Fob-Activated Door Lock

ECE 445 Senior Design Lab Project Design Document
Project #29

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1. Introduction

1.1 Problem and Solution:

How many times have you been carrying ten bags of groceries and arrived at a locked front door? You just carried the bags up four flights of stairs because your elevator was out, and now your reward is you get to put all of it on the wet balcony floor outside your apartment building (it just rained), fish your keys out of your pocket or purse, unlock your door, put your keys back in your pocket, pick up your groceries again (hope the eggs aren't smashed), and then finally take your groceries inside. Or worse, what if you need to enter your home as quickly as possible to avoid a potentially dangerous situation outside? A time-consuming or potentially dangerous situation such as these could be solved by a commercial “smart lock” system, however this solution still requires the user to punch in a passcode. This can be equally as time consuming, depending on the length of the passcode and whether the user even inputs it correctly the first time.

Our solution is an inductive charging RFID system that uses a Qi Wireless Charging receiver to open the door lock automatically instead of a traditional key. Imagine the same scenario at your rented apartment, except you arrive at a front door which automatically unlocks with a powered wireless transmitter fob, instead of fumbling with a traditional key or punching in a passcode. When the correct fob tag is detected, a motor would immediately spin to open the deadbolt with a button to re-engage the deadbolt and close the door. There would be no need for any connection to a wall outlet or power source to power the motor in the door. This design would utilize Qi Wireless Charging specifications to power the whole system inside the door including our pcb with the IC chips on it. This requires the use of Li-ion chargers and voltage regulators to convert and step down to the correct voltage supplied to the chips and motor.

1.2 Visual Aid:

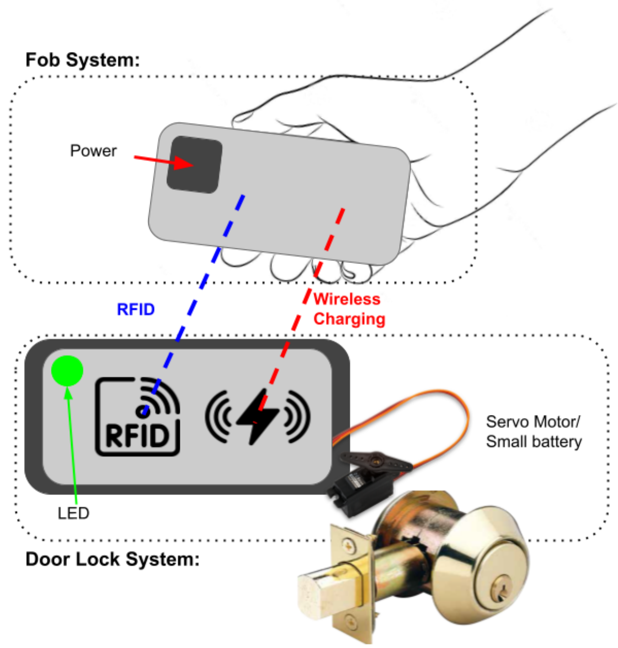

Figure 1: Interaction of the door and fob circuits

1.3 High-Level Requirements:

1. The RFID must match properly between the fob and lock. Success will be indicated by a green LED visible to the user
2. The fob must transfer power to turn the deadbolt within 15 seconds.
3. The deadbolt must continue through its full range of motion even when the fob (and thus the induced current) is removed prematurely by engaging the backup battery in the door.

2. Design

2.1 Block Diagram:

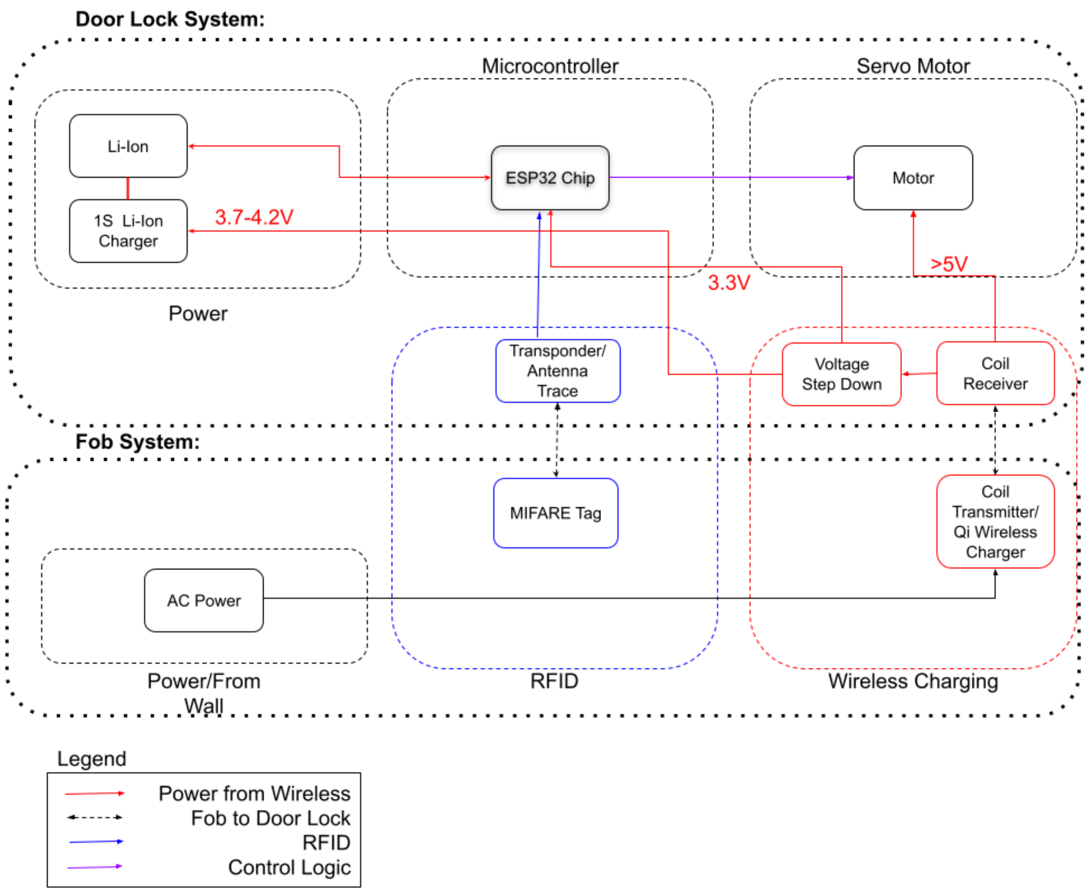

Figure 2: Block Diagram of our Lock and Fob systems

2.2 Physical Design

Our demo will be using the already built door with a deadbolt that is in the 2070 lab. It has already been designed using wood by the machine shop and includes a door frame with a shaft through the deadbolt. Our door lock system will be on a pcb that is connected to the servo motor and mounted using the already built plate.

Figure 3: Our physical door and lock mechanism

2.3 Subsystem Overview:

The Door Lock System and The Fob System will contain each coil of the Wireless Power and RFID in the subsystem. Our solution functions by utilizing these subsystems' wireless capabilities, which requires the necessary chip and transmitters to work. The Door Lock System will not be connected to any external power source such as a wall outlet in the home. The Fob system will have a power subsystem to ensure it can transmit the required charge, RFID signal and power any additional indicator LEDs. The Door Lock system will also require its own power subsystem that could be simply powered by low voltage Lithium ion batteries to ensure proper operation.

2.4 Subsystem Requirements:

2.4.1 RFID/Indicator LED

We will implement an RFID system using an ESP32 chip and the MFRC522 IC in the door lock system. The RFID transponder in the fob does not need any additional active circuitry and supports ISO/IEC 14443 A/MIFARE tags. There will be an RFID transponder in the door which will be powered by the wireless charging (which receives an induced current from the fob).

- We must induce a voltage of at least 3.3 V in the door's circuit when we hold the fob near the door lock so that the ESP32 in the door receives the power it needs to function.
- We also must induce this voltage of 3.3V for the MFRC522 IC which requires no additional active circuitry to communicate with the
- When there is a successful reading of data, a green LED indicator in the door will flash green. This LED will be powered by the door's coil as well, and it will only require about 10 mA of current.

Requirements	Verifications
1. RFID must successfully match within 2 seconds	1. Use Arduino to program the ESP32 using SPI.h and MFRC522.h protocols. Bring coils in close proximity, and upon successful RFID match, print tag's identification number to Arduino's serial monitor.
2. LED Indicator lights upon RFID match	2. In Arduino code, when RFID success is achieved, set LEDPIN to HIGH. Bring coils in close proximity, and ensure that LED lights up when serial monitor prints success.
3. Ensure PCB transmitter coil can transmit signal at exactly 13.56 MHz.	3. Attach positive and negative Multimeter probes to each lead of our coil, measure AC frequency as the RFID program runs. Confirm the frequency is 13.56 MHz.

2.4.2 Wireless Charging

This is the subsystem that is responsible for powering the majority of the circuit in the door lock system. This includes the servo motor, the Lithium Ion battery, the ESP32 chip, and the RFID success indicator LED. In the moment that the fob is brought into close proximity to the door lock, the coil must induce an alternating current using Faraday's Law in the coil in its sister coil in the door lock mechanism.

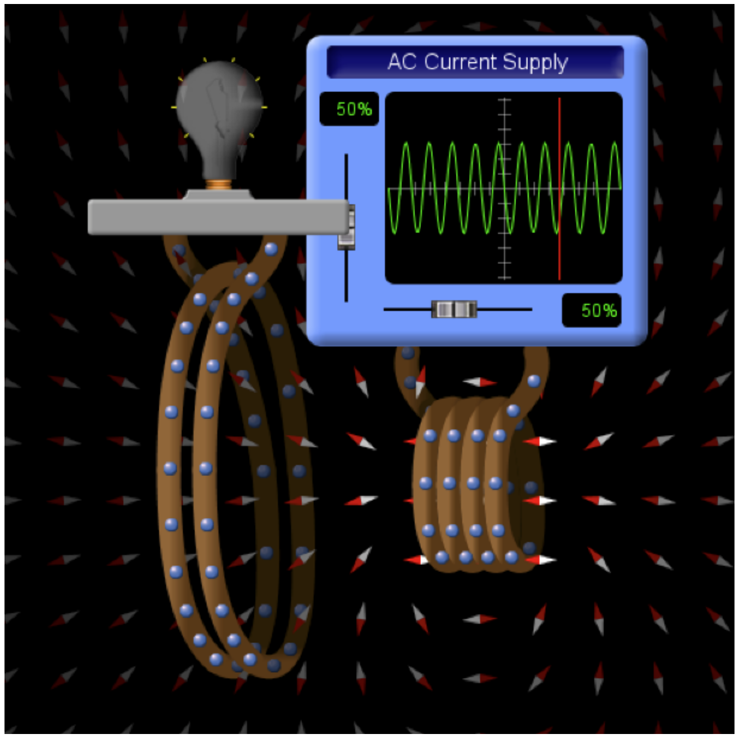

Figure 4: Simulation of Faraday's Law

In figure 4, it is shown how in our design the off the shelf wireless charger can wirelessly provide a voltage to the rest of our system. We will follow the specifications put by the Wireless Power Consortium[1] to ensure that our receiver module will function with an off the shelf transmitter. Some of these specifications include, the amount of turns of the coil that are specified and the physical dimensions that are required to transfer power.

- The standard servo motor we are considering for the deadbolt has an average operating voltage of around 5V.
- The LED requires about 0.7V.

This is manageable assuming these systems will be wired in parallel and we will be using a voltage regulator as necessary. Any leftover current will be discharged by the capacitor and rechargeable 1S Li-ion battery, which are used to power the servo motor in the case that the power from the fob is interrupted before the deadbolt achieves its full range of motion. The 9V battery's output can be manipulated to find the most efficient voltage that will power the wireless charging system to be operational.

[1] See References 7

Requirements	Verifications
1. The coil must induce an alternating current using Faraday's Law when the fob is in close proximity.	1. Measure the induced current in the coil using an oscilloscope. a. Measure the induced current in the coil using an oscilloscope, ensuring that the current waveform is alternating as per Faraday's Law.
2. The wireless charger must provide a voltage of 5V to power the system wirelessly.	2. Connect the output of the wireless charger to the VDD node in the test circuit. a. Measure the voltage output from the wireless charger using a multimeter, ensuring that the voltage is within the specified range for wireless charging.
3. The servo motor must operate at around 5V.	3. Power on the servo motor. a. Measure the voltage supplied by the coil to the servo motor during operation using a multimeter, ensuring that the voltage stays within 5% of 5V.
4. The LED must operate at around 0.7V.	4. Measure the voltage across the LED using a multimeter, ensuring that the voltage is within 5% of 0.7V.
5. The internal resistance of the coil is 72 mOh.	5. Disconnect the coil from any power source. a. Measure the resistance of the coil using a multimeter, ensuring that the resistance is within 5% of 72 mOh.
6. A 9V battery must power the coil to supply sufficient current.	6. Measure the current supplied by the 9V battery to the coil using a multimeter, ensuring that the current is within the specified range for optimal operation.
7. Leftover current must be discharged by the capacitor and rechargeable 1S Li-ion battery.	7. Interrupt the power from the fob before the deadbolt achieves its full range of motion.

	a. Measure the voltage across the capacitor and battery during operation using a multimeter, ensuring that they are discharging the leftover current effectively.

2.4.3 Microcontroller

The ESP32, shown in Figure 4, is a Wi-Fi and Bluetooth combination chip that has applications useful to the RFID side of our design. It has a typical operating voltage of 3.3V which will be provided by our wireless power coil design. It will also be able to logically control the motor to the specifications we program it with, as well as activate the LED indicator upon a successful RFID match. The ESP32 chip will communicate[2] with the MFRC522 chip using the SPI.h and MFRC522.h libraries.

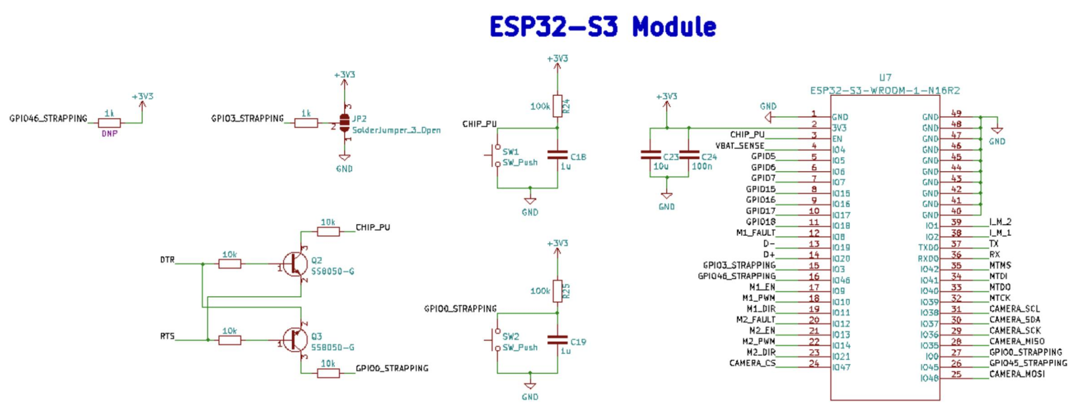

Figure 5: ESP32 Circuit

2.4.5 Servo Motor

This motor turns within the supplied voltage that is given by the wireless charging receiver as well as the lithium-ion battery in the door, which is only used when the fob (and thus the induced current) is removed prematurely. This motor is

[2] See References 2

part of the door's circuit and is responsible for moving the deadbolt through its full range of motion. It only engages upon the success of the RFID system. The servo motor which we will use has an operating voltage of 5 V.

Requirements	Verification
1. Operates at a 5V voltage supplied by the wireless receiver coil that turns over the motor 2. Runs smoothly in between the range from the minimum 4.8V-6V using the voltage regulator and Li-ion	1. Connect the output of the voltage regulator and charger which is supplied by the wireless transmitter coil to verify that motor will reach turn over voltage to start turning 2. Measure voltage across the motor using an oscilloscope and compare this voltage to the measured voltage over the 1S Li-ion battery to ensure the motor can utilize the extra voltage supplied.

2.4.6 Door Battery

We are planning to have a small rechargeable 3.6 V 1S Li-ion battery in the door lock system along with an electrolytic capacitor. This is to account for the case where the wireless charging subsystem gets powered partially by the fob but not enough to power the chip and motor system, or the case that the power from the fob is interrupted before the deadbolt achieves its full range of motion. This battery will be charged by the wireless charging receiver coil in the door.

3. Tolerance Analysis

The aspect of our design that poses the most critical risk to our success is the wireless charging subsystem. If we cannot induce enough current to produce the required voltage in the door's circuit, the ESP32 and MFRC522 chips will not work, the motor will not turn, and the battery in the door will not get recharged. The ESP32 and MFRC522 chips require 3.3V each, the lithium ion battery requires 3.6 V to charge, the LED requires 0.2 V, and the motor requires a voltage of 5 V. If all these components are in parallel, that means our door circuit will need to receive 5 V from the wireless charging receiver coil in the door. Since our wireless charging coil produces an output of 4.8 - 5.2 V, we will use the lithium ion battery to ensure that the voltage output from the receiver coil is a constant 5 V.

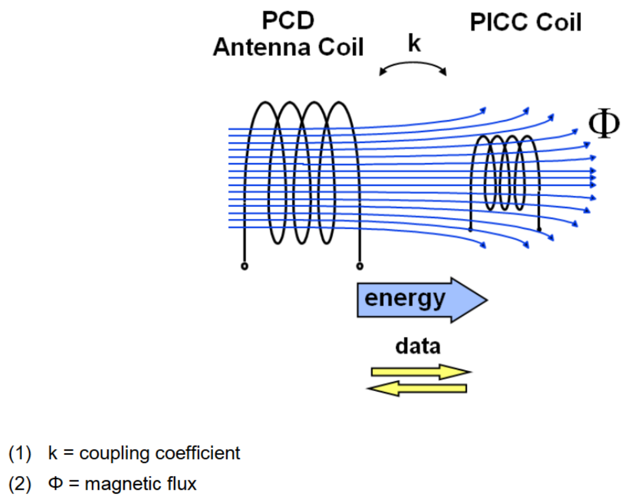

Figure 6. Tolerance of Wireless Power for 5V output

Starting with the wireless power transmitter from the Fob system, we plan to use an off the shelf Qi compliant wireless charger that will supply the minimum required 5V. According to the Wireless Power Consortium[3], a standard coil has 14 turns.

4.1 Cost Analysis

Parts Analysis:

Part	**Price**	**Link**
ESP 32	$10	ECEB Supply Center
Servo Motor HS-318	$13.54	ECEB Supply Center
RFID Reader	$5	https://www.digikey.com/en/products/detail/melexis-technologies-nv/MLX90109EDC-AAA-000-RE/1647934
RFID Tag	$0.99	https://www.digikey.com/en/products/detail/parall

[3] See References 7

		ax-inc/28141/17 74533
Lithium Ion Battery	$27	https://www.digikey.com/en/products/detail/jauch-quartz/LI18650JP1S2P-PCM-2-WIRES-70MM/9560969
MFRC522	$7.11	https://www.mouser.com/ProductDetail/NXP-Semiconductors/MFRC52202HN1115?qs=cbprxTG2Yq%2F%252BkR%2FEgMbBLA%3D%3D
MIFARE RFID Tag 13.56 MHz	$11.58	https://www.amazon.com/MIFARE-Classic-13-56MHZ-Black-Color/dp/B07CFWB68R/ref=asc_df_B07CFWB68R/?tag=hyprod-20&linkCode=df0&hvadid=521005456057&hvpos=&hvnetw=g&hvrand=14506144509379374157&hvpone=&hvptwo=&hvqmt=&hvdev=t&hvdvcmdl=&hvlocint=&hvlocphy=9022185&hvtargid=pla-1346192226361&psc=1
Wireless Power Receiver IC		
Electrolytic Capacitor		
DEVBOARD	—	
RC522	$5.52	https://www.digikey.com/en/products/detail/sunfounder/CN0090/18668629
Arduino UNO DIP	$25.44	ECEB Supply Center
Qi Wireless Receiver Module	$14.95	https://www.adafruit.com/product/1901

Total Parts Cost	**$121.13**	

Labor Analysis:

Assumptions:

- A typical graduate from ECE at Illinois makes on average $98,472 per year[4] which for a 40 hour work week, $47.34 per hour.

EE Annual Salary = $76,714
CE Annual Salary = $109,176

$$\frac{76{,}714 + 109{,}176}{2} = \$98,472 \text{ average}$$

- We expect to each spend an average of 12 hours a week working on our project.
- The cost analysis for labor only considers the nine weeks from 9/25 to 11/27

Calculations:

Total Labor Cost = ($47.34/hr) x (12 hrs/week) x (9 weeks) x (3 members) = **$15,338.16**

Grand Total = Total Parts Cost + Total Labor Cost = $15,338.16 + $121.13

Grand Total = $15,459.29

[4] See References 6

4.2 Schedule

Members' names listed under a specific week will continue with their task in the following weeks even if not listed.

Week	Tasks	Member
10/2	Order parts(see Part Analysis)	Max
10/9	KiCad Schematic Created ● ESP32 Module ● RC522 Module ● Wireless Charging Coil ● AC to DC unit	Antonio
10/16	KiCad File PCB Routing	Antonio
	Arduino Dev Board Research	Adam
10/23	Dev Board Arduino Setup / Assembly (Wireless Charging) ● Wireless Receiver Module ● Rip Qi compliant coil from module ● Unit test Li-ion battery component	Adam
	Dev board Arduino Setup / Assembly (RFID) ● RFID success outputs to Arduino terminal ● LED lights up upon success	Max
	Soldering Assembly	Adam and Antonio
10/30	PCB / Unit Testing individual components ● Wireless Charging ● RFID ● Motor	Everyone
11/6	PCB / Unit Testing	Everyone
11/13 (mock demos)	Finalizing Physical Design	Everyone
11/20 (Fall break)	Testing/Debugging	Everyone

11/27 (final demos)	Testing/Debugging	Everyone
12/4 (final presentations)	Testing/Debugging/Presentations	Everyone

5. Ethics and Safety

In terms of ethics and safety, we believe our project is sound in both aspects. In terms of the ethical standpoint, we do not believe that there are any outright violations in the context of the IEEE or ACM code of ethics, however, there are some precautions we will take due to the risk of a security issue. We as a team will be sure to uphold ACM 1.6[5], in regards to privacy and our design for the construction and augmentation of a front door lock. Our team will never use our technology for malicious intent, such as unlawfully entering a residence or monitoring data, including personal information. Our design is only equipped to respond to short-distance authorized fobs that could unlock a door and can never be accessed remotely. There will not be any technology that could collect any information on the status of the door lock or the location of a user.

This project will adhere to IEEE 7.8.II.9[6] in regard to the safety of the moving parts of an electric motor that could cause harm or property damage. We are responsible for the accurate testing and measurement of the torque that the motor will produce when induced with a current from our wireless charging design. This must be designed with caution from an electronic standpoint in order to ensure that our device will not damage an existing deadbolt or a person with misuse of the device. A potential misuse of our device that could cause harm is locking and unlocking the door with any obstructions. As a team, we also are responsible for testing and safety of the excess heat from the wireless charging subsystem. The power transferred wirelessly must be less than the amount to heat up the coil to an unsafe temperature that could lead to user harm.

Overall, we believe that our project is something that mainly achieves an easier lifestyle for the general population and has the same intent as a traditional key and lock system. We will abide by all the IEEE and ACM Code of Ethics by responsibly testing and honestly reporting all information about our design.

[5] See References 5
[6] See References 4

8. References

Bibliography

[1] "ESP32 Series Datasheet." Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

[2] Xukyo, "Using an RFID module with an ESP32 • AranaCorp," *AranaCorp*, May 03, 2021. https://www.aranacorp.com/en/using-an-rfid-module-with-an-esp32/amp/ (accessed Sep. 28, 2023).

[3] "DragonBot RFID PCB Design and SMD Reflow – Arxterra," *Arxterra*. https://www.arxterra.com/dragonbot-rfid-pcb-design-and-smd-reflow/ (accessed Sep. 29, 2023).

[4] IEEE, "IEEE Code of Ethics," *ieee.org*, 2020. https://www.ieee.org/about/corporate/governance/p7-8.html

[5] ACM, "ACM Code of Ethics and Professional Conduct," *Association for Computing Machinery*, Jun. 22, 2018. https://www.acm.org/code-of-ethics

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