and the locking mechanism was how it will be implemented into the homes of the customers. This brought about constraints of their own. The first major constraint was the door frame of the doggy door having to be very wide to house all the necessary hardware components to create the smart doggy door. This could limit the ways the door could be implemented into the house. Many normal doggy doors are placed inside already existing doors and are relatively easy to assemble. A hole would just be cut in the wooden door and then the doggy door would be placed inside and screwed into the door. However, this smart doggy door is eight inches wide in order for the RFID reader and the antenna to be placed inside as well as all the other hardware components. This makes it impossible to place the smart doggy door inside an existing house door without it sticking out. This made the next best place to implement the doggy door to be in an exterior wall of the house. Although it would fit appropriately and be a sturdy fit, this could be a difficult task for customers to do without professionally trained people to help them, which would only drive up the entire price the customer would have to pay in order to implement the smart doggy door. This could make customers wary of purchasing the smart doggy door and look at the other competitors to find another product that has an easier implementation even at the expense of the competitor’s door having less features to it. This could end up making the product less desirable and may need to be something that was looked at in the future to find a potentially easier method to implement the smart doggy door.

Another important constraint that needed to be addressed was the material that the smart doggy door is made out of. Ideally, the smart doggy door structure could be made out of metal or hard plastic to give it a more professional quality. This would allow for the smart doggy door to be mass-produced and perfectly sized pieces every time if enough units were desired by customers. This would ultimately drive down the production cost and make the overall cost of the product to decrease. That being said, a metal or plastic manufacturer would be needed, and to get one of those companies to create the prototype would be very costly for only one unit that could potentially not work exactly how it is supposed to. It would be a very high initial cost that would drive up the cost for each smart doggy door and this would cause customers to look to other competitors for cheaper products. For these reasons, the prototype was made out of wood. This significantly decreases the cost to make the prototype but does have its own drawbacks as well. It is not as durable as using metal or plastic and is not as weather resilient as the other two. Other products would have to be used to ensure that they can withstand the effects of the weather and this caused more money to go elsewhere in the budget of the project.

5 System Designs

This section will discuss design considerations made for both the software and hardware as well as the designs that we decided to go with.

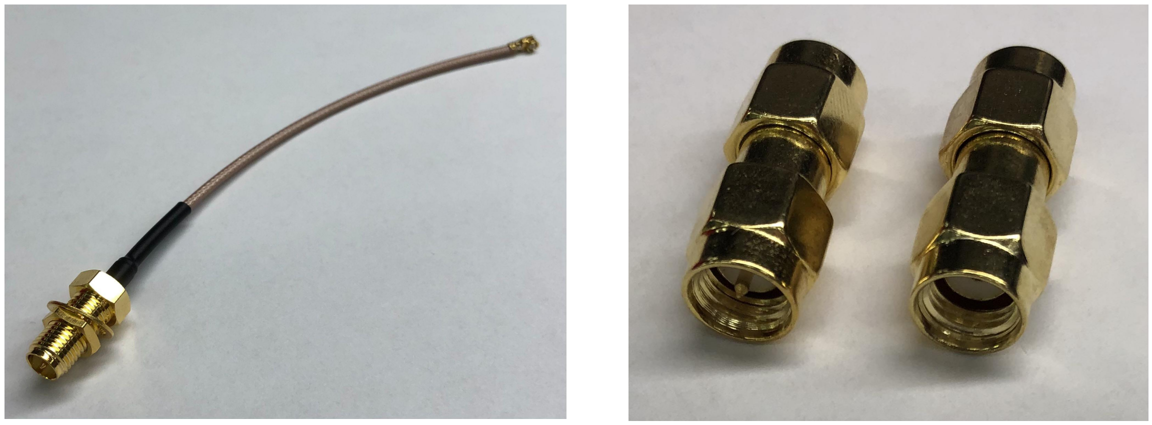
5.1 Hardware Design

Before any software applications were able to be discussed or considered, we first needed to lay a solid foundation. The team needed to research specific hardware components and make a selection based on certain desired parameters.

5.1.1 Antenna

In order to determine the location of the antenna, we needed to consider a few aspects of the IoT Smart Doggy Door. Firstly, the antenna must be set up in such a way that the beamwidth fully captures the desirable range of motion of the dogs in order to detect when to open the door. The antenna must capture when the dog is in close proximity to the door from both the inside of the house as well as the outside of the house. Given that the beamwidth for the Times-7 SlimLine Antenna radiates directly outward from the top, this narrowed the options down. With this information, the antenna had to be placed upside down above the door frame, or rightside up below the door frame. Secondly, we needed to think about the different types of dogs that may enter the door. Housing the antenna beneath the door frame as opposed to the top would provide more accurate and consistent results given two factors: Even if the chances are relatively low, difficulties with reading may have been presented from a very short dog where the collar is much lower to the ground. The second factor is the non-invasive nature of an embedded structure underneath the door as opposed to above the door, where there was a risk of a bulky eyesore. In a project where one's living space is involved, neatness and aesthetics are very important.

As far as its integration into the system, it was important to consider the specific connection types of the Times-7 antenna as well as the m6e nano simultaneous reader selected. In order to ensure proper connection, the SMA female connector type of the antenna needed to connect to the u.FL connector type of the RFID reader. For this reason, we needed two different cables with an adapter. First, however, the length of the cable as well as its thickness needed to be considered. If possible, the shortest length was desirable, due to the fact that more energy is lost the longer the cable is. As discussed in the next section, the reader is housed in the same space as the antenna, so the length of the cable could be very short. When connecting components in a tight space, a thick cable was not suitable due to a lack of malleability. An SMA male connection was required to connect to the antenna. In order to attach this type to u.FL, the configuration was as follows: An SMA male to RP-SMA male adapter connected between the antenna and an RP-SMA female to u.FL connector. Pictured below are the two cable components necessary for the design.



(a) (b)

Figure 24: (a) u.FL to RP-SMA female; (b) SMA male to RP-SMA male adapter

5.1.2 RFID Reader

The RFID reader is housed within the top of the door frame, out of view. This design choice was decided in accordance with the position of the antenna, as well as the safety concerns for the Simultaneous RFID reader m6e Nano. The datasheets give the warning of a health concern that arises when a living thing is within 21 centimeters of the reader for an extended period of time when the module is running at its maximum power capacity. Even though the reader is operated beneath the maximum power capacity for our design, tucking the module sufficiently above the door eliminates any potential danger that could arise. The location of the antenna heavily influenced this decision as well, given the physical connection required. If the reader was housed elsewhere, running cables would become expensive and inconvenient. With the reading module in an immediate vicinity mitigates these concerns.

The reader will be in charge of several important operations and communications. The ThingMagic Nano module connections are mostly taken care of on the Simultaneous RFID Reader module, however there was one aspect that needed to be changed: The Times-7 SlimLine Antenna had to be specified as the selected antenna. This was because the onboard antenna was chosen by default. Port 39 of the m6e nano module was responsible for the RF signal, which was chosen between the PCB antenna and the u.FL connector. Once the antenna was connected to the u.FL connector, a drop of solder was used to close the solder jumper to the u.FL port, as seen below.

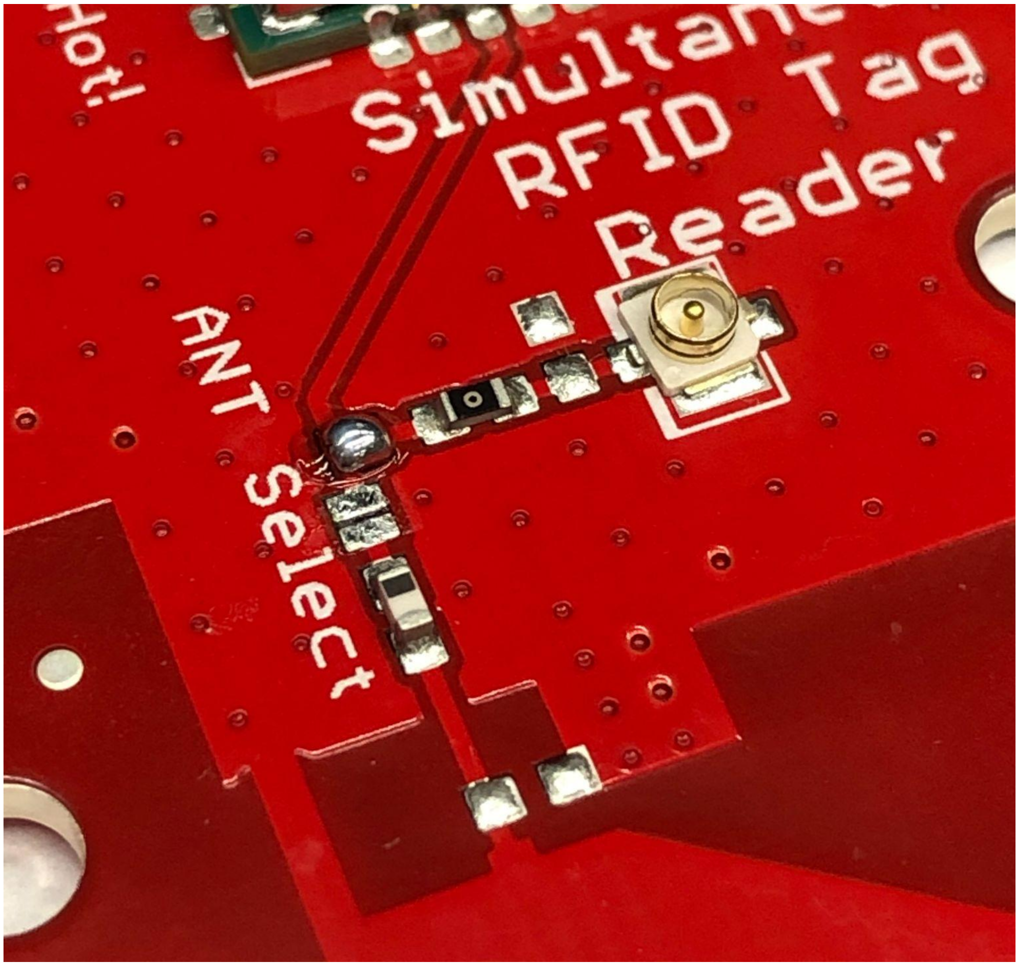


Figure 25: Antenna selection to the Times-7 Slimline

5.2 Software Designs

This section is dedicated to discussing different environments that will be used and software designs considered. While several options may exist for each section, we decided to choose the solution with the most functionality that we could best implement.

5.2.1 Software Environments

Software environments are an important consideration when developing and testing code. One of the most common environments is an integrated development environment. Some IDEs provide a lot of useful tools for installing new libraries, debugging, compiling, and more. The downside, however, is usually the expense of system's speed/performance, memory usage, and abstraction of resources. This is because a large application must be installed, and a graphical user interface (GUI) is being used to nicely display the contents of the software. Another alternative is to use text editors. Text editors tend to perform much faster, however, only offer a fraction of the tools (there are still ways to implement tools) of an IDE. Some text editors do not provide a GUI which makes the environment that much more lightweight. Unlike most IDEs, text editors usually support many languages whereas some IDEs only support one or two languages.

	Integrated Development Environments	**Text Editors**	**Command Line Interface Text Editor**
Languages Supported	Few	Many	Many
Speed	Slow	Fast	Fast
Tools	Many	Many once setup correctly	Few
Learning Curve	Medium	Easy	Hard
Setup	Hard	Easy	Easy
System Resources	Demanding	Light	Very Light
Prototyping	Medium	Easy	Easy
Developer experience	Some experience	A lot of experience	Some experience

Table 19: Software Environments

Not all development needed to be done on the Raspberry Pi. The mobile application, APIs, and database setup could all be done on a more capable computer. Our choice of environment was a text editor even though our computers were capable of running larger IDEs. The main reason being that we did not need all the features offered by an IDE. If any feature is needed, we would find a way to implement it. IDEs are also usually language dependent and provide a steeper learning curve. The developers have a lot more experience with text editors and much prefer the speed of them as well. One editor the developers have experience with in particular is VS Code. VS Code is not only fast, but it offers a large supportive community as well. While VS Code can run on a desktop without a problem, the Raspberry Pi does not offer the same performance specifications to run the editor. Therefore, for development on the Pi, we opted in to use a command line interface (CLI) text editor. This type of editor allows for quick development once mastered. CLI text editors also provide many simple, yet powerful commands to keep the development process fast and efficient.

5.2.2 Software Integration with Hardware

While this system holds many electrical and mechanical components, the software is what holds everything together. To get one component to talk to another, a communication protocol had to be established before acting on the data. This doggy door uses several methods of communication whether it be serial, Wi-Fi, radio frequency, or through the use of general purpose input output (GPIO) pins. Therefore, our design had to be flexible and capable to handle different forms of communication.

When we were first deciding hardware components, we also recognized that, depending on the hardware, the software would also be affected. Our goal was to use a Raspberry Pi, however, if that was not possible, we would have to use a microcontroller instead. The benefit of the Pi was that it has wifi, sufficient processing power, and camera capability all in one. If we had to use a microcontroller, it had to be capable of handling several outputs as well as communicate data back and forth to the Wi-Fi module and camera. While this option could have worked, we believed that having all the components exist in one system controller would allow us more time to focus on developing the project rather than focusing on getting parts to communicate with one another.

5.2.3 User and System Integration

To make this project as flexible and as user controllable as possible, we determined that we would need some sort of framework to be established. By including both a database as well as a smartphone application, the user will have control over the system. From the user’s phone, the database can be updated via some action on the phone that is registered to an API. We then had to consider how we would get the information from the database to the Raspberry Pi. Our initial thought was to communicate the Pi to the smartphone and the smartphone to the database. This approach was not sufficient for several reasons. Firstly, the user’s phone must always be within range of the door in order to remain connected and transmit requests. This restricts the distance from which the door can be controlled. Secondly, if at any point the Wi-Fi is changed or disconnected on the user’s phone, the communication of data would be disrupted even though the Raspberry Pi is still connected to the Wi-Fi. Finally, there would be additional latency when sending and processing requests between the Pi and the database. This is because the Pi needs to talk to the database, not the phone itself. Adding the phone in the line of communication puts that much more distance between the two endpoints. With some rethinking, we decided to make the Pi connect to the database and the database would then connect to the phone. This was possible because we are able to process API requests on the Pi which will then be able to communicate directly to the database. This configuration will allow the user to control the system as long as they have an internet connection without any additional latency. This setup also allows the user to control the system with multiple phones. In the initial design, the Raspberry Pi must be told what phones to communicate with.

5.2.4 Offline Operation

After designing how the communication will be established in the system, we started to think about edge cases. One edge case was that the power may go out. Despite having a backup battery to allow the system to remain on for a little longer, the Wi-Fi would be disconnected, and the Pi would no longer be able to connect to the database. While the door is being powered by the external battery, we wanted the system to still be operable. Even though the Pi cannot connect to the database without an internet connection, the software is designed so that we can establish a local storage on the Pi that will store the most recent updates made on the database. Therefore, without Wi-Fi, the Pi would still be able to process tags. Even though the Pi is able to process updates made to the online database, the system can mimic all changes made up until the disconnect.

5.2.5 Programming Languages

We have considered multiple languages to design our software in. Our first initial thought was to use C due to its speed. We also considered Java because those designing the software have had the most experience with this programming language. Lastly, we also considered Python for its simplicity and quick development time. Both C and Java are supported by the ThingMagic Mercury API which is used to program the RFID reader. However, a Python wrapper for the C version of the API was created. Therefore, any of the languages mentioned were viable so far. When choosing a language, we wanted to be able to have simple development. Python is known for its almost human readable syntax. Because Java was so familiar to us, this was another option for simple development. While the software designers have had experience with C in the past, we felt as if it required more work to get a simple program running. We wanted our software to be fast, however, the difference between C (the fastest language) and Python (the slowest language) was minimal for our use case. We also preferred an interpreted language because it would be easier for us to test our code on different platforms compared to setting up our environment and testing with compiled languages. Scripts are easy to create in Python and can be created to run in the background. Doing so allows us to run multiple processes at once. One downside to Python was that it uses dynamic typing instead of static typing. This could be an issue when trying to debug the code. A mistyped variable could simply create a new variable and still run normally, which may produce unexpected results. With all considerations, however, we still believe Python is the best language for our application. Below is a table expressing the key features to each language.

	C	Java	Python
Language Type	Compiled	Compiled	Interpreted
Speed	Fast	Medium	Slow
Development Time	Slow	Medium	Fast
Static vs Dynamic	Static	Static	Dynamic
Portability	Not portable	Semi-portable	Very portable
Ease of use	Hard	Medium	Easy
ThingMagic API Support	Direct support	Direct support	Indirect support through Python wrapper of C

Table 20: Software Design Considerations

5.2.6 Reading an RFID Tag

Software design also needs to be considered when reading RFID tags. The tags have user memory, reserved memory, electronic product code memory (EPC), and tag identifier memory (TID). For user memory, the storage size will typically increase as the price of the tag increases. This memory is able to be edited by the user, but usually only after the EPC becomes full. Reserved memory is dedicated to permit or disable tag functionality. EPC is memory that can also be written to by the user. This is the most common memory to be utilized. Depending on the class of the tag, the tag may be written to only once or can be written to many times. Finally, there is TID which is a unique identifier created by the manufacturer of the tag. This memory banked cannot be altered.

While the user memory and EPC allows the user to create their own password for the tag, we planned to utilize the TID. The EPC is not always unique and can be copied onto other tags. The TID, however, will always be unique. This not only ensures a unique identity between every collar, but it also provides an additional layer of security. The EPC could be used for other applications though. While the TID is the unique identifier for the dog, the EPC can be used to store the animal’s name, age, breed, or the owner’s contact information.

Below is an image that shows the layout of the different memory types in EPC Gen2 memory:

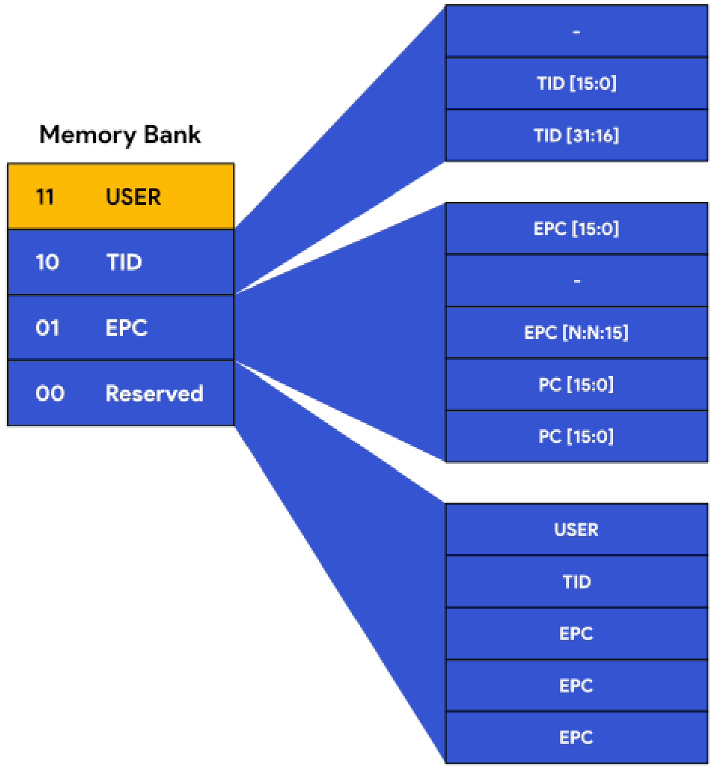


Figure 26: EPC Gen2 Memory
Reprinted with permission pending, from [37]

5.2.7 RFID Reader Interrupts

Once the tag is read and processed by the system, there must be an interrupt in the code. An interrupt is when your code stops what it is doing to process some other code. Interrupts also have a priority. Interrupts may interrupt other interrupts only when a higher priority is present. Otherwise, an interrupt will finish its code before resuming back to normal. Interrupts are important because an event can be processed as soon as it happens. For our project, we only wanted to process the first tag read by the antenna, not all tags within range. Therefore, once the tag is read and processed, an interrupt will occur and prevent the antenna from reading any other tags. From here, the tag can be processed further and even sent to the database to return relevant information for that one tag.

5.2.8 Motion Sensor

Motion sensors play an important role for our system. Not only do the motion sensors detect outside movement and trigger the camera, but the motion sensors also maintain the state (inside or outside) of the animal as well.

Much like the RFID reader interrupt, the motion sensor also have an interrupt as well. Two motion sensors are set up on the door frame of the system where one sensor faces the inside and the other motion sensor faces the outside. Only the motion sensor on the outside will trigger the camera on the Raspberry Pi. For this to occur, an interrupt had to be set on the pin the motion sensor is connected to. Whenever the motion sensor detects movement, the code will pause to then take a picture from the camera and send it to the database for viewing. A delay is introduced so the camera does not continuously take pictures every time it detects movement.

The motion sensor is also vital for keeping track of whether the animal is inside or outside. After the reader processes the tag and the Pi receives permission from the database to unlock the door, the reader is paused for a couple of seconds. While the reader is paused, the motion sensors then are ready to update the state. If both sensors detect movement, within the window the reader is off, it can be assumed that the animal went through the door. Otherwise, if only one sensor is triggered, then it can be assumed that the animal did not pass fully through the door.

5.2.9 Locking and Unlocking

The software is designed such that after a tag is processed and the animal receives permission to pass through the door, an output is produced to toggle the locks as well as the buzzer to signify that the animal has permission to pass through. The output is in the form of an electrical signal that are processed through various integrated circuits. This output are used to activate the solenoid locks. Once these locks are activated, they will lift up, which will, in turn, pick up the locking pins as well, due to their physical connectivity. This will remain active for a few seconds before the output is turned off and the locking pins fall back into their original spot due to gravity. Due to the nature of solenoids, they should not be turned on for long due to low resistance and high current flow. This will allow for a lot of heat generation.

The unlocking mechanism can be used in conjunction with the state of the animal as well. This state is determined by the motion sensors and is stored as a variable inside the database. When the Pi generates an output for electromagnets to activate, depending on the state, only two locking pins will be raised. This will allow a one-way exit or entry for the animal. This will also prevent other animals from trying to run in from the opposite direction.

5.2.10 Background Scripts

Code ran on the Raspberry Pi runs in the background using Python scripts. When the Pi initially boots up, a script starts immediately setting the whole system into motion. By running scripts in the background, this allows the Pi to not dedicate its attention to a single process. From the main script, other python scripts can be called as well. This process was helpful in compartmentalizing the code and organizing functionality.

5.2.11 Mobile Application

For the application, we used React Native and the Expo framework for development. While this combination allows for development on both iOS and Android, the demonstration will be shown on Android. Therefore, a stretch goal would be to have a functioning application on iOS. This would not require that much more work due to the nature and portability of React Native.

We understand the fact that iOS is one of the biggest mobile operating systems in the world and the current biggest in the US, but for our testing we believe that Android devices will better suit our needs. When bringing our product to consumers' houses we will have a planned solution of how we will make sure that they are able to set up their newly bought Internet of Things doggy door no matter what mobile device they use.

When the user opens the app, they will be prompted to login/sign up in order to continue inside the application. After providing the correct credentials, the user will be able to see the list of animals they have registered. If the application displays the name and breed, the animal has already been registered inside the database. If the application only displays the EPC, the collar has been recognized, but it is not tied to any animal. To update the name and breed of the EPC, the user can press on the dog card that has appeared. From here, the collar/card can be deleted from the database as well. The user will also be able to press the image button on the home page to load all images taken by the camera located on the outside of the doggy door. A couple of design considerations were taken into place regarding the scanning of a new tag. We ended up going with having a physical button on the system itself that prepares the system to scan a tag. From here, the tag will be sent to the database. We decided not to go with a button on the application that will prompt the system to scan a new tag as we saw it more intuitive to our design to include a button on the outside for scanning new tags. Finally, to change the permissions for each of the animals, the user can simply press on the card. Our final design can be found below:

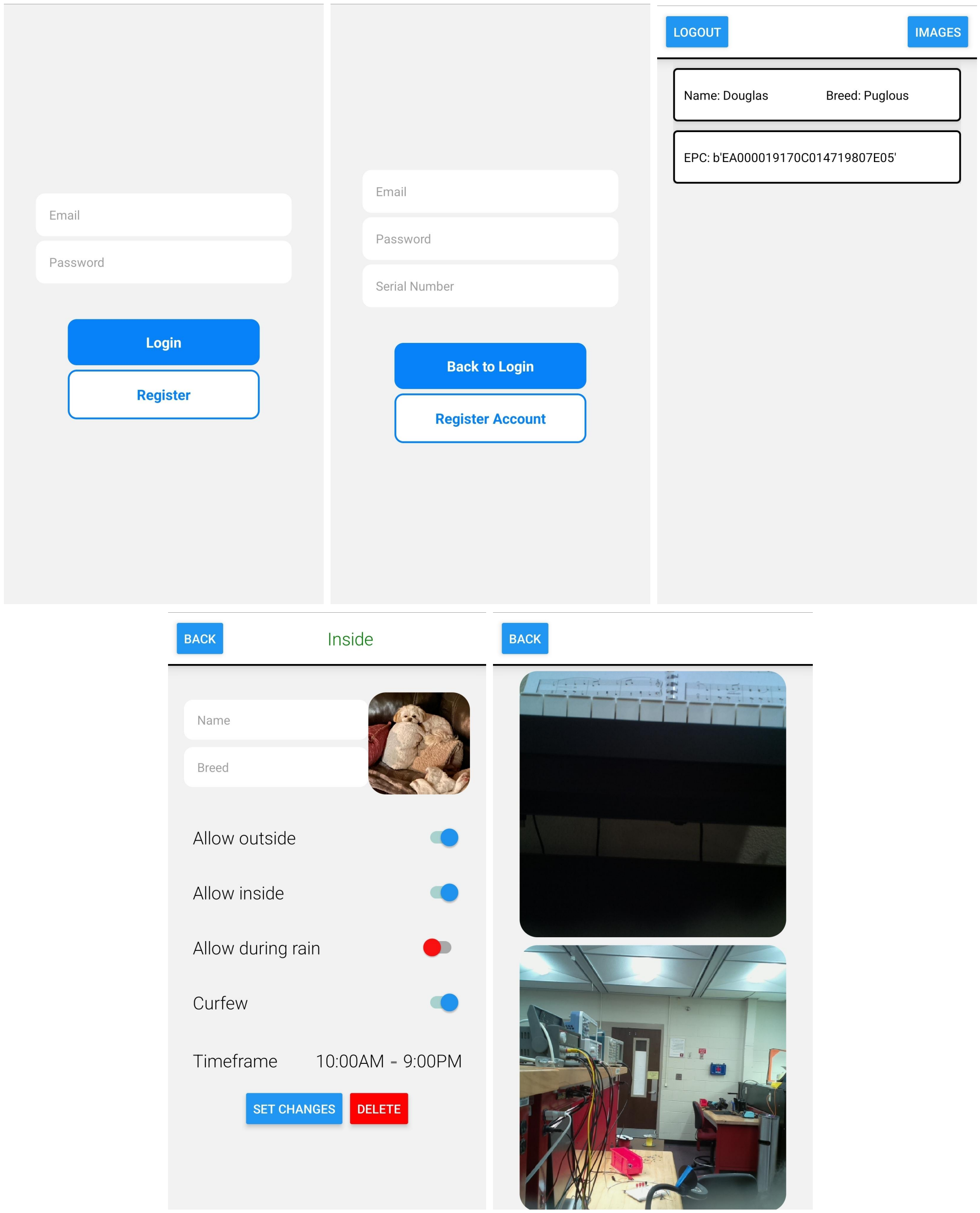


Figure 27: Mobile Application Design

5.3 Door Construction Designs

Throughout the process of designing the smart doggy door, different components have been changed or altered that affect the way the doggy door will function. This caused multiple prototypes to be created to test out these different ideas, whether it is the structure of the doggy door, the flap mechanic, or the locking mechanism.

5.3.1 Initial Door Design Concepts

After researching the current doggy doors on the market, a few door designs were made that each had their benefits and disadvantages. The first design was very similar to a regular doggy door. The door would have a flap style mechanic and would be opened and closed manually by each pet. The door had magnets on the side of the door and these would bring the door back to the starting position to allow for the door to be locked. The door would be automatically locked using two push pull solenoids that would extend into a slot in the door. When the dog approaches the door and the tag the dog carries is read by the RFID reader, the solenoids would retract, unlocking the door. The main concern for this door design is that the magnets would interfere with the electromagnetic waves coming from the RFID reader. For this reason, more research was done into alternative door designs.

The second door tries to solve the issue of the door coming back to the starting location within 2-3 seconds after the dog exits through the door by using a locking mechanism that is made of a metal sheet. There will be two of these metal sheets on the inside and outside of the door and they will slide up and down and lock by trapping the door in between them. When the dog exits the door from inside to outside, the set of these locks on the outside will lower while the set inside stays up, allowing the door to only open towards the outside. Once the door swings back, the door will hit padding on the back side of the lock to dampen the door swinging. This will eliminate the number of times the door swings and bring the door back to its starting position sooner.

The third design concept for the door used a different door mechanic. Instead of using a door that swings open and closed, the door would slide up and down on a track. The door would be connected to a linear actuator which would open and close the door. From [38], when the actuator was fed 12V, the door would open and when it was not fed any voltage, the door would close again. To lock the door, the actuator would just remain closed and the door would slide an inch below the bottom of the door frame and the actuator would hold the door in place making it unable to slide the door up. This design concept fixed some of the previous issues but created more issues. The door would have to be about four and a half feet tall to allow for the linear actuator to fully extend and retract properly. This design would be less appealing for customers and they would be less willing to make an incision in a door or wall for this to fit. Another concern was the price and quality of the actuator. The minimum price of an actuator that was the right size was about sixty dollars. This is already a large sum of the project budget which made it less appealing as a solution. After further research, it was found that the actuator had a maximum speed of 4.5 mm/s. After discovering this, this design was no longer considered because of the slow extend/retract speed which could cause an impatient animal to potentially break the mechanics of the door.

A door concept that was researched that is very similar to the one above, is to use a pulley system to automatically open the door for the dog. Two motors would be placed at the bottom of the door and a wire would be back up around the pulley track and then attached to the door and this would allow the door to slide along a vertical track. The main concern for this design is that a dog could be impatient and push up on the bottom of the door. This would cause the door to move up and cause the pulley wire to have slack and then immediately snap back to have resistance again. This could cause the pulley system to break or malfunction and it was seen as not being as reliable of a door design.

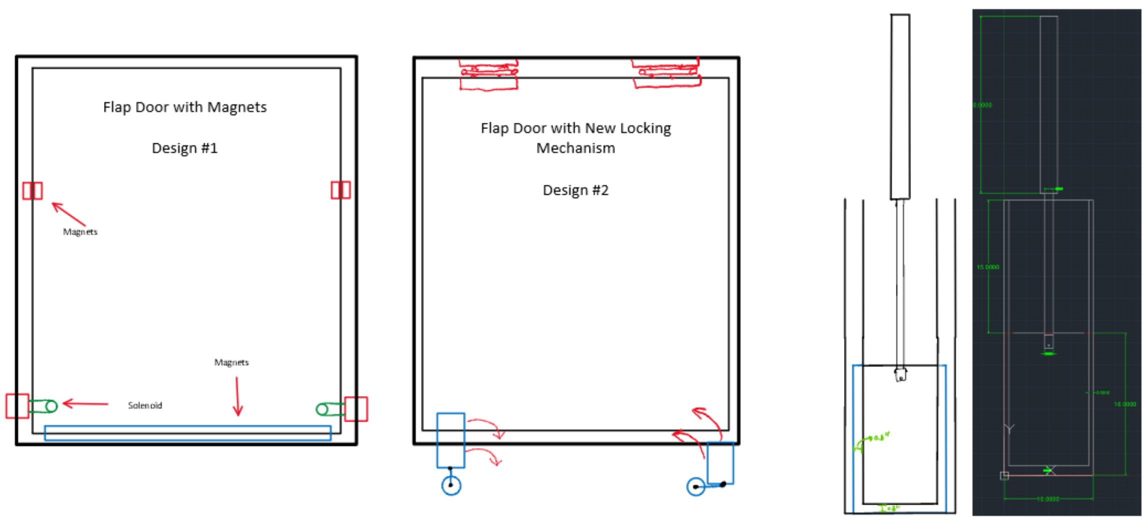


Figure 28: Sketch of the initial doggy door designs that illustrates their concepts

The first prototype for the doggy door was constructed primarily out of wood. The wood for the frame was made from 1x8x8 wood planks and the door was made from plywood about quarter an inch thick. Although polycarbonate sheets are most likely going to be used for door flap in the final design, plywood was a cheaper option for the first prototype constructed. This prototype was primarily constructed to see if the door frame design would work and if the dimensions were accurate to the research conducted on the appropriate size of doggy doors. The door frame is 10”x19”x8” with a smaller box on top to house the hardware equipment that is 8”x5”x8”. The door flap was connected to the frame using two normal door hinges with one part connected to the door flap and the other connected to the ceiling of the door frame. For the first prototype, it worked well and a lot of knowledge was learned from doing this. The first thing learned is that the tool to cut the wood did not work as well as it was hoped and a different tool may be used to cut straighter and more precise pieces. The next thing that was learned from this prototype was that the door hinge did not work as hoped. The door flap had a full range of motion on one side and was able to open the full 90 degrees and came back appropriately. The other side however, only had a range of motion of about 30-45 degrees. This was due to the wood being attached on that side of the door hinge and when the door was opened, the top part of the door flap would press against the ceiling of the door frame and block the range of motion. Therefore, a new hinge design will have to be implemented, either a completely new hinge or an attachment that can lower the door flap from the ceiling of the door frame to allow for a full range of motion.

The second prototype was constructed out of wood just like the previous prototype. The second prototype was designed to allow the 3D printed locking mechanism to work to verify if the entire locking mechanism works as it is designed. The shaft of the locking mechanism is placed near the bottom of the inside part of the walls. Due to this, the top and bottom pieces of wood need to be longer to allow for more space between the walls and the door flap. Once the shaft of the locking mechanism is drilled into the side walls, the knob is attached to the end of the door flap on each side. The knob will push the locking pins up to allow for the door to be locked and unlocked. With this current prototype, the door will be automatically locked when the door swings back after being opened, however, this is not a piece of equipment in this prototype to unlock the door. For this reason, the door has to be manually unlocked by pressing the locking pins up by using our fingers. Once the shaft and the knob of the locking mechanism are in place, a small piece of wood is attached underneath the shaft to allow for a place for the locking pins to rest so they do not fall through the shafts. The same thing is done to the top of the shaft to ensure that the locking pins do not fly out of the shafts when the door flap wings back and pushes the pins up. Throughout this prototype a lot of challenges were faced that created setbacks for this prototype. The major setback was that the power drill that was used to screw in pieces to the wood broke half-way through assembling the door, limiting the quality of the build. While this is the case, the main reason for this prototype was to see if the 3D locking mechanism worked and if it did by what degree did it work and this information was still able to be acquired once the locking pins were placed in the shaft and the prototype was tested. After testing, the group found out that the locking mechanism was able to lock the door flap in place from a 90 degree swing angle. It worked with only one set of locking pins as well and this was done as a stress test to ensure that the locking mechanism could handle the force of the door flap swing back. After this prototype, adjustments to the door structure and 3D printed locking mechanism that would make for a better design for the final prototype.

The final design that is used for the prototype takes aspects from a couple ideas and tries to take the best parts of each. The design consists of a doggy flap made of polycarbonate sheet instead of wood. The polycarbonate sheet is connected to the ceiling of the smart doggy door with a small door hinge and this will allow it to swing 90 degrees in both directions. This provides weather resilient properties as well as being durable. It is also semi-transparent which will allow light to come in but will not allow people to see into the house. Each side of the smart doggy door has two layers with a gap in between to house the 3D printed locking mechanism. The innermost layer is a quarter inch thick and has a rounded opening for the locking knob to travel through so it can push up the locking pins that are inside the gap. The outermost side of the door is thicker and is used as a support structure for the smart doggy door. The gap in between the two layers has the 3D printed locking shafts as well as the locking pins that are used to lock the door when it is not being used. There is also a storage space on top of the door frame to allow for the RFID reader, antenna, and other hardware components to be placed to ensure that it is out of the way from the animals and that it can be protected from the elements outside.

Figure 29: Picture of the first (left) and second (right) prototype of the doggy door

To ensure that it was thoroughly protected, the smart doggy door was coated in a rain guard water sealer. This protects the door frame from being weakened by the water while also protecting the hardware components from being damaged from rain. The 3D printed locking mechanism has also been updated to provide a better locking mechanic. The locking pins now contain a square top to prevent them from falling through the locking shafts. This eliminates the need for a wooden platform that the pins would have to sit on to prevent them from falling. The locking pins also have a connection piece on top of the square top to allow an easy connection between the locking pins and the solenoids that are used to lift up the pins in order to unlock the door when being used. The locking shaft was given extra support in the design to prevent damage from occurring from the force of the door when it swings back and forth. The locking knob was also altered and the base of the circular part of the knob now starts wider and gets narrower as it travels upward. This was done to create a sturdier connection so it can withstand the force of the door swinging back and pushing the pins upward. When all of the parts that make up the locking mechanism are used together, it allows the door to lock automatically by using the force of the door moving backwards. The knob pushes up the locking pin and then is stopped by the neck locking pin that is in the opposite direction. This eliminates the need to use a sensor and try to time the solenoids to lock the door that was used in previous door designs.

Door Design	Cost	Advantages	Disadvantages
Flap w/ solenoids and magnets	$30	Cheapest door solution	Would have to use a sensor to catch the door between two solenoids to lock the door. Leaves error in locking the door
Vertical Door w/ linear actuator	$159	Used to lock the door as well as open and close it	Slow locking speed, high cost, large door frame (~4.5'), dogs could easily damage the door, could injure pets
Flap with Rotary Dampers and Solenoids	$47.34	Slow and controlled closing of door, would reduce error of timing the solenoids to lock the door, works bidirectionally	Damping force to high to be used, hard to implement into design
Flap with solenoids and 3D printed locking mechanism	$51	Designed exactly what was needed, locks automatically using the force of the door when it swings back	Designs need to be very precise to work, multiple moving parts working together

Table 21: Door Design Considerations

The door comes in three parts to allow for easy installation that will connect with each other using screws that also go through the exterior wall for a sturdy connection. The parts included are two exterior frames that attach to the wall on the interior and exterior sides, as well as a middle piece that is able to fit in the hole made in the wall that houses the door itself as well as the hardware for the doggy door. The frames allow for external factors such as rain, dirt, bugs, ect, to not be able to get inside the walls and cause damage. For the middle piece, all the hardware comes already mounted on the door and covered so no additional installation steps are needed for the customer.

5.3.2 Final Door Design

The final come is made out of wood because it was inexpensive yet also sturdy. The flap of the door is made out of a polycarbonate sheet and this was chosen because it is durable and weather resistant. The locking mechanism is contained on the side of the door down by the bottom. It is housed in a small side compartment that is covered and consists of the three custom made 3D printed components as well as four solenoids.

Each side of the door also has a motion sensor. When motion is detected and the tag is within range of the reader, the reader will query the database and retrieve the corresponding information and unlock the door accordingly. The outside of the door also contains a camera above the motion sensor and will take photos outside whenever motion is detected. This is done regardless of whether or not a tag is within range of the reader and done so to allow the customer's to be able to see their dogs when they go through the door and are outside. This was also done as a safety feature to indicate when wild animals and intruders are outside so the customers can prevent their dogs from going outside and take any necessary actions.

The inside section of the door also has a button on the top right corner of the door. This is used to register new tags and is done so by holding the tag within range of the reader and holding down the button for three seconds. Once done so the phone applications will retrieve this information and the tag will be registered.

The door uses AC 12V and when it is unplugged or the power goes out, the power will switch to a 12V external battery that is housed in the hardware compartment on the top of the doggy door. The external battery can power the door for about an hour before needing to be charged. This is done by using the battery charging cord and plugging it into the charging port at the top left side of the door. The process of switching from AC power to battery takes the system about 30 seconds to reboot until it will begin to work again. When the door is plugged back into the wall, or the power comes back on, the door will automatically switch back to the AC power source and a reboot would not be necessary.

Figure 30: Final Door Design, (Inside on Left), (Outside on Right)

5.3.3 How to Install

The door is designed to be installed in an exterior wall. As seen in [34], to install the door, the first step is to locate the studs in the wall. Once they are located, they will be promptly avoided. The interior side of the IoT Smart Doggy Door on the wall will then be traced in preparation for cutting. Once the outline is traced, four holes will then be drilled in the corners of the doggy door. Next, use a jigsaw to saw out the outline. This process will be repeated for both the inside and the outside. Once the hole is cut, insert the first piece of the doggy door and then repeat for the other side. After this, use the given screws to connect the two pieces of the door together while also drilling through the wall for added stability. Once the frame is installed, use a screwdriver to screw in the doggy door flap. Once completed, plug in the IoT Smart Doggy Door into a wall outlet and the IoT Smart Doggy Door is now operational.

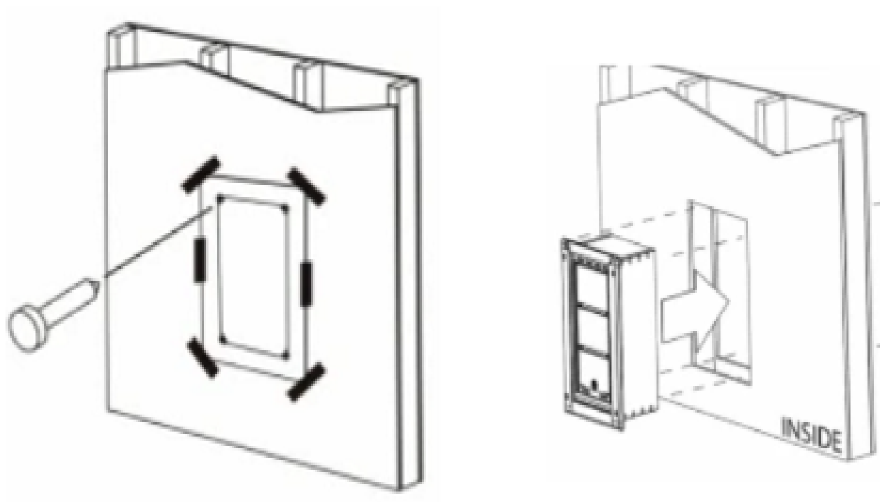


Figure 31: Diagram of the Installation Process [34]

5.4 Initial Setup

Upon receiving our door, the customer will also be receiving a small booklet that will be our quick setup guide and an SD card that comes preloaded with the Raspian operating system. However, in the quick setup guide, we will make it clear that this preloaded operating system still needs some user configuration. So we will walk the user through the process of plugging the SD card into their personal computer and lead them to our website where they will first fill out certain information like their timezone, WiFi network id and password, and their location for the weather API we use. Once all the fields have been filled they will press a button that will load this information onto a bash script that we will have run on the Pi's initial setup. The quick setup guide will then instruct them to remove the modified SD card and take it to the door and insert it into the pictured spot on the door.

This project was designed to give the user customizability along with ease of use. A defining feature of this project is the interaction between the RFID reader and the database created. The user is able to connect to a database through their smartphone, where they have the ability to instantiate and uniquely identify RFID tags located inside a dog's collar. In order to initialize a tag to the database, the user must first hold the tab within range of the reader and then hold the button that is on the front of the door for three seconds. Once a tag has been registered, the user is able to edit the profile picture, breed of dog, and entry/exit permissions. From the mobile app, the user has the ability to customize multiple ranges of times that their pets are allowed to lock/unlock the door. This IoT project also includes a section on the app that will display a picture of their dog anytime motion is detected and a tag is scanned simultaneously.

6 System Fabrication

The entire process of designing a PCB is very involved and requires extensive thought and precision. The complete project design must be considered, including electrical specifications, products available on the market, the financial and physical constraints assigned to us, and much more. Careful research into datasheets as well as theory of hardware components is crucial in ensuring that maximum efficiency and proper operation is maintained.

With such a broad subject, finding a place to begin is a good approach. First, the PCB components needed to be decided. As discussed in previous sections, the project requires the power supply to be fed through the mains voltage from a common household wall outlet. Rated for 120 VAC, this voltage needed to be stepped down and converted to DC voltage. For this reason, we began with identifying an AC to DC converter that will provide sufficient output power as well as output current needed to power our system. We also needed to see what DC output voltage we needed for our design as well. We also kept in mind the efficiency of the converter, and decided whether or not the specifications that we have require higher efficiency, or if a low efficiency is acceptable. In consideration of these three things, we needed to find a topology that met these requirements.

For DC to DC regulation, very similar parameters are required. The team first needed to identify the output voltage that is required for the second rail, and how many rails the project needs in the first place. The input of the DC/DC converter had to be able to take the value of the first rail that was created from the AC/DC converter. The amount of output current needed to be enough to supply that rail's total current demands, and the output power had to be able to supply the power requirements of the current rail as well as all subsequent rails. In addition to this, the efficiency of the converter had to be taken into account, ensuring that the output power of the previous stage would be able to overcome the efficiency loss. All of these factors were considered when we chose a topology.

The project also had to include an external battery that supplied the power required for the project when the power from the wall goes out. This was accomplished with a solid state relay design that connected a 12 V battery to the 12 V rail when the mains voltage turns off. When the power comes back on, the relay will switch the power supply to being from the mains voltage source.

For PCB design, we had to find a software that was fitting for our design. After a software was chosen, we had to create a Bill of Materials (BOM) that listed all of the necessary components' quantities, descriptions, and prices. Footprints for relevant components needed to be compiled onto the schematic editor, where the visualization of PCB design will occur.

6.1 PCB Design

The process of designing a Printed Circuit Board is highly involved, and it can be quite extensive in its application. The specific hardware component chosen to be the PCB in our team's design was the Power Supply Unit (PSU) for the project. The PSU is in charge of powering the entire design, including the RFID reader, the RFID antenna, the Raspberry Pi Zero W, the infrared sensors, and the camera. Many important things to consider in the PCB design, such as components, voltage regulation, schematic layouts, and design software will be discussed in this section. Thorough research was conducted in order to determine the appropriate components and software used for the PCB design process. Calculations as well as reasoning will be given as to why certain choices were made, including schematics and block diagrams that are relevant to the project.

6.1.1 Power requirements

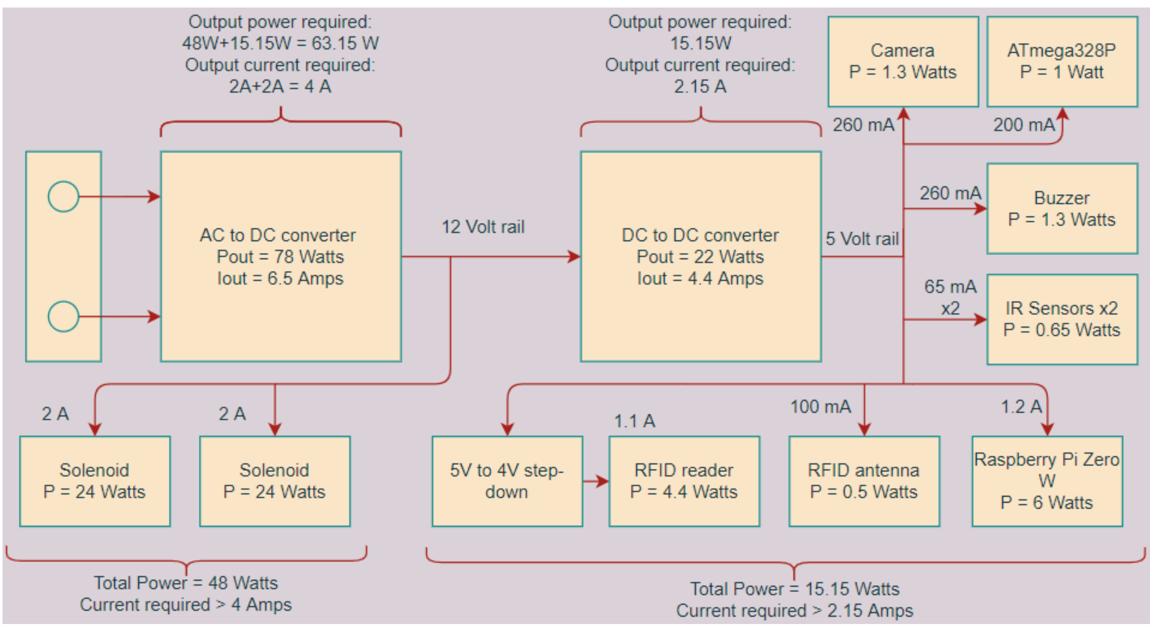


Figure 32: PCB Converter schematic

The PCB consists of multiple sections. Firstly, we needed to identify a series of converters that could supply power to our design. For this, the team turned to reference designs on the Texas Instruments website, where several converters were considered. Ultimately, the parameters were set through a few important requirements. It is important to note that our design only needed two voltage rails, a 12 Volt rail and a 5 Volt rail. The AC/DC converter required a 120 VAC input voltage compatibility and a 12 Volt output rail. The current that the AC/DC needed to supply was at the least 4 Amps. In total, the amount of power that the system will need is roughly 63.15 Watts. The DC/DC converter requires an output wattage of 15.15 Watts and an output current of at least 2.15 Amps.

The output voltage will result in a rail voltage of 5 Volts. All of these values can be found within the power table included in section 6.1.3. A schematic of the converter design can be seen in the figure above.

The power requirements must be met by the designed PCB; however, it was crucial to have a battery that met these parameters as well. As mentioned in section 3.3.8, the TalentCell rechargeable battery was the supply of choice in this project. It is capable of providing 72 Watts, including a 12V barrel jack input/output port, a 9V barrel jack output port, and a 5V USB port. The battery is rechargeable through its 12V input. The amount of current that this battery is rated for is variable depending on the output port chosen. 6A is the maximum current supported for the 12V connection. As for the 9V barrel jack, only 1A of current can be drawn. Finally, the USB can output a current of 2A. For our project, we will be using the 12V barrel jack, which will be able to supply the needed 63.15 Watts, as well as the desired 4A.

6.1.2 AC to DC Converter

Our design requires an Alternating Current (AC) voltage as the input. However, the voltages for our components must be Direct Current (DC). For this reason, we needed an AC to DC converter. The first step in constructing this converter was including a transformer at the input of the AC current, which in this case is a home outlet. Our desired step down voltage factor to be provided from the transformer was a factor of 10. Considering the 120 VAC output of a home outlet, this means that the AC voltage output of the transformer then had to be around 12 VAC. Next, a full bridge rectifier was needed in order to produce purely positive voltage cycles. Then, a coupling capacitor is included at the output of the full bridge rectifier in order to provide a more steady voltage, whose value stays relatively close to the peaks. These are things we considered when we were designing our own AC to DC converter. Reference designs were also obtained from Texas Instruments' website as well. Due to the dangers of mains voltage, our group chose to look at reference designs.

First, the inputs and desired outputs needed to be established before looking into designs. Since we were powering this through a home wall outlet, the input of the converter needed to be 120 VAC. The outputs that we desired were as follows: Voltage needed to be 12 VDC (in order to power our highest voltage requirement, which was stepped down for other components). For each voltage rail, each component needed to draw a particular amount of current. For our project, there only needed to be two voltage rails, where the first voltage rail was 12 Volts and the second voltage rail was 5 Volts. For the solenoids, we had the 12 Volt rail. The RFID reader, RFID antenna, raspberry pi zero W, IR sensors, camera, and buzzer were all supplied 5 volts. Adding each of these component's currents yielded the amount of output current that the voltage rail's converter needed to supply. The datasheets of most of these components specify the values such as current and output power, but for some of them, they must be found in the contexts of our particular design and how we decide to operate them. In order to determine how much current the antenna needed to be drawing, we had to see how much voltage was being supplied as well as how much power it would be consuming. The power we chose to operate the antenna at is 27 dBm, which corresponds to 0.5 W of power. Given that the input voltage for the reader is 5 V, then the current draw for the antenna can be found by dividing the power by the voltage, which yields 100 mA. The output power of the AC to DC converter must also be sufficient in order to power our entire project. In order to calculate this minimum output power requirement for the converter, we needed to superimpose the maximum input powers of each of our components. Even though the maximum input power of 6 W is specified in the datasheet, the power of the RFID antenna was around 0.5 W in application, so 0.5 W is the power that was considered. In addition to this, the IR sensors were operated at 0.325 Watts. With this information, we saw that the minimum output power for the AC to DC converter had to be at least 62.75 Watts, and the amount of output current that was needed is the superposition of the current requirements of the 12 Volt rail, which we discussed a bit more in section 6.1.5. The last extremely important thing to consider when choosing an AC to DC converter was whether or not the converter is isolated. If it is isolated, then it is much safer and there is a very low chance of electrocution. If it is non-isolated, then it is much more dangerous. For this reason, our design looked into reference designs that are isolated.

Component	Voltage	Current Draw	Maximum Input Power
RFID reader	5 V	< 1 A	5 W
RFID antenna	5 V	100 mA	6 W
Solenoids	12 V	Max 2 A	3 W
Raspberry Pi	5.1 V	1.2 A	6.12 W
IR Sensors	5V - 20V	65 mA	0.325 W - 1.3 W
Camera	5 V	260 mA	1.3 W
Buzzer	5 V	260 mA	1.3 W

Table 22: Power Requirements

There are many different topologies to consider when choosing an AC to DC converter. The top three topologies that were looked at were Flyback controllers, LLC controllers, and Power-factor correction (PFC) controllers. The Flyback topology's transformer consists of a mutually coupled inductor pair. The primary inductor winding is on the input side of the transformer, and it controls the secondary inductor winding, which is connected to the output side of the transformer. This topology makes use of a switch mode power supply (SMPS) that utilizes MOSFETS in order to switch the inductors from the storage of energy to the releasing of energy. A huge advantage to this topology is the fact that it does not have the need for additional circuitry to create a galvanic isolation between the input and output, due to the coupled inductor's role as a transformer. This is definitely a valuable asset, considering the cost of additional inductors for storage that are essential for other topologies. Another advantage to this type of topology is its ability to safely produce multiple output voltages that are all isolated from the input, again due to the versatility of the coupled inductors. In addition to this, the flyback converters generally tend to have fewer components to its base design. The drawback of this fact, however, leads the topology to claiming a much lower efficiency when compared to some of its AC to DC counterparts. In addition to this, they're peak currents tend to be very high, which yields a relatively low output current in the context of other converter topologies [39].

The LLC controllers are an incredibly efficient topology. This powerhouse of a topology is extremely valuable. They are capable of achieving output powers ranging from tens of watts to hundreds of watts, all while maintaining a very high efficiency. This is accomplished through the topology's titular components: two inductors and a capacitor. One inductor is used as a magnetic storage for the transformer while the other inductor and capacitor is a resonant circuit so-to-speak, in charge of tuning the circuit to a particular resonant frequency. This concept gives this topology the ability to achieve its most important aspect: softswitching. Softswitching can be described as zero voltage switching (ZVS) as zero current switching (ZCS). This characteristic lends this topology with its high efficiency. This comes into play when the network turns a DC voltage into a square wave via a switching bridge. The current through the LLC tank located before the transformer then becomes sinusoidal in nature. When the MOSFETs switch on or off, the current and voltage overlap in their transitions from either high to low for a brief period of time. Each time this occurs, there is an amount of power that is wasted within the circuit. The LLC resonant tank fixes this issue and achieves ZVS by establishing a resonant frequency to prevent the current from rising until very shortly after the voltage has reached zero. ZCS is then accomplished by maintaining a zero voltage across the switch while the MOSFET is on until the current reaches zero. The main advantages of this topology are as follows. It has the capability of achieving less EMI, as well as its obvious high efficiency over not only a wide range of loads, but also with a large coverage of output power. It does not need an output inductor, leading to a lower cost of BOM. Some of the drawbacks for this topology are complexity of such a design, making the design and control of this converter to be extremely challenging, as well as its use of a variable frequency, which proves to be much more challenging than dealing with a fixed frequency [40].

A very important parameter to consider when discussing the workings of a converter is the power factor. Power factor is defined as the true power divided by the apparent power, where the true power is the useful power being used to transfer utilizable energy given to the load and the apparent power is the total power that is being used in the entire system, also expressed as the addition of the reactive power plus the true power. The culprits of low power factors are any capacitive or inductive components/loads. This is due to the fact that these components cause the current running through a given point in the system to either lead (in the case of capacitive loads) or lag (in the case of inductive loads) the system. When finding the power expended across these components, it can be seen that the voltage multiplied by the current yields a power that will not provide its maximum possible value. In order to fix this, power factor correction (PFC) controllers seek to mitigate the loss in phase through several complicated methods. In order to correct lower power applications (where the energy that is to be supplied is less than 100 watts), passive PFC makes use of capacitive and inductive components to counteract each others' effects at a particular resonance frequency. Active PFC is for applications that exceed ratings of 100 watts. This type of power factor correction uses a control circuit IC, such as a pulse width modulator in order to tune the duty cycle of the voltage and current signals to where their phases align as closely as possible. The unfortunate truth this project had to face is that the active PFC correction would not be usable due to the fact that we need much less than 100 watts of power for the supply. For this reason, we had to look towards the passive PFC controllers when deciding on an AC to DC converter. The advantages that a passive PFC controller provides are great affordability and simplicity. On the other hand, the drawbacks to this design are a very small range of allowable voltage inputs, as well as a large and rather cumbersome build, with an absence of any controller ICs [41].

Topology	Advantages	Disadvantages
Flyback Controllers	Mutually coupled inductors isolate the input from the output, capable of providing multiple different output voltages, each separated from input, simplistic design (very few components required)	Unable to produce too high of an output current/power, the transformer gap results in more EMI, greater ripple current
LLC controllers	Reduced EMI, ZVS, ZCS, high efficiency, large range of output power/current, lower BOM cost in regards to output inductors	Complex design, requiring extensive research for design and control
(PFC) Controllers	Simplistic design, affordable due to a lack of complicated hardware components	Small range of input voltages, large and bulky, also quite heavy

Table 23: AC to DC Converter Topologies Advantages vs Disadvantages

6.1.3 Voltage Regulators

Given that voltage regulators are one of the most important and vastly utilized electrical components in printed circuit boards, it was predictably integrated within our team's Printed Circuit Board (PCB) design. The hardware component chosen as our designed PCB was chosen to be the power supply of the project.

It was crucial to choose the right type of voltage regulators for our design. Containing either a classification of step-down or step-up, these electrical components determine the input voltage, the output voltage, and the maximum load current. There are two main types of voltage regulators, each with their own benefits as well as weaknesses: linear voltage regulators and switching voltage regulators. Linear regulators are only capable of stepping down a voltage, where the component will output a lower voltage with any given input voltage. A huge benefit to these linear regulators is that they have very low susceptibility to noise and are exceptionally effective at producing a clear signal. Another benefit to these regulators is that they are very cheap and relatively simple in their design. However, something to look out for when considering this type of regulator is the power that will be wasted, and the amount that is acceptable for the design.

When choosing a linear regulator, it was important to keep in mind the power that was generated in the process of regulation. The power dissipated by the regulator can be found by multiplying the output current by the difference of the input voltage and the output voltage. This indicates a risk in stepping down the input voltage significantly. It was also important to note that these electrical components have a "minimum" voltage difference it is able to step-down, meaning careful investigation and consideration of the output current was required. Given that many of our hardware components are capable of drawing a maximum of around 1 Amp, this had to be something the team was wary of. The datasheets provided an in-depth description of how much heat the component could potentially generate and provided a value for a variable called Theta-JA. This value multiplied by the power dissipated yields how many degrees Celsius above room temperature that the regulator will reach. This calls for consideration of the temperature the component is housed in to ensure that the regulators would not exceed the recommended maximum of 125°C.

The second type of regulator is a switching regulator. Able to take the role of either a step-down (also called a Buck Converter) or step-up (also called a Boost Converter), these regulators are very versatile. One very important quality of a switching regulator is its high efficiency. Many of these regulators are about 90% efficient in their power transfer, meaning that oftentimes they only waste about 10% of power in the process, diminishing the primary issue linear regulators have with overheating. With this great efficiency, these regulators are capable of stepping the voltage up or down significantly with ease. The downside to these regulators is that they are unfortunately highly susceptible to noise, and will likely not provide a clear enough output voltage for a particular component's input voltage requirements. A common practice is to utilize the benefits of both of these regulators. First, a switching regulator can be placed in order to provide a significant voltage drop. Then, a linear regulator can be utilized to provide a sufficiently small voltage drop, so as to minimize the power lost, and to provide a clear output voltage for the receiving hardware component [42].

6.1.4 Converter Selection

Before choosing specific voltage regulators and converters, it was important to find certain specifications for such components. Knowing the amount of wattage required for each device we planned on powering was crucial. Therefore, we had to find the voltage required as well as the maximum current that was to be drawn from each component. For these parameters, the team included a power table for every element that was powered in the previous section. In this section, however, more exact numbers were analyzed, and a thorough discussion of specific reference designs were also seen. Particularly, Texas Instruments large archive of reference designs were methodically investigated in order to find the perfect design for our project. Eventually, specific reference designs were selected in order to provide a framework for our idea. These designs fit the specifications of our current draw required, as well as each voltage rail's power required.

For our DC/DC converter, ultimately we knew that we needed an output power of 14.75 Watts and an output current of at least 2.95 Amps, as seen in section 6.1.1. The output voltage must be a 5 Volt rail and the input voltage for this converter had to be 12 Volts, considering the fact that it was connected directly from the output of the AC to DC converter. For this reason, we found the reference design PMP7170. This design had a few different output voltages, so more specifically, the PMP7170.1 design on the Texas Instrument website fits these requirements sufficiently well. The PMP7170.1 reference design had an input voltage of 12 V, an output voltage of 5 V, an output current of 4.4 Amps, and an output power of 22 Watts. It was also important to consider the efficiency of the converter as well, to ensure that it has enough input power to supply its output requirements. The input power into the DC to DC converter was approximately 30 Watts. The output efficiency was given by the graph below found within the test reports of the product. It can be seen that it has an efficiency of about 93% with a current draw of around 3 Amps. The amount of power that the DC to DC converter will need from the AC to DC converter can be found by dividing the output power by the efficiency, which will yield about 24 Watts. It was also very important to grant the power supply a sufficient amount of "wiggle room" so that there is no risk of an inadequate amount of power. Given that the AC to DC converter was supplying 30 Watts, the DC/DC converter had to have a sufficient amount of power.

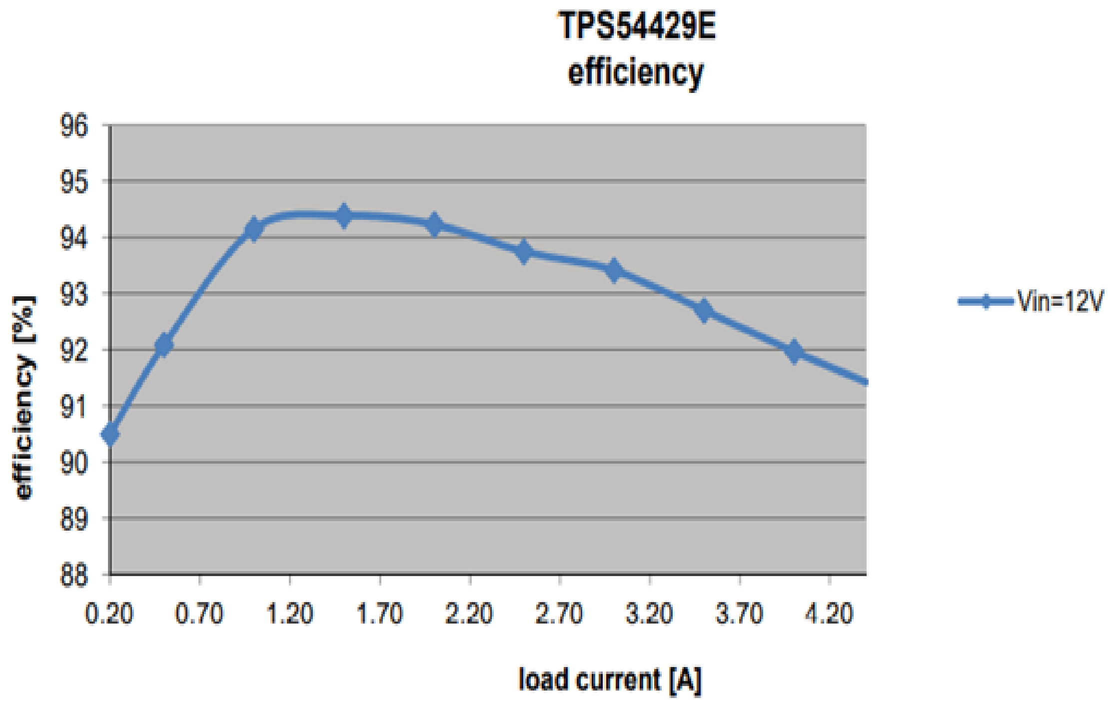


Figure 33: PMP7170.1 efficiency graph [43]

There were a few very important parameters to consider when choosing a specific AC/DC converter for a project. Firstly, the first voltage rail had to be determined, which was said earlier to be 12 Volts. The total amount of power that was required to power the project was approximately 62.75 Watts, so we needed an AC/DC converter that was able to supply, at the least, 65 Watts. The amount of output current that was needed only depends upon the current demands of the output rail of the AC/DC converter. The 12 Volt rail was supplying power to the four solenoids, where only two solenoids were active at a given time. Considering each of these solenoids have a max input current of 2 Amps, then at a maximum, about 4 Amps would be drawn for this voltage rail. Therefore, we needed an isolated topology that had an output current of at least 4 Amps, an output voltage of 12 V, an input voltage compatibility of 120 VAC, and an output power of at least 62.75 Watts. Considering all of these parameters, the PMP10335 was chosen as the AC/DC converter that was used for this project. It has an input voltage of 85-265 VAC, an output voltage of 12 Volts, a maximum output current draw of 6.5 Amps, and a maximum output power of 78 Watts. The table below shows the efficiency under certain power supply conditions. For our design, we had an output power of about 63 Watts, so the efficiency for this converter had to be between 84.28% and 84.51%, so 84.4% is a close approximation to the efficiency for this converter in the context of our project. Keeping in mind that the amount of output power that this converter was supplying is 62.75 Watts, the amount of power that this converter had to draw from the source is roughly 74.34 Watts of power with its 84.4% efficiency.

Vin=120V_{AC}/60Hz

Vin(ac)	Iin(A)	Pin(W)	Vout(V)	Iout(A)	Pout(W)	Eff. (%)
120.01	1.326	93.44	12.02	6.498	78.11	83.59%
120.02	1.233	85.84	12.03	5.989	72.05	83.93%
120.02	1.142	78.51	12.04	5.496	66.17	84.28%
120.04	1.049	71.28	12.04	5.003	60.24	84.51%
120.05	0.952	63.89	12.05	4.494	54.15	84.76%
120.06	0.857	56.74	12.06	4.001	48.25	85.04%
120.06	0.757	49.39	12.06	3.492	42.11	85.27%
120.07	0.658	42.31	12.07	2.999	36.20	85.55%
120.08	0.559	35.32	12.07	2.505	30.24	85.60%
120.09	0.457	28.11	12.06	1.995	24.06	85.59%
120.1	0.356	21.17	12.06	1.503	18.13	85.62%
120.11	0.249	14.2	12.09	1.009	12.20	85.91%
120.12	0.139	7.15	12.23	0.5	6.12	85.52%
120.12	0.082	3.614	12.28	0.245	3.01	83.25%

Figure 34: PMP10335 efficiency [44]

6.1.5 Final Power Supply PCB Layout

Pictured below is the final layout for the PMP10335 schematic and board. The flyback controller was designed in the EAGLE software. The PCB was manufactured by JLCPCB. The board is seen in figure 37 from the top view. It includes copper pours that carry signals for the board, usually a common ground. The grounds between the AC side of the circuit and the DC side of the circuit were isolated and connected together through a capacitor. For this design, a PWM controller was needed.

Figure 35: UCC28630 PSR flyback controller

The microcontroller used in this converter is a primary side-regulated (PSR) flyback controller. The pinout of this 7-pin integrated circuit consists of CS, DRV, SD, VDD, GND, HV, and VSENSE pins. The CS pin is a current sensing pin. A shunt resistor in series with the high power MOSFET will sense the amount of current that is flowing. The CS pin will detect this current through the voltage across the resistor, and the PWM signal will be sent to a low once the threshold has been reached. The DRV pin is the output pin responsible for sending the PWM signal generated to the MOSFET. SD is the pin that acts as a safety measure for the IC to prevent damage. It is referred to as a “latching fault shutdown pin” that needs an external thermistor to convey temperature data through its resistance value. As its temperature increases, the resistance decreases, lowering the voltage at the SD pin. Once the voltage lowers beneath a certain voltage (2.3V), then fault mode is activated. The HV pin stands for high voltage; it is an input pin that takes the high voltages from the AC input in order to initiate an efficient start-up current. The chip is powered through fixed bias power provided from the auxiliary winding from the primary side of the transformer (hence the name PSR). This auxiliary input is sent to the VDD pin, which has external hold-up capacitors in order to ensure that the IC’s power is maintained even if the auxiliary winding briefly loses power. VSENSE is mainly a feedback measuring pin. The voltage from the transformer is connected to this pin through a resistance scalar, sensing the power delivered from the transformer in order to protect the IC from voltage spikes. The drive pin is connected to VSENSE as well to make sure the output voltage is not too high.

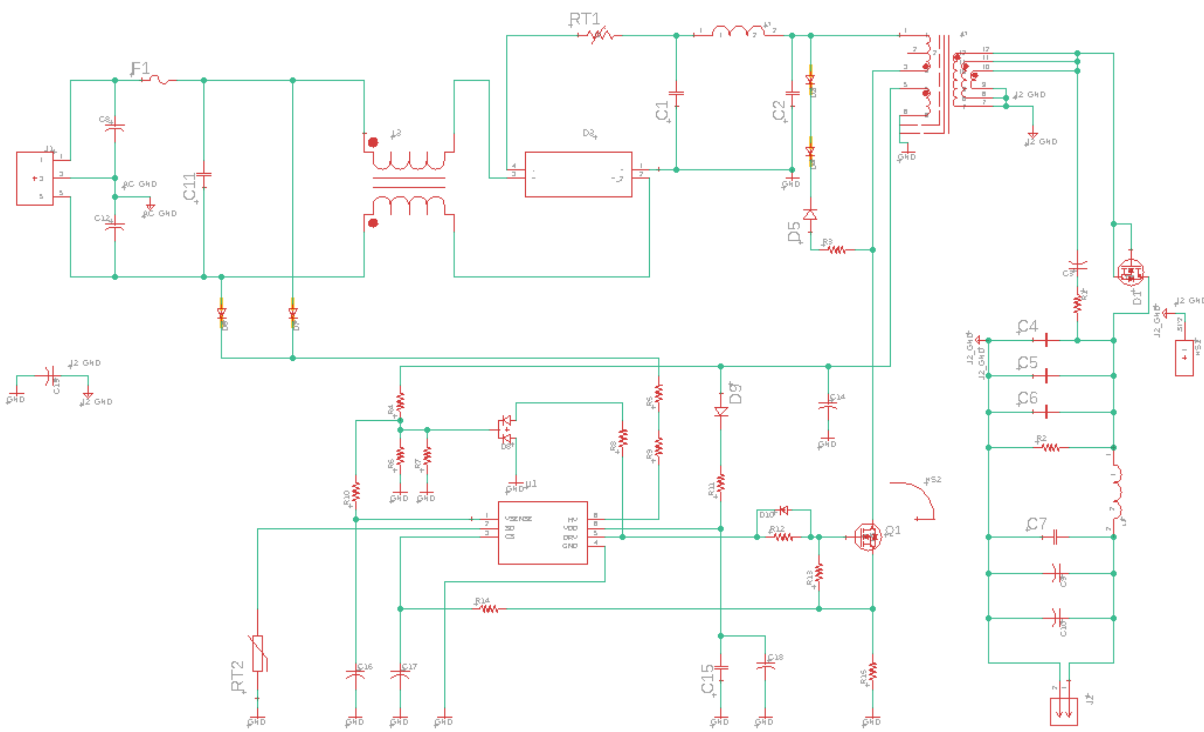


Figure 36: PMP 10335 schematic

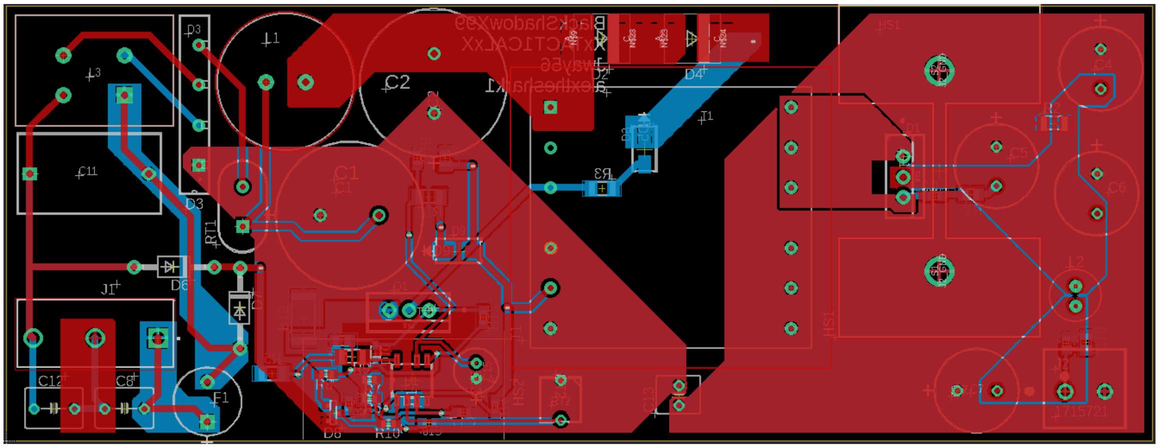


Figure 37: PMP 10335 board layout

6.1.6 Solenoid Driver

The actuation feature of the doggy door required a circuit in order to facilitate such a process. The team designed a solenoid driver that consisted of 4 MOSFETs, each assigned to one solenoid. The Raspberry Pi 0 W communicates to the ATmega328P chip, which then activates the MOSFETs, allowing current to flow into the solenoids. The PCB needed I/O pins that would allow for the solenoids to connect to the circuit, as well as for the raspberry pi to communicate to the ATmega. The circuit also contained a clock connected to the ATmega which was needed in order for the chip to work properly.

The solenoid driver circuit itself was rather small, consisting of the mentioned MOSFETs, a few resistors, and I/O pins for the solenoids, raspberry pi, and 12V power. With such a simple circuit, we saw the opportunity to create a multi-purpose PCB. In addition to the driver circuit, we also included the circuit necessary for the buzzer. Including a few more I/O pins, this board acted as a central wire-management hub, where mostly all power I/Os would be connected. In all, 26 I/O pins were created, 12 of which were responsible for providing the 5V voltage rail, powering most of the components in the project. Pictured in figure 34, the full schematic for the final PCB design can be seen, as well as the top of the board layout in figure 39.

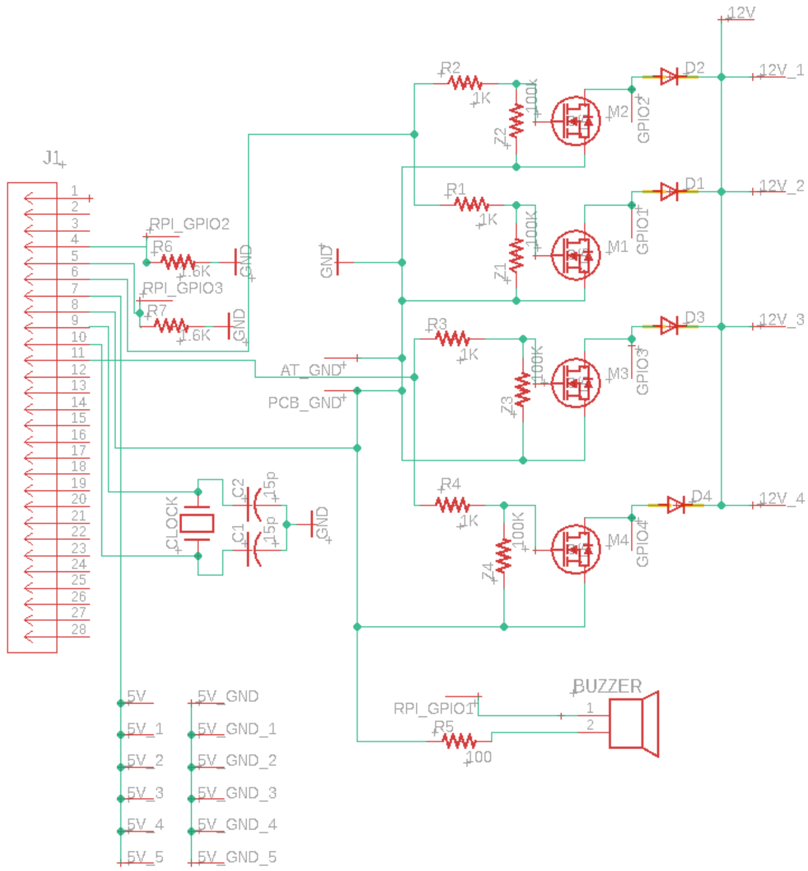


Figure 38: Solenoid Driver and wire management PCB schematic

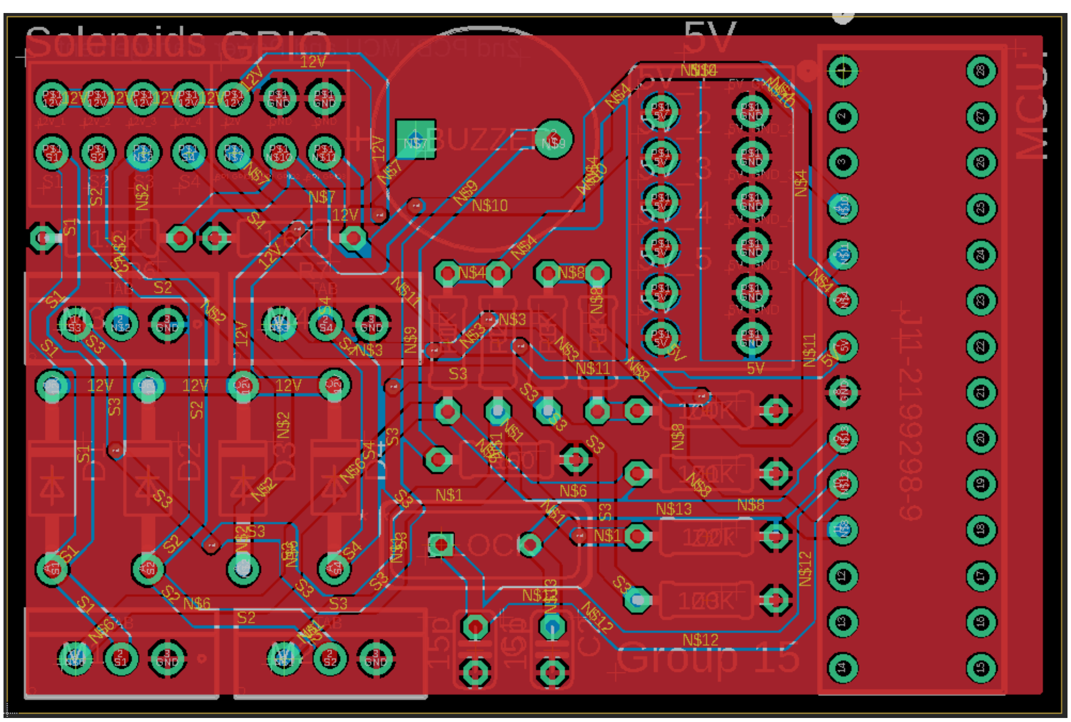


Figure 39: Solenoid driver PCB layout top view

6.1.7 PCB Design Software

There are a few different methods of designing a PCB. Some of these software are more accessible and appropriate for our design. Some EDA softwares include very useful features that speed up the PCB design process considerably, as well as providing perspectives that would not be attainable through other software. It was crucial that the software chosen was capable of schematic and PCB layout simulation. The following list provides a brief look into a few different PCB design softwares and their properties, along with the reasoning as to why we chose the software implemented in the designing process.

KiCad: This software offers a free and very simplistic downloadable software. The program is capable of schematic, simulation, and board layout design. One of the attractive features that this software supplies is a three dimensional view of your PCB board. This allows the user to edit the board given the input of a different perspective. In addition to this, this software is able to create a bill of materials (BOM) along with a tabular view.

EAGLE: EAGLE stands for Easily Applicable Graphical Layout Editor. This program offers a variety of useful features. A very desirable feature that this software has is its auto-routing. Once a schematic has been assembled, the program attempts to automatically connect all of the traces together. This is not only a matter of convenience, but it also prevents incorrect connections that could potentially be accidentally made. This software is capable of schematic and simulation through Ngspice.

Altium: Altium comes with quite a few benefits. It’s latest 365 platform offers a cloud-based storage system, which means that no download or installation of the software is necessary, and access to whatever PCB project is being worked on can be on any computer that is desired, as long as it can reliably connect to the internet, of course. Altium is capable of schematic, simulation, and PCB editing. It is able to take in many different import file types, as well as export various file types. Altium, however, is not a free to use service, as there is a subscription required for their program, which is a yearly subscription.

EasyEDA: EDA stands for Electronic Design Automation. The main draw to this design software is that it does not require a heavy download and storage on your computer, which means that the PCB design process takes place on the website itself. With this web-based system, the PCB designer has the option to edit his or her design from any computer, as long as the computer accessing EasyEDA has an internet browser capable of handling the software. As the name implies, the interface and functionality of EasyEDA is relatively simple in comparison to some its PCB designer counterparts. With millions upon millions of libraries, the user will most likely never run into the issue of a missing symbol. If on the off chance that there is a symbol that is not present, then the software has an option to create a custom one.

All of the above PCB design softwares were able to achieve the goals for this project. Ultimately, EAGLE was chosen as the software that we built our printed circuit board on. This was mainly due to the team's familiarity with this particular software, given its implementation in the University of Central Florida's mandatory class, Junior Design (EEL 3926). The program itself can be quite dense, requiring a very involved and methodical approach to the design process. From the software, particular footprints can be chosen to represent the components. EAGLE has a vast library of thousands of relevant footprints. This is especially important, because without the correct footprint, then the PCB would not have the proper connection type, size, or dimension that it may need. Certain components may prove to be an issue over others. In particular, some parts are very specific in their design, and finding the correct footprint may be difficult on some softwares. This is something to keep in mind when building a PCB. Components like resistors and capacitors are very easy to find, and present no issue when building a PCB. The hardware parts that present the most concern are IC's, transformers, and other such components. For example, an SMPS (Switch Mode Power Supply) transformer was practically unavoidable for our project, considering that the role of our PCB is to be the power supply of the project. With this in mind, the team needed to carefully research the specific components of the reference designs chosen in order to ensure availability.

7 Prototype System Testing

For our prototyping we utilized the senior design lab available to us at UCF. As students in the class, we were allowed to use the lab whenever it was open. Even when we were in the first half of the class and mainly focused on completing this paper, we wanted to get ahead of the curve and start prototyping our components before we would only have a semester for everything. This meant that we had to order all our parts early on as we wanted to test things together as that would be how we can expect to see it on the final design. Once things started coming in we decided to move forward with the set up processes for all components to ensure that they were ready, tested and prepared to be put to use in conjunction with other parts.

7.1 RFID Reader Testing (3dBm)

Once we received our RFID reader we decided we wanted to put it to the test right away. We had a couple of options to test the reader. Firstly, we could have tested the reader by using the ThingMagic® MercuryAPI. This would require us to already have the Raspberry Pi setup for programming. The API only offers Java, C, and .NET programming environments; however, a Python wrapper was created by other users for ease of use and faster development. Though the Python wrapper would have made testing simpler compared to that of the other supported languages, testing would have taken more time than desired. The second option was to use the Universal Reader Assistant (URA) provided by the manufacturers of the M6e Nano. This only required a USB to Serial converter and the URA. The application created a graphical user interface to allow the user to easily manipulate the settings (such as power, reading behavior, and more) of the reader. The latter option allowed for the quickest testing possible. The RFID reader comes with an on-board antenna that gives us a certain amount of range that is advertised by the manufacturer on their datasheet. This range is stated to be 2 feet but reviews of the reader were quick to point out that this range wasn't actually achievable and people were getting max ranges of 6-12 inches.

The first day that we put our antenna to the test, we did not know how to set it up with a power supply just yet. For this reason, the team decided to continue using USB power. Using this method, our antenna power was limited. The software the team used was able to operate from a potential max of 27 dBm to only a disappointing 3dBm. Once the testing was completed, the results showed that the reader and antenna worked. This was great to see and reassuring that everything was working as it should. Although this was considered to be a breakthrough, there was one aspect of the results that were quite disappointing: The ranges were less than favorable. Shown below is our initial prototyping setup with the values we obtained using a few of the RFID tags we purchased to test. This test was using 3dBm as we had no method of connecting our antenna to any sort of power supply at this time.

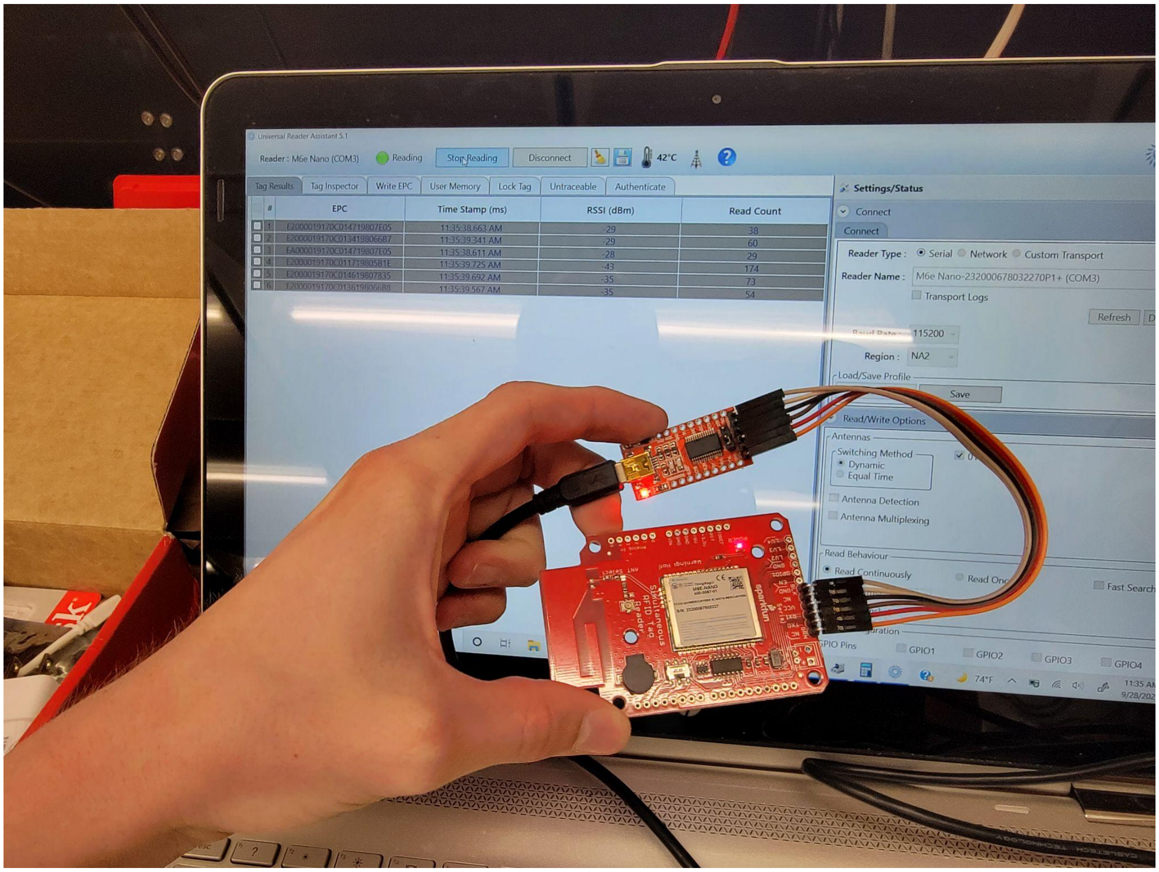


Figure 40: RFID reader testing

7.2 RFID Reader Testing (27dBm)

After looking into the datasheet, the minimum current found to operate the reader at maximum power, which is 27dBm at 5V, was 640mA. For safety concerns, we operated the RFID reader at 25dBm and 5V with a supplied current of around 700mA. The datasheet specified that the current draw was 580mA, however, with our testing, we reached a current draw of about 630mA. We believe that the 580mA was the current draw needed to operate the reader at that power, not to operate and transmit/receive at the same time. Our USB power source for initially testing the RFID reader provided the 5V required by the reader, however, it only offered a max current supply of 500mA. If we risked operating above 5dBm, the reader could have suffered some possible damage. To ensure that our reader was working at higher powers, we had to find another way to power the reader. The first option was to provide an external power supply to two pins on the board. The second option was to provide power to the reader via an Arduino style board. Here, the RFID reader would act as a shield for the development board. We preferred the first option because it did not require us to order any additional components. Therefore, we used the power supply unit provided to students in the Senior Design lab. After configuring the power supply and attaching it to our reader, we were able to get a read range of about a foot and a half. The onboard antenna proved to be insufficient for our application, therefore, a new antenna had to be ordered and set up. Once the antenna came in, the reader had to be configured to use the external antenna instead of the onboard antenna. This was done by removing soldering from one joint and adding solder to another. Operating at 27dBm, the same power before, the read range increased about 3ft. Another distinguishable factor was that the tags no longer had to be placed within line of sight of the antenna. The new antenna offers a much higher beamwidth. Therefore, the tags can be placed off to the side of the antenna (by a couple of feet) and still be easily read. As seen in the images of our testing below, we really were able to move around the tags and still pick up a signal. We started slowly just moving it away from the antenna and quickly noticed that we were getting quite far and yet the tags were still being picked up. The most interesting part was that as we moved it in other lateral directions around the antenna, we saw that it still was picking up the tags and even at some greater ranges. Next we went ahead and put it behind objects and it still was picking it up. Once we saw this we wanted to see if we could combine the previous two realizations that we made and put it under the table right under the antenna and even thought at this point it was not at all to our surprise, the reader was still doing a magnificent job at picking up the tags even as we moved them away.

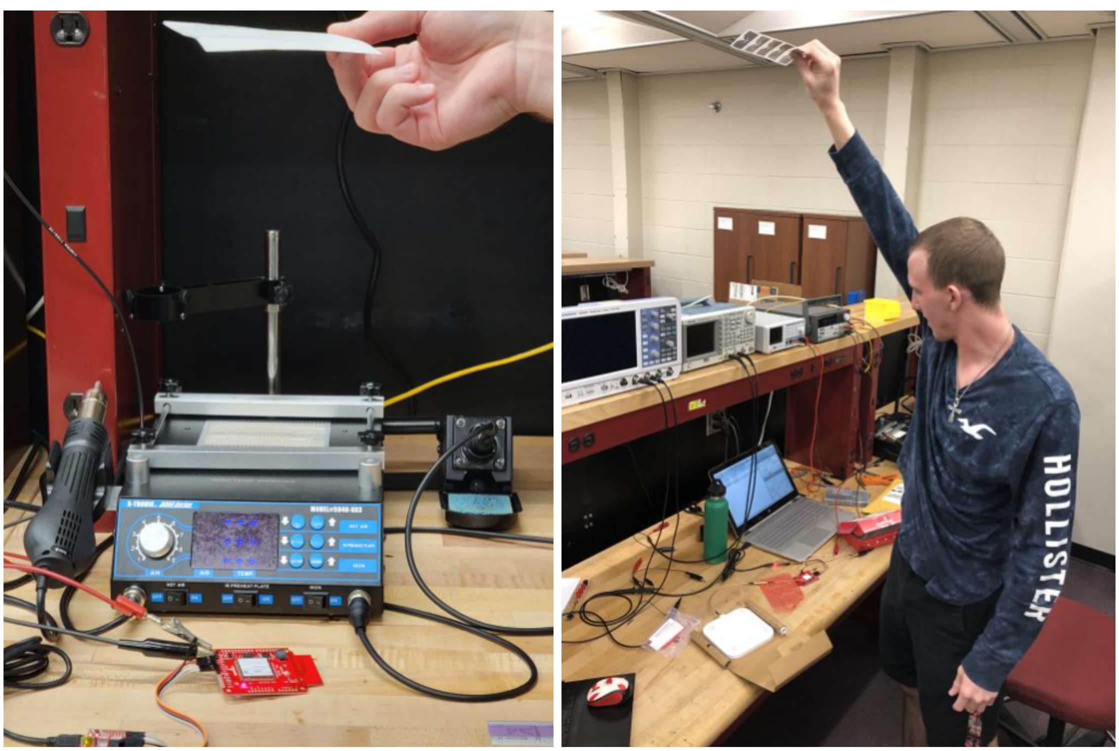


Figure 41: Onboard vs external antenna

Below is a table that compares the information found from both the onboard and external antenna:

Antenna	Input Power	Distance from antenna (average)	Received Signal Strength Indicator (RSSI) (average)
Onboard	3dBm	< 1in	-38dBm
Onboard	27dBm	0.406m	-60dBm
External	3dBm	6in	-50dBm
External	27dBm	1.37m	-60dBm

Table 24: Onboard vs External Antenna

7.3 Door Testing

One issue that we foresaw with the making of our door, was that after one animal gets permission to pass through the door, there is a brief window that another animal may dart through the door while it is still unlocked. If the latter happens, this will defeat the purpose of making a unique profile for every animal registered on the system because not every animal will be able to enter or exit under the same circumstances. This problem is created if the doggy door flap is not able to lock into place soon after an animal passes through the door. Therefore, the transient state of the doggy door must be minimized as much as possible without making the door fall too slowly. Our initial thought was to apply some sort of strip to the edge of the door flap that will reduce its speed as it falls back to its original position.

Though this may work, it will not be a sufficient solution on its own. Alternatively, a rotary damper, which reduces the angular velocity of an object, could also be used. Once the velocity of the door is reduced enough, we need some way to detect if the door is within locking distance. This can be done with a reed switch. This component can detect a magnetic field and produce some output. By placing a magnet on the bottom edge of the door flap, and the reed switch on the door frame just below the normally closed position, we can detect when the door is returning to its closed state. As the reed switch detects the magnetic field, our goal is to use locks to catch the door, as it is falling, and lock it into place. As seen in the prototype in the pictures below, the red LEDs represent the locks of the door. When they are off, the locks would be retracted. When the LEDs are on, the locks would be activated. Because the door was falling too fast, the “locks” (or red LEDs) were not activated until the door passed its closed position. This issue can be resolved by using the mentioned stripping, rotary dampers, or some combination thereof.

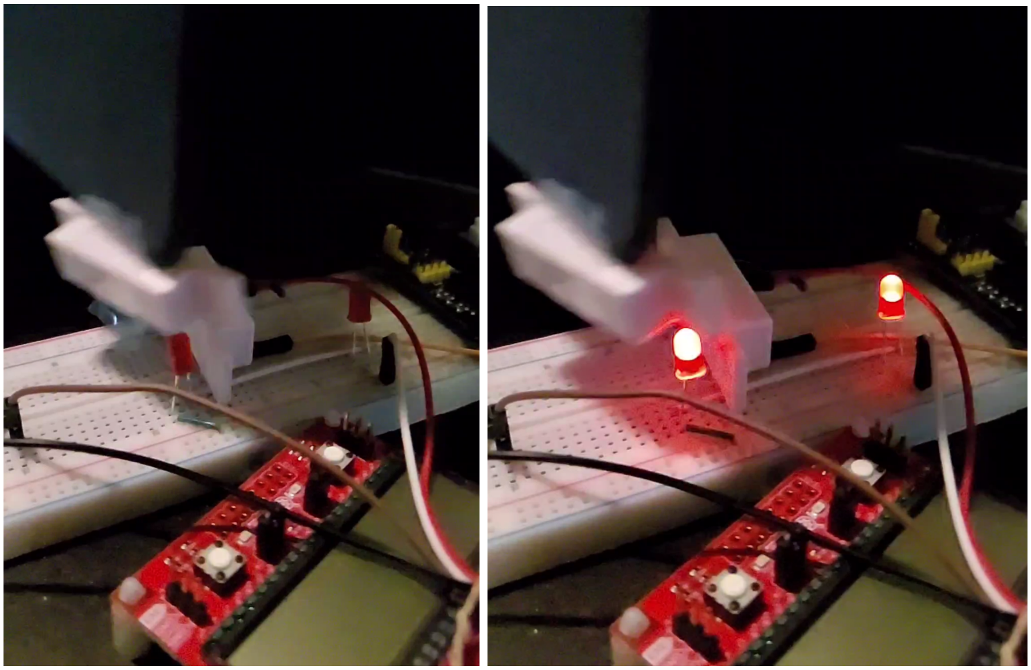


Figure 42: Reed switch prototype on and off state

7.3.1 Prototype Construction

One of the main components of the project was the doggy door that was used for the project. The doggy door was built using wood and was built to have a door open that is twelve inches long by nineteen inches tall. This allows for large dogs to be able to use the door. The door flap is made of a polycarbonate sheet to allow for greater durability while also being resistant to weathering. The locking mechanism was designed using AutoCAD and then 3D printed. Although the locking mechanism is made of plastic, the design used allows for it to be very durable to add extra security. Finally, the door also has a small box on top to house all the hardware components used for the smart doggy door and will be covered to prevent any damage or tampering with the hardware.

With such an embedded project, there was no doubt that the team would need the assistance of advanced equipment in order to deliver power to the system under construction during the prototyping phase. The University of Central Florida, more specifically the equipment provided in the Engineering building, played a huge role in the success of this project. The equipment provided as a resource to the students helped our team deliver the necessary electrical demands of the project, allowing us to prototype and troubleshoot when necessary, which included the use of oscilloscopes, power supplies, and digital multimeters. In addition to these instruments, UCF’s engineering labs also provided soldering stations, an assortment of solder heads, and other components to aid in the relevant needs of building custom PCBs. Early on, before the permanent connections were made, the team needed a way of temporarily connecting hardware together. In order to accomplish this, our group used various breakouts and breadboards.

7.4 Initial Raspberry Pi Testing

As great and convenient a Raspberry Pi was, getting everything set up for our specific usage in our specific setting was not without its obstacles. Pis are very capable and intelligent system controllers that not only utilize most of the great features found on modern MCUs but also function with a complete operating system that takes full advantage of the Pi’s hardware. This operating system needs to be stored somewhere, and like any desktop computer some sort of storage device is required to hold the operating system. In the case of our tiny desktop we will be using a micro SD card of 32 GB to store our operating system along with anything else that may be required of our project.

7.4.1 SD card setup

Setting up this SD card with the correct operating system for the Pi is rather simple and straightforward following the helpful guides provided by the Raspberry Pi company themselves. Keep in mind however, that our use for this Pi was strictly in its headless mode. Besides the initial setup that was also done in a somewhat headless form for every user, the device was intended to be embedded into the door system and left alone. No external connections of mouse, keyboard, or monitor are meant to be made and realistically shouldn’t be to keep everything working as we intended. We want to give the users peace of mind that they can purchase this product, follow our guided initial setup, and then never have to worry about the Pi again.

The first tricky situation we ran into had to do with our connection to the internet. When formatting the SD card and loading it up with the operating system, we are required to enter our Wi-Fi network that we would want the Pi to connect to. It isn’t necessarily required for every case, but since we will be running headless, we will need the Pi to connect to the internet for us to be able to access it and work on it. Normally you would be able to simply install the operating system on an SD card and if you don’t add the Wi-Fi network right away you can just add it once you boot up your Pi and use your connected mouse, keyboard, and display to navigate the interface. To emulate the somewhat headless setup our users will have to do, we wanted to keep every step of the process headless.

7.4.2 SSH setup

Above we mentioned that in order for us to be able to access and work on the Pi, we needed to have it connected to the internet. This was because the way we are going to set it up remotely is by remoting into it. In order to do so we used a free SSH and Telnet Windows platform called PuTTY. This client allowed us to run remote sessions on a computer over a network. When setting up the Pi, we were given the option to turn on SSH which we did, allowing us to use this. Through PuTTY we are able to use any of our own Windows devices to remote into whatever the Raspberry Pi is displaying as long as it is powered on and it is on the same network as the Windows device we are running PuTTY off of.

The PuTTY interface provides us a complex looking screen that is actually not too difficult to follow for our use of it. All we had to do was make sure our connection type was set to SSH, which it was set to by default, and enter the Pi's IP address which we tried to obtain in some different ways. The first main issue with the Wi-Fi was mainly an issue with the plan we had in place. We wanted to connect to the UCF Wi-Fi so we wouldn't rely on a specific person's device for connecting and essentially working on the Pi. However UCF uses a very unique Network configuration and we ran into a wall trying to connect to it. The system they use to connect consists of entering a username and password while the Pi can only connect to networks that their security authentication only requires a password. Furthermore, finding the IP address of the Pi on a network that is used by thousands of people at once was sure to be an issue in and of itself.

7.4.3 Hotspot setup

This leads us to have to resort to alternative options. Thankfully, it didn't take us long to think of the possibility of having the Pi connect to a hotspot. By connecting to a hotspot the Pi would essentially be on its own network along with the device programming it. The Pi was also able to connect to any of our hotspots as when the situation arose that one of us did not have that feature on our phone through our mobile carrier, we found out that our laptop was just as capable of sharing the network it was connected to with other devices. Best of all, on this network with only the Pi and the device, finding the IP address of the Pi was as easy as it could be and lead to seamless connection.

When a correct address is entered the first thing we are greeted with is a security message from PuTTY asking us to make sure that we want to connect to the IP that was entered. After authorizing our connection we are brought into our command line terminal where the first line presented to us is asking us for our login username and once that is entered, the password. After a successful login using the credentials we assigned to the Pi during its operating system set up, we are now finally at the desktop level accessing everything on the Pi through the command line. This system runs Ubuntu, a version of Linux, which means through the command line we could do basically anything we want, especially programming wise.

7.4.4 VNC viewer setup

However, we still could have wanted to see the GUI of our desktop in this Pi for many different reasons. Again through the amazing free software that you can download off of the internet, this remote access that basically displays what we would see if we plugged the Pi into an HDMI was possible. For this process we use an application called VNC Viewer. One of the first things we have to do to get this to work is use our setup with PuTTY to access the Pi's config and set the VNC server to enabled. After this once we open VNC Viewer we are presented with an application that almost mimics a web browser. On first launch we will see an address bar with nothing in the window below it. After connecting to a session, all our previous sessions will begin to appear in that said window. After putting our Pi's IP address into the address bar we are presented with a pop up window that asks us for the login credentials. After entering it we will finally be getting the full Raspberry Pi viewing experience remotely. This will fully function with our keyboard and mouse to navigate around the desktop, use the file explorers and other applications, and even utilize the command line from it's desktop application if we wish to.

After setting up the Pi for our programming needs we decided to get to some early testing to get a feel for what we can expect. As is tradition in the programming world, we decided to write a very quick python version of "Hello World". We came to find that the best way for us to write programs as of right now is through the command line. Using a command titled 'Nano' we are able to create and open any sort of file for editing through the command line. We realized that through the VNC Viewer there can be a slight lag when utilizing the command line terminal, so we decided for most of the time we will be working on the Pi; we will likely only be accessing it through PuTTY. Our first command was word for word "nano hello.py". This command created and opened a file for us to edit line by line. The ".py" extension indicates to the operating system that the file is a Python file. With Python being as user friendly and simple to grasp as it is, this hello world program was simply one line in the editor where we would print "hello world". After writing it up, we saved it in nano and exited the editor that is built into the command line. Once it brought us back to the command line, we simply entered "python hello.py". This command line indicates the operating system that we would like to run a python script of the version of Python that we are using on the system. Without any issues our script ran and printed out "Hello World".

7.4.5 LED setup

Now that we understood where we were going to be writing these programs, how we could create them and edit them without even opening a separate window, and how they were going to run through the command line, it was time for us to step up the difficulty a bit and lean more towards understanding certain aspects of the Pi that we are going to be utilizing heavily, Leading us to decide that our next task was to light up an LED through one of the Pi's GPIO pins. First we did some research as we wanted to make sure that we didn't mess up any component. Using a multimeter in the lab in diode mode we were able to turn on the LED with 2.3V. Looking into datasheets for our Pi we found out that the GPIO output pins supply 3.3V. We built the circuit, and using previous knowledge gained from classes and a few burned out LEDs in some of our pasts, we made sure to add a resistor to control the current flowing through the LED.

After setting all of this up it was time to get to the software side of things. This time around we created a folder for all the python projects we are probably going to create on the desktop called "Projects". Within this newly created folder we would create the python file that would run our LED script simply titled "LED.py". As simple and vast as base Python is, it still needs some additional libraries for certain things and as you would expect, importing them is no harder than you would think. There are two libraries that we will have to access for this small task of ours since we not only want to turn on the LED, but also turn it off after a certain amount of time. To do this we will need to add the libraries 'gpiozero' and 'time'. But more specifically, we want to import 'LED' and 'sleep' from each of these respectively. The sleep functionality from 'time' will allow us to essentially put our program to sleep for a specific number of seconds. This will be used to put our program to sleep between turning the LED on and off. LED from 'gpiozero' allows us to create a variable that will hold onto a certain PIN number based on the GPIO pins on the board and treat it as an LED. Meaning that with the variable we assign to this pin we can turn the LED on and off with simple built in functions.

While originally seeming like a somewhat daunting task that might take us a bit of research and time to figure out, the mix of research with safe testing led us to quick understanding of certain concepts and how our board works with the programming. Using one wire to connect the GPIO 17 pin to the positive leg of our LED on the breadboard, and another wire to connect the back half of the resistor to the ground on our Pi, we complete the circuit that will power on our LED. Now it was simply instructing the Pi to run the script that we gave it and without any issues it immediately was able to power on the LED. Initially we forgot an additional sleep at the end of our while loop and were very confused as to why our LED was not blinking or turning off at all but after better analyzing our code we saw our simple mistake and were able to correct it.

7.4.6 Motion sensor setup

Our next task while working with our Raspberry Pi would entail trying to set up our motion sensor. As expected, our PIR sensor has three pins that need to be connected to our system controller. Our sensor has three pin headers that stick out the bottom of the board but when looking at their roots at the bottom of the board we see no label. However, if we pop the plastic casing of the sensor off the top we will be able to see the labels for it. The three labels are for VCC, GND, and OUT. The VCC will connect to a 5V pin on the Pi, the GND to ground, and the OUT to any GPIO pin. All of the mentioned can be seen in the images below.

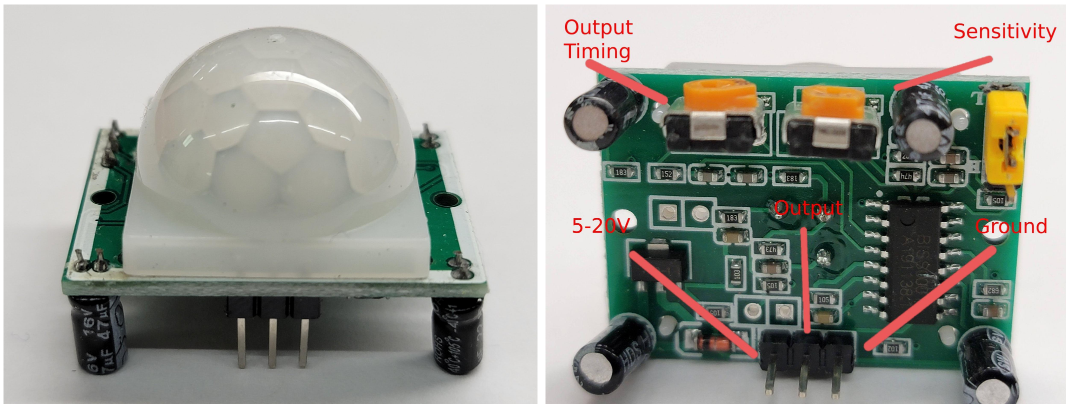


Figure 43: Passive Infrared Sensor

Now to set up the correct program for our sensor, we have to have a little refresher on how exactly these devices work. These passive infrared motion sensors have a fresnel lens and an infrared detector along with the supporting circuitry. The lens focuses any infrared radiation present around it towards the infrared detector. Any heat that is detected by the sensor alerts the circuitry to output a 5V signal for a period of time as soon as the heat is detected. The way the sensor knows it's motion and not just an idle heat signature is by detecting changes in heat around it. Something that our testing would be sure to show us, that we were quite unaware of, is that this sensor is highly sensitive.

Keeping in mind that the sensor will give us a 5V signal directly to the Pi is important to note as that will be what we will be looking for with our software. This means that we will be using the GPIO pin that the sensor is connected to as a GPIO.IN connection type. From here on out our code can simply be an infinite loop that either detects if we are getting a '1' or '0' from our GPIO.IN pin. The reason it is not '5' and instead it is '1' is because the software and the libraries know to detect a HIGH signal that is 5V as a 1 and any LOW signal that can be 0V as a 0.

The last thing to address before getting into the initial findings of our testing is a certain aspect of certain PIR sensors, including the one that we are using for our project. Our sensor has two orange components with sockets that fit a Phillips head screwdriver. These orange components are potentiometers that we will be using to adjust certain attributes of our sensor. The potentiometers allow us to adjust both the delay and the sensitivity of our sensor by rotating the sockets with any sort of Philips head screwdriver. These would prove to be essential to understanding our initial testing as we were a bit confused when we were first testing.

When we finally set up our sensor with our Pi and programmed everything, we initially weren't even aware that the switch between a HIGH signal and a LOW signal weren't instant. We were expecting to see our looping text automatically change to the motion detected text when we moved our hand over the sensor and then immediately back after we moved it back. However, only half of this assumption was true, we saw the immediate change to motion detected happen, but this was printed quite a few times after we had already moved our hand away. This is because of the fact that the delay will cause the high signal to stay for an extended period of time.

There was another issue that was prevalent. The next thing that we noticed was that the sensor occasionally gave undesired readings. Sometimes, without the presence of any moving objects, the sensors continued to detect some type of motion. Discovering the root cause of this issue proved to be quite a challenge. Due to the fact that there is no clear way of knowing what exactly the sensor could be detecting, this was a lot trickier to figure out and debug. Another possibility is user error; we could have potentially hooked something up incorrectly. After running into both of these issues repeatedly, the troubleshooting process led us to the potentiometers. We began by tweaking these components in an attempt to try and change the delay and sensitivity. Thankfully, the delay was not too difficult to figure out. At the end of this, we found that we were able to resolve our problem through surprisingly easy means, which consisted of messing with that socket.

In terms of the sensitivity, unfortunately it wasn't as easy. Even though we were able to move the socket and technically change it just as easily as the delay, the problem always came back to the fact that we could never really know what was causing the motion being detected and whether it was a problem with the code, with the sensor, with the sensitivity setup, with objects in the testing area, etc.

8 Administrative Content

This IoT Smart Lock Doggy Door was a large project that branched out to many fields of both Computer and Electrical Engineering. Each member had strengths and weaknesses, so by dividing every part of the project to have two individuals not only ensured the completion of a part, but having two sets of eyes tackle one problem at a time reduced issues encountered. When working on such a large project and for extended periods of time, it was crucial to maintain goals as well as effective communication. From the beginning, a Discord server was created to allow for constant communication between all members. This server also served as a meeting location if we were not able to meet in person. Google Docs and Google Sheets also proved to be very useful to keep every individual accountable. These applications also allowed all the group members to work in parallel which helped reduce the time spent on certain areas immensely.

Tackling this project all at once would have proved to be daunting and overwhelming. Therefore, a new approach had to be devised. Project milestones were formed to ensure that we could gauge our progress throughout the semester and meet project deadlines. Our milestones were also carefully planned to allow us to finish early rather than right at the deadline. This was very important because personal matters cannot always be predicted. Having that extra buffer secured our completion of the paper by the actual deadline for the course. Also, while every milestone could have been broken down even further, we decided to keep all similar milestones under one title. Having too few or too many milestones can add unnecessary stress. By creating realistic goals and deadlines, we were able to move at a consistent pace.

Budgeting for this project was another large factor to determine. Maintaining an affordable project while managing bills was paramount to all of us. We prioritized making our project feature rich and easy to use. Therefore, to meet the two previous criteria while maintaining a low cost, careful planning had to be done. Parts were researched extensively to increase the ratio of functionality to cost. This ratio could be increased by either finding a part with a lot of features or a part with a really low price tag. This project was also largely software oriented which allowed us to expand our features even further without raising the price with additional hardware components.

8.1 Project Milestones

Our milestones were carefully planned to ensure project completion ahead of time while being conscious of events that could not be accounted for. To reduce the stress load among each of the members, weekly deadlines were set to maintain a constant pace while completing the paper and starting to prototype. The milestones that took the longest to complete were researching and ordering components. Every part researched had to be taken into consideration while discussing the pros and cons to each part. Once a list was compiled, the team looked over these factors and considered what would be best for the project. After research, not every part could be purchased from the same vendor. While some orders only took a couple of days to come in, other parts took up to a couple of weeks. One of our most difficult milestones to accomplish was to establish a two way communication between the door, database, and smartphone application. Another difficult milestone to accomplish was optimizing the door as much as possible. There were many intricacies and small parts that went into the design of the door, and many of our initial design ideas involved pulley systems, which required knowledge of Mechanical Engineering. None of the members on the team had experience with this particular subset of Engineering, causing the door designing process to be that much more difficult.

Number	**Milestone**	**Week**
1	Finalize project idea	1
2	Finalizing Hardware Components	5
3	Order Components	6
4	Configure System Controller	10
5	Prototype with Breadboard	15
6	Plan Design of PCB	16
7	Order PCB	17
8	Setup Database	16
9	System Controller Communicates with Database (API)	19
10	Door Constructed	19
11	Combine Hardware with Door	22
12	Build Android Application	23
13	Revisions	26
14	Final Tests	29

Table 25: Senior Design 1 and 2 Project Milestones

8.2 Project Budget

While the budget came out to be on the higher end, the project was rich with features and satiated our desire for a truly “smart” Doggy Door. Splitting the cost over two semesters and four group members made the return on investment that much better. This fact alone made the design process transition smoothly to its implementation. The even distribution of finances helped facilitate a project budget, aiding the team in the planning process. Our most expensive items turned out to be the RFID reader integrated module, as well as the external antenna. However, this could not be bypassed while still maintaining long read ranges. Luckily, the cost of the rest of the materials were much more affordable. The prices of all the components can be found in the table below, showing the item, the quantity, and the price:

Item	**Quantity**	**Price**
RFID reader	1	$235
RFID external antenna	1	$119
Raspberry Pi Zero W	1	$10
microSD Card	1	$8
UHF Tags	5	$2
Camera	1	$14
Buzzer	1-2	$1.50
Motion Sensor	1	$8
Solenoids	4	$30
PCB	1	$20 - $30
Antenna Connectors	2	$12
Door Materials	-	$70
3D Printer Filament	1	$20
External Battery	1	$50 - 60
TOTAL	N/A	~$599 - $620

Table 26: Project Budget

8.3 Personnel: Project Team Content

Logan Waln is attending the University of Central Florida and will be receiving his Bachelor's of Science in Computer Engineering upon the completion of his degree in May 2022. His love for technology started with the game of Minecraft back as a little kid and has since expanded to the field of Embedded Systems. After graduation, Logan will be actively searching for jobs to acquire new skills and later pursue a Master's degree.

Jordan Carraway will be receiving his Bachelor's in electrical engineering at the University of Central Florida and will graduate in May of 2022. After graduating Jordan will be starting his career with AECOM working on the controls systems for the New York City subway trains.

Hunter Herrold is a 23-year old electrical engineering major who will be graduating in May of 2022 with a Bachelor's of Science degree. Upon graduating, on top of pursuing his own personal electrical projects, Hunter plans to begin working in the field of electrical engineering, specializing in power or PCB design while looking into an M.E. program.

Alexis Quintana will be receiving his Bachelor's of Science in Electrical and Computer Engineering in May of 2022. After graduation, Alexis plans to use his double major to find a job in the industry where he can continue to work on the seamless integration and communication between hardware and software.

9 Appendix

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9.2 Permissions

Figure 1: Doggy Door

Logan W <logan.waln@gmail.com> Mon, Nov 8, 8:51 AM
to services

Hello,

I am a student at the University of Central Florida, and I am part of a team of students who are building an Iot Smart Doggy Door for our Senior Design projecct. We would like to use some of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for reproduction.

We are hoping to obtain permission for the following images:

https://www.attshop.tw/ProductDetail.aspx?iid=289590735&pr=59.88

Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.

Thank you in advance for your help,
Logan Waln

Figure 4: Rotary Dampers

Photo Permission

Jordan Carraway <jordancarraway98@gmail.com> 3:20 PM (0 minutes ago)
to sales

Hello,

I am a student at the University of Central Florida, and I am part of a team of students who are building an IoT Smart Doggy Door for our Senior Design project. We would like to use some of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for reproduction.

We are hoping to obtain permission for the following images:

A picture containing indoor, lock, several Description automatically generated

A picture containing disk brake, gear Description automatically generated

Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.

Thank you in advance for your help,

Jordan Carraway

2 Attachments

Reply Forward

Figure 8: Anatomy of an RFID Tag

Contact Us

We would love to hear from you! Please fill out this form and we will get in touch with you shortly.

Name *

Logan — First

Waln — Last

Email *

[redacted]

Phone

[redacted]

Message *

We are hoping to obtain permission for the following image underneath the heading of "RFID Antennas":

https://www.analogictips.com/rfid-tag-and-reader-antennas/

Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.

CAPTCHA

I'm not a robot

reCAPTCHA

Privacy - Terms

SUBMIT

Figure 10: Different Tag Form Factors

Logan W <logan.waln@gmail.com> Tue, Nov 23, 9:12 PM (7 days ago)

to sales

Hello,

I am a student at the University of Central Florida, and I am part of a team of students who are building an Iot Smart Doggy Door for our Senior Design projecct. We would like to use one of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for reproduction.

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Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.

Thank you in advance for your help,
Logan Waln

Figure 14: Push Pull Solenoid

Adafruit Industries <support@adafruit.com>
to me

all good, feel free to use.

On Sat, Dec 4, 2021 at 3:44 PM Jordan Carraway <contact_us_forms@adafruit.com> wrote:

> contactname : Jordan Carraway
> email address : jordancarraway98@gmail.com
> Positive Feedback : Hello,
> I am a student at the University of Central Florida, and I am part of a team of students who are building an IoT Smart Doggy Door for our Senior Design project. We would like to use some of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for reproduction.
> We are hoping to obtain permission for the following images:
> https://cdn-shop.adafruit.com/970x728/3992-01.jpg
>
> Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.
> Thank you in advance for your help,
> Jordan Carraway

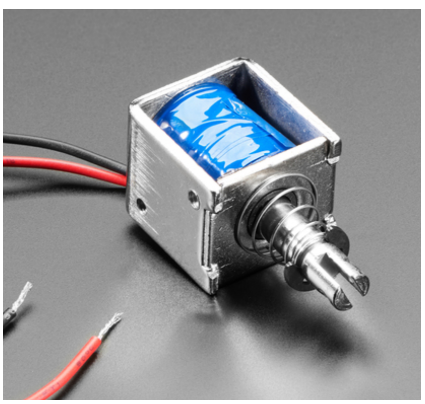

Figure 16: Electromagnet

Image Reuse Inbox x

Logan W <logan.waln@gmail.com> 9:15 PM (1 hour ago)
to press

Hello,

I am a student at the University of Central Florida, and I am part of a team of students who are building an Iot Smart Doggy Door for our Senior Design projecct. We would like to use one of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for reproduction.

We are hoping to obtain permission for the following image:

https://www.adafruit.com/product/3872

Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.

Thank you in advance for your help,
Logan Waln

phillip torrone <pt@adafruit.com> 9:18 PM (1 hour ago)
to me, press

yep, all good - approved!

Figure 26: EPC Gen2 Memory

RFID4U

Hello,

I am a student at the University of Central Florida, and I am part of a team of students who are building an Iot Smart Doggy Door for our Senior Design projecct. We would like to use one of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for reproduction.

We are hoping to obtain permission for the following image:

https://rfid4u.com/rfid-epc-gen2-memory/

Please let me know if this is possible. Feel free to direct me to someone more suitable if you are not the proper point of contact.

Thank you in advance for your help,
Logan Waln

First Name	Logan
Last Name	Waln
Email	logan.waln@gmail.com
Message	Hello, I am a student at the University of Central Florida, and I am part of a team of students who are building an Iot Smart Doggy Door for our Senior Design projecct. We would like to use one of your images in our documentation. Our report will be published on the UCF website upon its completion (http://www.eecs.ucf.edu/seniordesign/). I was hoping you may be able to assist me in obtaining permission for