RFID-Enabled IoT Smart Doggy Door

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***ABSTRACT* – The Smart IoT Doggy Door was built in order to combine customizability with ease of use for pet owners. This RFID-enabled product offers dogs and other pet owners alike the ability to choose when their furry friends are allowed outside, all achievable through the mobile application designed by the team. With this design, dogs and other household animals have their own "key to the house," so long as permissions are met. This paper will describe in detail the design, specifications, and many features that were incorporated into this embedded project.**

I. Introduction

As the Internet of Things (IoT) becomes both more popular and accessible, there is no surprise to the number of markets affected by this architecture. While most aspects of typical houses have been affected by IoT in one way or another, our team discovered a gap to be filled in the market for doggy doors. While smart doggy doors are not necessarily a new idea, current implementations certainly lack IoT features. The vision of the team was to create a doggy door that was user-centric, feature-oriented, and easy to use. The system was implemented with radio frequency identification (RFID) to ensure that the system would perform reliably and allow the collars to be cost-efficient. Other peripherals included are motion sensors to detect animal movement and an external camera to maintain a record of images taken within the past day. To allow for remote user control, a mobile application was created to allow the user to easily interface with the door. The application allows the user to maintain and configure all registered animals within the system. By adding a database, the user can access the information connected to their account. Under normal conditions, the door is powered by a standard wall outlet to maintain continual operation. In the event of a power outage, an external battery has been implemented to ensure door operation is not disrupted for an extended period of time.

II. Design Specifications

This section will discuss the design specifications required for the door to operate as envisioned. These specifications were designed to keep the system easy to use and operate smoothly.

A. Safety Specifications

This system was carefully designed to prevent any risk of injury to either animals or humans. This system was kept as low profile as possible with minimal protrusions. This also made the system less prone to taking any damage. The hardware had to be carefully concealed. The closing part of the door was the biggest concern that most people would have. Due to the desire of simplicity we adopted the traditional doggy door flap design.

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.

B. Power Specifications

Understanding the need for a technical analysis of the power requirements, the team designed a comprehensive flowchart of the power specifications. Fig. 1 shows all calculations required for the project. Identifying the highest voltage of a 12V signal for the solenoids, a 120VAC/12VDC converter was needed. All other hardware components were set to operate at 5V, therefore a 12V to 5V buck converter was required. It is important to note that the reader was actually operated at 4V. For this reason, a 5V to 4V step-down voltage regulator was also included in the project, but the calculations for the power included in the converter diagram were accounted for. With these power calculations, the appropriate converters that were capable of delivering according to these needs were selected.

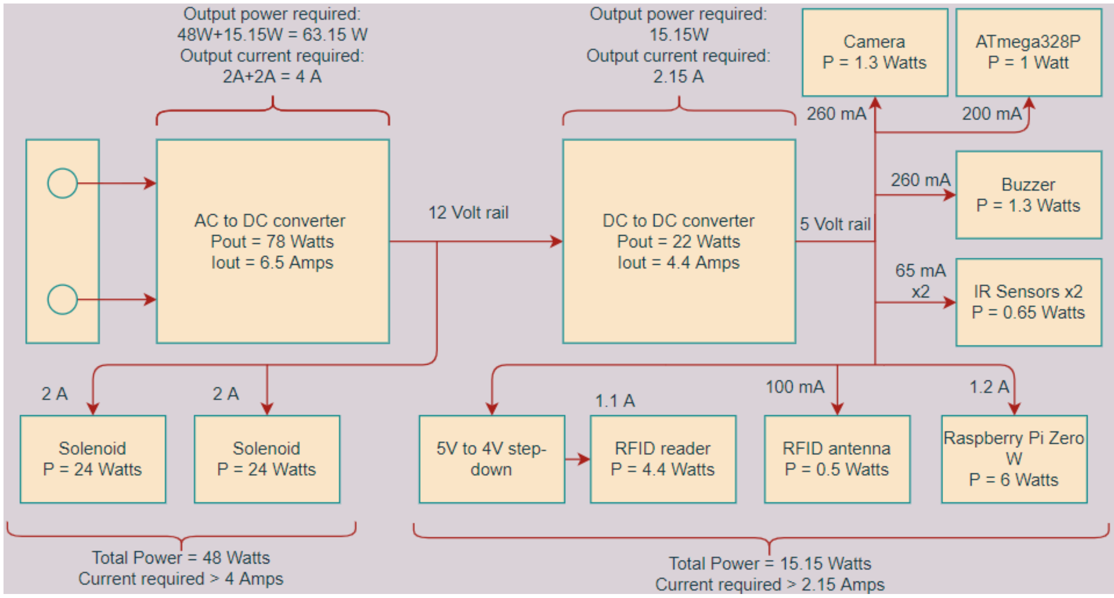


Figure 1: Converter Power Calculations Block Diagram

For the 12V converter, its output needed to be able to supply a sufficient amount of energy for the entire system, requiring a total wattage of 63.15 Watts. The power demanded from the 5V step-down only depended upon its respective peripherals, which turned out to be 15.15 Watts. When choosing a converter, the team decided to overshoot how much power each one had to ensure that the project had enough energy.

C. Database Specifications

Firebase was the service selected to handle our entire backend as it has a seamless connection to its database through high-level api calls. The asynchronous listeners that are provided by Firebase offered us an intuitive way to listen to certain variables in the database and run a callback code if the change was detected. Firebase also offers an offline mode that keeps the software running even if systems go offline and then keeps track of any changes made since the last connection to update them accordingly. This is in part made possible by the fact that Firebase uses a cloud hosted real-time database allowing all clients to share one real-time instance and auto receive updates.

III. System Components

This embedded project consists of multiple components, with each module having its own needs and characteristics. The introduction of a microcontroller allowed for various peripherals, opening up the possibility to add more features to the design. Therefore, this section is needed in order to have a briefing on the technicalities of all aspects of our project.

A. RFID Reader

The Sparkfun Simultaneous RFID Reader - M6E Nano development board contains an onboard antenna, as well as a u.Fl connector, compatible with an external RFID antenna. Due to the onboard antenna having too short of a read range, the u.Fl connector was used. The Sparkfun reader operates on the Ultra High Frequency (UHF) range. The power is adjustable from a range of 0dBm through 27dBm, which will achieve a larger read range. This reader requires only 5V, and consumes a maximum power of 5 Watts. The reader outputs a voltage of 5V on its transmission line, which must be stepped down to 3.3V to ensure reliable data communication to the Raspberry Pi.

B. Antenna

The onboard antenna on the Sparkfun reader only achieved a maximum reading range of a foot, an external antenna was needed. The Times-7 SlimLine A5020 Antenna was chosen for our project. It is circularly polarized, allowing for more accurate tag reading conditions. This antenna is capable of read ranges of up to 4.3 meters (14 feet), depending upon the amount of power delivered to the device. It is compatible with the UHF frequency needed for the project. Its beamwidth is specified to be roughly 115 degrees, providing a significant range of power transfer. The SlimLine antenna has a maximum power operation of 6 Watts; however, in our application, the amount of current delivered to the antenna will be significantly reduced in order to achieve a more appropriate read range. Delivering a current of 100 mA, the antenna will only consume about half of a Watt.

C. Tags

When deciding which type of tags to use for the door, we were left with two options, with it being either a passive tag or an active tag. After further researching, we determined that for the project a passive tag would be the better option for several reasons. One of the main factors is that it is the cheaper option due to it not needing a power source. This would prevent the customers from having to constantly charge the collar and can keep the collar on the dogs at all times. Passive tags do have a shorter read range when compared to active tags, however, for the project we do not need more than a couple of feet. This read range was accomplished by using an antenna and therefore passive tags did not only work for the project but were also cheaper and required less maintenance.

D. Raspberry Pi Zero W

The Raspberry Pi is a single board computer (SBC) running a linux based operating system and is capable of communicating with the internet. An SBC was selected over a microcontroller as we will be having this system controller communicate with many different devices including an RFID reader and camera which can take more processing power than most microcontrollers offer. The step up in RAM from the KiloByte range to half a GigaByte also was helpful in running all these tasks simultaneously and having them communicate with each other while sending certain updates to the database through the internet connection.

The choice of the Pi Zero W itself was made mainly for its compact size and its cheap price. When comparing it within its same family we were only considering the Pi 4 B as an alternative. The Pi 4 B is a powerful SBC showing just how far Raspberry Pi has come over the years while still maintaining a relatively compact size. Still comparing it to the Raspberry Pi Zero W, the Raspberry Pi 4 is quite large and it is also over three times as expensive. Both devices aren't going to break the bank at $10 and $35, but it was just another factor in our decision-making. As we put many different components on top of this doggy door we wanted to try and keep all footprints as small as we can possibly keep them.

E. Camera

The camera of choice is the raspberry pi's signature ArduCAM. It is placed on the side of the doggy door that is directed outside. It will be used to take pictures of when the dog exits and send them to the owner. This is to give the owners peace of mind knowing and seeing when their dogs exit through the door. It will also be used to indicate when wild animals are outside of the door so the owners know to not allow their dogs to exit at that time. Operating at a voltage of 5V, the ArduCAM will require a maximum current of 260mA. This indicates a maximum power consumption of 1.3 Watts.

F. Motion Sensor

A motion sensor is attached to the front of each side of the doggy door. This will allow for the door to detect motion and activate the camera to take pictures. The sensor is a peripheral for the raspberry pi, requiring the 3.3V HIGH signal from the Pi's GPIO pin. Drawing a low current of about 65mA, these two devices pose no issue with power consumption, requiring only 0.65 Watts at a maximum.

G. Buzzer

The buzzer is contained in the housing unit on top of the doggy door. It will be used to indicate to the dogs when they are allowed to enter or exit through the door in an attempt to teach the dogs when they can use the door. Since the buzzer is contained inside the wooden box on top of the doggy door that houses other hardware components, the buzzer had to be loud enough for the dogs to be able to hear it throughout the house but not too loud that it scares the dogs. For this reason, the requirement specification for the buzzer that we achieved was for the sound pressure of the buzzer to be between 70 dB and 90 dB. We found that this is the perfect range for the buzzer because this is a range that is commonly found in dog kennels as seen in [1], and will not damage the dog's hearing while also achieving the sound pressure loud enough to be heard throughout the house.

H. Battery

The TalentCell 12V 3000mAh battery pack is capable of providing a 12V output, reliably sustaining a constant 3A current over the course of an hour. Included with a female to two male splitter, the external rechargeable battery has a barrel jack output 12V input/output port, allowing for simultaneous charging and delivering of power. The battery also contains a 5V USB output port. In addition to these features, there is a row of LED lights, indicating the charge left on the battery.

I. Locking Mechanism

The locking mechanism consists of three parts that were all designed using AutoCAD and then 3D printed. The entire locking mechanism will be housed in a compartment on each of the sides of the doggy door. This will prevent the locking mechanism from being tampered with and damaged. The three different mechanisms consist of a locking pin, a shaft to hold the locking pins, and a knob that is attached to the polycarbonate door flap and will push the locking pins up when being opened. The locking pins are a rectangular prism with the end slanted to allow the force of the knob to push up on the slant and push up the pin. Each shaft has two holes for a pair of locking pins to sit inside of them. While in the shaft, the locking pins will both have the slant side facing away from each other. This is done so that when the knob slides underneath the slanted part of the pin, it will immediately come in contact with the flat part of the next pin and lock the doggy door. In total the locking mechanism consists of four locking pins, two shafts, and two knobs.

J. Solenoids

The locking mechanism also consists of solenoids that will be attached to the top of each locking pin and will be used to raise the locking pin when the dog wants to exit through the door. Only two of the solenoids will work at any given time to allow the door to only work in one direction at a time. This was done to prevent any wild animals from coming inside after the dog exited through the door. When the solenoids are not active they will remain down and keep the door locked. Once the solenoids are given power, they will pull the locking pin upwards and remain up for two seconds to give the dog enough time to exit through the doggy door.

IV. System Concept

In order to approach such an ambitious project in a limited amount of time, a conceptual view of the project needed to be made. From the intricacies of what electronics were needed to the contents of the software, everything was accounted for in advance. All interactions, ranging from the software to the hardware between themselves and each other, are analyzed in this section.

A. Overall Design Concept

First, our system needed several different forms of communication. The system needed a way to handle animal collars. To process the data from the collars, a UART connection had to be established between the reader to the Raspberry Pi. After processing the collars, data had to be sent to and from a database. A mobile application was also implemented for the user to be able to retrieve user-specific information from the database. Because this system had several high power components, a custom power supply had to be designed as well.

B. Hardware Block Diagram & Explanation

From the beginning a block diagram for the hardware needed to be created in order to understand the electrical interactions in this embedded project. The design would consist of some sort of transmitter/receiver. Early on, RFID was the method of communication established. The transmitter/receiver would communicate to a system controller capable of connecting to wifi and containing a means of storage.

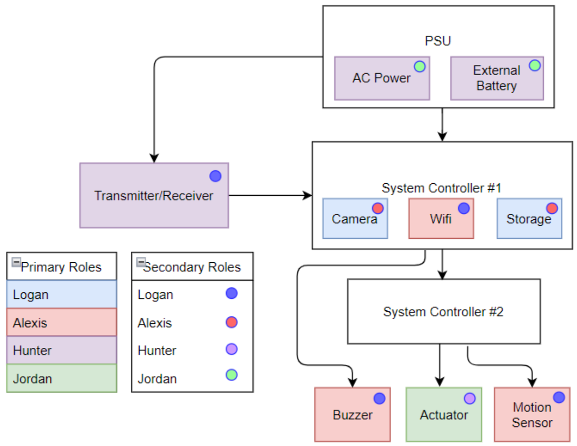


Fig 2: Hardware Block Diagram

This system controller is essentially the brains of the project. Connecting to wifi, the controller has the ability to provide the user with information such as weather updates. It is also compatible with a camera whose images would be uploaded to the database. Once the controller receives the proper signal, it responds accordingly by delivering power to a circuit in charge of facilitating the actuation which will subsequently unlock the door. This proper signal will also sound the buzzer, indicating the successful RFID interaction. In order to ensure the camera picks up the image desired (the pet as opposed to a stray animal), the controller makes use of a motion sensor. Once the motion sensor and RFID are triggered simultaneously, the controller will initiate a command to the camera, which will upload its picture to the database.

Like any electronic application, the project needed a source of power. There were several designs that the team considered. A wall plug seemed to be the best choice in terms of power, considering every home has a wall outlet, and the power delivered would be more than sufficient for the application. In addition to this, a wall-powered design requires no charging or replacing of batteries. However, powering the project in this manner raised concern regarding a somewhat common occurrence: Power outages. In the instance of a power outage, there are too many undesired outcomes and risks. In order to mitigate these concerns, an external battery was included in the design, where, in the event of a power outage, the system would remain operational.

C. Software Block Diagram & Explanation

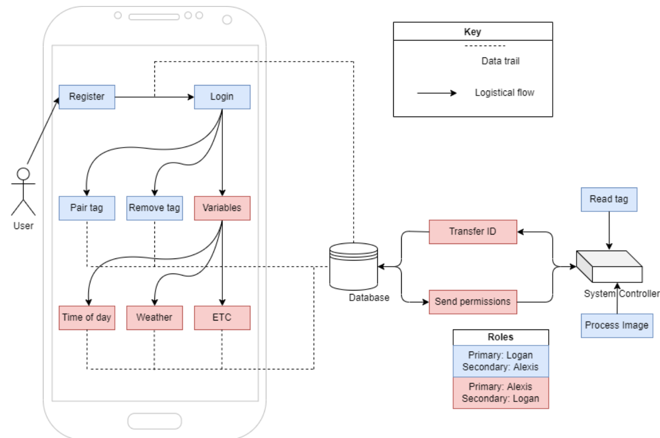


Fig 3: Software Block Diagram

Before writing software, we needed an overall structure. In software development, it is common to have different prototypes to use as a rough reference for how the end result of the written software should look. Our first pseudocode came in the form of a software diagram where we visually laid out the flow of our mobile application interfacing with the database and system controller.

Being laid out from left to right we see the correct order of how a user navigates our project. Starting with the mobile application they can register their own personal account where they will have all their information. After registering and logging in, they have the option to add as many pets to their door as they want. With each pet, they register they can change the variables/permissions that each one has. As shown in the diagram, all of these steps are to be communicated with the database which passes it onto the system controller per its request.

V. Hardware Details

The amount of hardware in this design requires a detailed analysis. The core components of the project are discussed in this section, outlining technicalities of its embedded nature. Content involving the two PCBs that the team custom designed, the RFID components (reader and antenna), as well as the integration process, will also be discussed.

B. Reader & Antenna

For the reader and antenna setup, the frequency band that the team will be operating in is ultra-high frequency (UHF). Operation in this band typically lies between 860MHz and 960MHz. By using such a high frequency, long-term exposure to radiation needs to be taken into account. The datasheet of the onboard antenna specifies that the power density at a distance of 21cm, an antenna gain of 8.15dBi, and an operating power of 27dBm, is 7.35W/m^2 [2, p. 63]. The antenna gain the team used was 5.5dBi and the required distance for the reader's setup was also 21cm. Using (1), a new power density could be calculated. Keeping the new power density lower than the original value by only decreasing the antenna gain, long term exposure to radiation was no longer an issue.

$$Power\ Density = \frac{P \times G}{4 \times \pi \times D^2} \qquad (1)$$

A. PCB Design

The team designed a power supply to meet the Senior Design's PCB requirement. We decided to power through a wall outlet, requiring an AC to DC converter; specifically, we needed a 12V output from our power supply. The converter we chose supplies a 78 Watt output power, meaning that it is able to supply a maximum of 6.5 Amps.

The design is quite involved; the power supply built by the team is a flyback controller. It includes a mutually coupled inductor pair in order to achieve voltage isolation for extra efficiency and safety. Safety precautions were the first priority in the process of this project. The converter also includes a pulse width modulator (PWM). This driver chip controls the high power MOSFET which delivers high currents to the transformer.

Considering the fact that the entire project is powered through this PCB, maintaining a constant voltage is crucial. Various coupling capacitors are placed throughout the design in order to ensure this clear signal to the output, mainly at the output of the step-down transformer, preventing any complications with subsequent power delivery.

The second PC we designed, seen in Fig. 5, was in charge of driving the actuation of the solenoids, as well as a general wire management board. The board consists of an ATmega328P, powered by the 5V rail

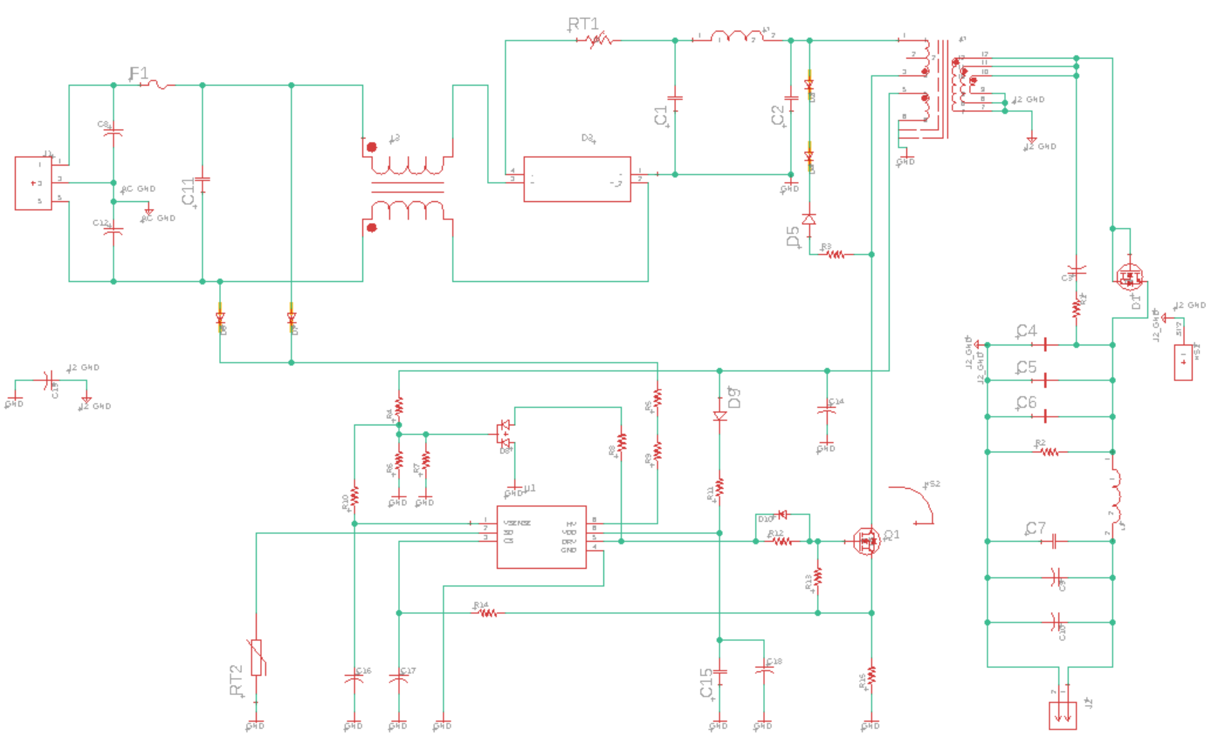


Figure 4: 120 VAC to 12VDC power supply schematic

located on the PCB. It is routed to receive inputs from the Raspberry Pi to excite the gate of two MOSFETs, activating the driver circuit, where each pair corresponds to two solenoids. Multiple other I/O ports are used for voltage rails and Pi pinouts. The 12V rail will have one pair of input ports which will be utilized by the 12V power supply PCB. The other 12V pinouts are used to power the solenoids The 5V rail I/O ports connect step-down converter, the Raspberry Pi, the voltage regulator, and the motion sensors.

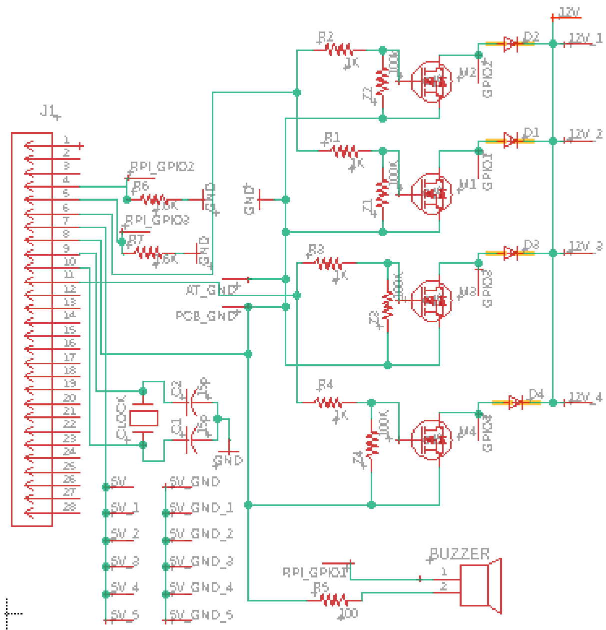


Fig. 5: Solenoid Driver PCB Schematic

C. *Door Design Layout / Integration*

For this project, the layout of where all the hardware components were placed was very important to ensure nothing was damaged, especially with dogs going through the door multiple times a day. The locking mechanism, as well as the solenoids, are housed in a compartment on each side of the door. A panel was used to cover these compartments to ensure a secure enclosure. The majority of the remaining hardware components sit on the roof of the doggy door with a box enclosure around it to prevent it from being damaged. This includes both PCBs, the reader, Raspberry Pi Zero W, the buzzer, and the step-down regulator and converter. The antenna is also enclosed in the box on the bottom of the housing unit. This was done to get the maximum read range around the door flap. The only components that are exposed to the outside of the doggy door are the motion sensor and camera. This is done to give a clear pathway for the sensor to pick up motion and allow the camera to take pictures outside of the door.

VI. Software Details

The project requires a large quantity of components. Each of these parts needs to interface with one another. Therefore, software was vital in making our design function properly. In this section, we will be giving a brief overview of how the software was laid out and constructed.

A. *Mobile Application*

A mobile application was created using React Native and is available on both Android and Apple. From their own devices, the user can view all animals registered to the doggy door. Additionally, the user can view images taken by the camera peripheral within the last 24 hours. In addition to this, they also have the ability to change permissions individually for each animal, edit dog information, as well as remove animals from the database.

B. *Backend*

The software of the system was written in Python on the Pi and uses the Firebase Python library to be able to make quick and easy API calls to the database.

Initially, the code will start off by checking the serial number of the Pi to cross-reference with the database and establish a connection to the user. Through the implementation of event listeners, changes made to the database are stored in a local cache. If the internet goes out, the local cache acts as a replacement for Firebase, allowing continual door operation Finally, all the GPIO interrupts are added to be ready for when motion is detected or when the button is pressed to add a tag. This partial run through of the initial setup is always run when the Pi turns on and finishes off in a never ending while loop so all the listeners and interrupts are kept active until the door is unplugged.

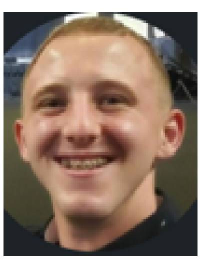
VII. Conclusion

This project was the largest, team-oriented project that any one of us has accomplished. Throughout the two semesters, not only did each of the members apply skills they have learned through previous coursework but many new skills were acquired as well. However, this is not to say the project did not introduce some of its own challenges. The largest issues that persisted throughout all of Senior Design were the effects of COVID-19 and the chip shortage. Parts for our PCB were difficult to come by and shipping times were extended. Another issue was that a lot of parts for our PCB were no longer being manufactured. For some parts, we had to find replacement components. One part, in particular, a transformer, had to be specially made for our PCB. Another part had a broken pin which led to unpredictable results and many hours of testing. Despite these issues, we were able to complete a successful project that utilized the following: RFID, Wi-Fi, motion sensors, a camera, and more.

VIII. Acknowledgements

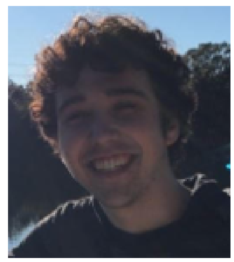
Thank you, Dr. Wei and Dr. Richie. Thank you Dr. Chan for mentoring us throughout this project and providing much valuable insight. Thank you Renco Electronics for specially manufacturing a transformer for us that was obsolete.

IX. Biography

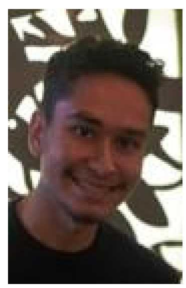


Logan Waln is attending the University of Central Florida and will be receiving his Bachelor's of Science in Computer Engineering upon the completion of his degree in May 2022. His love for technology started with the game of Minecraft back as a little kid and has since expanded to the field of Embedded 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.

X. References

[1] M. Garvey, J. Stella, and C. Croney, "Auditory stress: Implications for kenneled dog welfare," Purdue Extention, pp. 1, Dec-2016.

[2] Jadak, "THINGMAGIC NANO USER GUIDE", M6E-NANO datasheet, Mar. 2015 [Revised Sept. 2018].