Magic Doors

Design Document

sddec20-18

Daji Qiao (ECpE, ISU)

Daji Qiao

Mitchell Bratina [Project Plans Engineer]

Calvin Christensen [Engineering Activities Director]

Isaiah Exley-Schuman [Report Manager]

Collin Kauth-Fisher [Team Engineer]

Joseph Kueny [Meeting Facilitator]

sddec20-18@iastate.edu

sddec20-18.sd.ece.iastate.edu

Revised: February 20, 2020

Executive Summary

Development Standards & Practices Used

Hardware

- Enclosure must have an IP rating of IP20 (protection against finger intrusion)
- Device must remain operational within parameters when subject to temperatures between -10C and 40C
- All wireless transmission/reception will comply with FCC laws
- Base station hardware will be primarily PCB based

Software

- Code shall not contain more than one statement in any given line
- Code shall not implement 1 character variable names except in iterative loops
- Code shall not contain lines of length more than 100 characters
- Code shall follow consistent use of variable naming schemes
    - e.g., camelcase
- Code thall not ignore exceptions
- Each nested block shall be indented more than the previous block

Summary of Requirements

- One base station module and one door module will be designed and physically implemented
- The base station module will interface with a phone application and the door module
- The base station module will notify the phone user when the door has opened, as determined by the system
- The door module will not be powered by battery or by wire
- The system must accurately report "door open" status 99% of the time, and "door closed" status 95% of the time
- The door module must cost less than $70 to produce
- Door module must weigh less than 1 pound and be less than 6"x6" when installed

- Base station must identify door status up to 30' away line of sight, or 10' away through a wall
- System must notify phone user of a door opening within 1 second of the event
    - Must implement a disarming system
- Reporting of door events must be wireless
- Total system cost must be less than $300

Applicable Courses from Iowa State University Curriculum

• CPRE 185

• CPRE 288

• CPRE 489

• EE 201

• EE 230

• EE 311

New Skills/Knowledge acquired that was not taught in courses

• RF Harvesting

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

Current Parts List

Item Number	Manufacturer Part #	Digi-Key Number (If applicable)	Description	Cost in USD	Quantity
0	ATTINY85-20PU	ATTINY85-20PU-ND	IC MCU 8BIT 8KB FLASH 8DIP	1.20	3
1	DK-6R3D105T	604-1018-ND	CAP 1F -20% +80% 6.3V T/H	4.27	1
2	KR-5R5C104-R	283-2806-ND	CAP 100MF -20% +80% 5.5V T/H	3.17	1
3	KR-5R5V474-R	283-2815-ND	CAP 470MF -20% +80% 5.5V T/H	5.53	1
4	PHV-5R4H155-R	283-4206-ND	CAP 1.5F -10% +30% 5.4V T/H	10.65	1
5	MX-FS-03V	-	HiLetgo 315Mhz RF Transmitter and Receiver Module	4.69	1
6	PGM-11801	1568-1079-ND	TINY AVR PROGRAMMER	16.25	1
7	-	-	ESP-32S Development Board	7.50	2
			Total Cost	$59.56	

1 Introduction

1.1 Acknowledgement

If a client, an organization, or an individual has contributed or will contribute significant assistance in the form of technical advice, equipment, financial aid, etc, an acknowledgement of this contribution shall be included in a separate section of the project plan.

1.2 Problem and Project Statement

General Problem Statement

Currently, self-installable home security systems (i.e., Ring ™) utilize many door and window sensors to determine whether those doors or windows are open. These sensors generally report (over wifi) back to a base station that gathers all the state information about the sensors and reports it to a user's device, such as a phone. These sensors require a battery to operate causing the user to replace the battery when it dies. This means that the user cannot "set and forget" his security system. If a user forgets to replace a battery in any one of the sensors in their home, it compromises the integrity of the security system.

General Solution Approach

Our team wants to create a self-installable home security system that does not require any batteries or wires to be used with the sensors. We plan to do this by utilizing RF harvesting so that the devices will be able to be constantly charging. This would remove the requirement of the user to replace batteries and would increase the integrity of the security system. By the end of this project, we hope to produce a base station and a door sensor proof-of-concept. This door sensor will be able to consistently run, while meeting our previously specified requirements, without any sort of battery or wired power. It will also send its status (door open or door closed) to the base station wirelessly. We also plan to utilize CSI (channel state information) using Wi-Fi so that we can have a second source checking the state of the door. This will increase accuracy of our readings.

1.3 Operational Environment

Because our sensors and base station will be within the home, they will not need to withstand many of the so-called "elements." The door sensors will likely be mounted to exterior doors, and the window sensors to exterior windows, so they will be made to withstand a reasonable range of temperatures. They will be charged using RF harvesting and will send their state data wirelessly. The modern home is full of signals of different frequencies, we will need to find ideal frequencies on which to operate our devices. One challenge of CSI is that we will have to make sure natural movements within the home do not interfere with the signals being read.

Another aspect that we will keep in mind throughout our project is the fact that these devices will be within the home, so they should be beautiful looking tech, or at least not displeasing to look at.

1.4 Requirements

Physical

One base station module and one door module will be designed and physically implemented

Door module must weigh less than 1 pound and be less than 6"x6" when installed

Functional

Must implement a disarming system

Reporting of door events must be wireless

Base station must identify door status up to 30' away line of sight, or 10' away through a wall

The base station module will interface with a phone application and the door module

The base station module will notify the phone user when the door has opened, as determined by the system

The door module will not be powered by battery or by wire

The system must accurately report "door open" status 99% of the time, and "door closed" status 95% of the time

System must notify phone user of a door opening within 1 second of the event

Financial

Total system cost must be less than $300

The door module must cost less than $70 to produce

1.5 Intended Users and Uses

Our end user base has the potential to be very large. Essentially anyone who wants to protect their home and possessions can use our security system. Because our devices will be designed with a certain placement in mind (i.e. door sensors), the uses will be very specific to how we design them.

1.6 Assumptions and Limitations

Assumptions

- The sensors will be used indoors
- There will be a readily available powersource for the base station
- The house will have wifi so that the base station can communicate statuses to users' phones

Limitations

- The base station must accept a wall outlet rated at 120 volts because this is the most common voltage
- May not have many sensors on one base station
- RF harvesting doesn't provide much power

1.7 Expected End Product and Deliverables

Our end product deliverable will include: one base station (including power cord), one sensor (additional can be purchased), a free downloadable app, and one user manual.

One base station (including power cord): The base station will be set in an area of the home near the door(s) of interest that also has Wi-Fi signal. It will receive state information about the doors from the door sensors wirelessly. The base station will then upload the information from any sensors to a server and an app on the user's phone will retrieve the information and notify the user if necessary.

One sensor: The sensor will be placed upon the door of interest to the user (while utilizing instructions contained in the manual). Once placed, the door sensor will report the open or closed state of the door back to the base station. As a final product, this sensor would also be compatible with windows, but as a proof of concept only a door module will be sufficient.

Free downloadable app: The app will be available on the mainstream app stores (GooglePlay ™ , Apple ™ App Store) It will interface with the system, identifying the status of each sensor in real time and implementing the arming and disarming system. The app will have no use outside of the associated hardware.

All of these deliverables will be delivered by december 11th 2020.

2. Specifications and Analysis

2.1 Proposed Approach

We have not tested or tried any methods yet; however, we have two options that we are looking into.

Methods of approaching this problem:

- Using RF Harvesting to power a transmitting circuit.
- Using CSI to detect an antenna position to sense if the door is open or closed.

We had intended to start with the RF Harvesting method by first testing the transmitting and receiving of data between the sensor and the base station. Due to the extenuating circumstances caused by Covid-19, however, we will not be able to meet in person to work on our RF harvesting circuit. We will instead be testing CSI in our own homes. We don't need as advanced parts to test CSI as we do for RF harvesting. We plan to either have one member of the team (who has all the parts) do the RF harvesting testing on his own, or begin testing when we return to school in the fall.

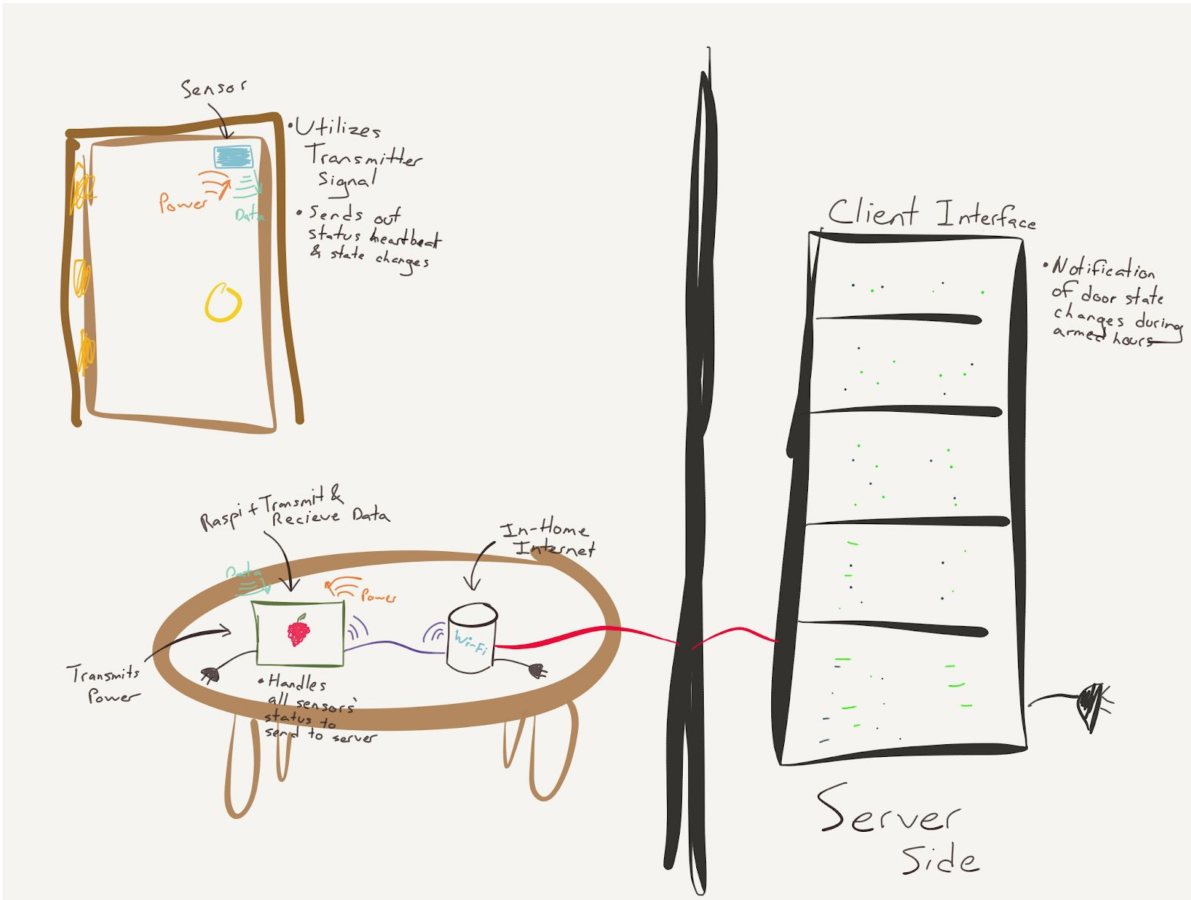
2.2 Design Analysis

We just recently received the last of our parts that we were waiting on, but now we are all stuck in different geographical locations because of Covid-19. We will have to find ways to get RF harvesting parts to one person on our team, and get the CSI parts distributed so we can individually start testing CSI.

2.3 Development Process

Our team will be using the V-Model design process. We believe that this will be the best process for us because we will incrementally have to build new parts upon parts that we have already built. The further we get without testing to be sure we are meeting our requirements and the customers' needs, the further back we will need to go in our process to correct any problems that arise. This means it will be to our benefit to constantly test our parts, prototypes, and product. Because our supervisor is also our client, this will make it easy to have a constant feedback loop on what we are accomplishing.

2.4 Conceptual Sketch



3. Statement of Work

3.1 Previous Work And Literature

There are currently no completely self-sufficient security sensors in the market, but there have been other attempts at remote RF powered devices which we are basing our project on. One such previous attempt was a senior design project from ISU in the fall of 2019. There was a group that tried to collect power from an average home router, but a big problem with it was that the effective distance was only a few inches. This project is not very similar to what we are trying to accomplish, but studying their antenna design may help us with our approach in using CSI.

3.2 Technology Considerations

A strength in our project's technologies that we will be able to play off of is the existence of parts meant for more general tasks similar to what we want to do. There are parts that we have ordered that have been built to assist in RF harvesting and CSI. A weakness we have however is that the restriction on cost is going to require us to be more conservative in what we use. We believe, however, that the parts we have acquired will be able to get the job done. Another weakness in relation to our technology is that our team has not done much in the past with some of the parts with which we will be working. We will have to spend more time learning about these parts.

3.3 Task Decomposition

The task decomposition is only for the current Spring 2020 semester because of our limited access to lab resources due to the Covid-19 response by campus. For the return to campus during the Fall 2020 semester, we will be able to create a task list for our RF approach to the project.

- Get each team member their own ESP32 Development board to work with.
- Learn about signal gathering and sending with the ESP32 chip.
- Develop several rudimentary antenna designs for Wi-Fi reflection.
- Research machine learning to handle the incoming CSI information.

The RF circuit will be further developed when we have regained access to the proper equipment.

3.4 Possible Risks And Risk Management

Cost of the system and power collection abilities will be our most limiting aspects at this point in our project. If the parts that we ordered do not meet our needs, the parts that we would have to purchase instead would most likely be more expensive. This causes us to run the risk of increasing our cost dramatically. The power collection abilities run along with this because, at the moment, this seems like the area that has the highest risk of failure.

Another risk that we run is not meeting some of our originally intended deadlines. Now that we are all separated and have to meet virtually due to Covid-19, it makes it difficult to work on hardware. We run a very high risk of not completing all of our hardware-intensive tasks.

3.5 Project Proposed Milestones and Evaluation Criteria

Three milestones that we have discussed so far are related to the components of our project:

1. Have the ability to read the state of a door (through CSI and/or RF harvesting)
2. Have a base station to receive sensor transmissions, handle the statuses, and relay the information to the server
3. Have a server to handle the interaction between the client and the system

Milestones 1 and 2 will run together when using CSI because the base station will be transmitting signals that will be reflected by the "sensor" on the door to find out the state of the door. This will be easy to verify that it is working because we can simply open and close the door. We will, however, need to be able to sense the door is open correctly 99% of the time and that it is closed correctly 95% of the time (as per our requirements).

When utilizing RF harvesting, milestones 1 and 2 will be able to be more separated. When correctly powered, we can connect directly to the sensor module and check the state of the door that would be sent if we were attempting to transmit wirelessly. Then when we have accomplished milestone 1, we can start transmitting that state information to the base station to complete milestone 2. As will CSI, it should not be difficult to test as long as we keep in mind our requirements.

Milestone 3 will be quite easy to test. Once we have the server up and have created a client application, we just need to make sure the user can reliably get the information from the server using their client device and application.

3.6 Project Tracking Procedures

We will be using GitLab Issues to track progress.

3.7 Expected Results and Validation

The end result will have a break sensor that requires no attached power source with an antenna to aid with CSI, a base station in the home for local arming/disarming, CSI collection, and information relaying, and a server for the client application interfacing. At a high level, we can test the system as a whole by setting up the system in one of our real homes and checking to see that it all works as expected.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

<table>
<tr><th>Week Zero</th><th>Week One</th><th>Week Two</th><th>Week Three</th><th>Week Four</th></tr>
<tr><td>Everyone gets ESP32</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Signal Gathering and Sending</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Antenna Design and Research</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Machine Learning Development & Processed Data Handling</td></tr>
</table>

Our Gantt chart was created to be generic for the time being, because we are not sure when each team member will have the parts to start individual development. Once we have the components, then we will be in Week Zero, and we can start from there. This is our idealistic chart for the rest of the semester, and we do not have a Gantt chart for the upcoming semester because it is unknown what circumstances will be surrounding it.

4.2 Feasibility Assessment

The project will be a prototype of a home security system that does not require intermediate involvement for sustainability. The largest issue with the project is maintaining power to door sensors throughout a house. The other issue we will have is the lack of access to campus resources for half of a semester.

4.3 Personnel Effort Requirements

We are each keeping personal work logs that we can share with submissions of the design document.

4.4 Other Resource Requirements

Physical parts are listed under the tables section after the table of contents. The other required resource is server space.

4.5 Financial Requirements

We have a budget of $500.

5. Testing and Implementation

Unfortunately, we were unable to do much testing for our senior design project. Our group was spread across the Midwest due to COVID-19. Our project is very hardware oriented and it was difficult to do much testing and implementation. The little that our group was able to do is described below.

5.1 Interface Specifications

Our interfacing tests would have been involved the most in the RF circuit. We will need to build the circuit and develop the lowest resource intensive software, so that we can determine the level of RF power we will need to supply the circuit.

The other interfacing test that we will need to complete is the interfacing of the door state calculated by the raspberry pi and the server for client connection.

5.2 Hardware and software

Hardware we required for our testing were a voltmeter and a function generator. These were useful because we needed to be able to charge and discharge our capacitors to find out how it would be able to power our sensors.

5.3 Functional Testing

We have plans to do more functional testing when our group is able to return to Iowa State and can obtain the parts required to build and test our system.

5.4 Non-Functional Testing

We were able to do a slight amount of testing with our capacitors right before leaving Iowa State. We tested how quickly power was released from a capacitor after it was disconnected from a source and were pleasantly surprised to find that it released at a good rate and held a change for longer than expected. This is important to our project because we want to use the capacitor to power a sensor when a door is opened or closed and it will have to be able to be powered up while the door is not in use.

5.5 Process

We currently have not been able to test the parts from Section 2. This will be updated as this changes.

5.6 Results

We have a strong belief that our capacitors will work for our project, but we have not been able to further test this theory.

6. Closing Material

6.1 Conclusion

So far we have researched technologies available for our door sensor design. The options we have come across are CSI and harvested RF powered transmitters. Parts for our first design choice have been ordered and will allow us to measure our power necessities to determine if RF harvesting is a feasible option.

6.2 References

Nothing available at this moment.

6.3 Appendices

Nothing available at this moment.