ENGINEERING DESIGN PROCESS

Prepared By

Habilou Sanwidi
hss67466@uga.edu

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AUTONOMOUS DOOR

Design Process

Define the Problem

For many of us, the simple action of opening a door is so easy that we don't think about it. However, Individuals with disabilities may find this process difficult. Some of the obstacles could be first getting to the door, unlocking it, opening it and locking it afterwards. Gaining access to doors/entrances will not be my main focus as there exists many solutions to this problem. Instead, I will focus on creating a device to unlock and lock a door. To many people, this is not an issue, but for individuals with disabilities, this step can be a real problem.

Take someone who is disabled from the chest down, for example, using their key to unlock the door may not be an option. Another example would be an individual with impaired vision. Looking further, certain people will not lock their doors either because they forgot or that they find it tedious, which could lead to very expensive consequences.

On the market right now, we can find keyless and fingerprint door locks. A keyless door lock can be convenient because it does not require the user to carry his keys around. You simply enter a password and the door will unlock. Though the keyless lock is convenient, it does have some flaws. For example, keyless door locks can lead to shoulder surfing. Shoulder surfing is a term used for someone who looks over your shoulder while you're typing in your code. This can be a severe security risk. Another flaw of keyless door lock is wear and tear. The user can change their code as much as they like, but as time goes on, dark marks will be left of the buttons, making the numbers or letters difficult to see. Extreme weather is also unfavorable for keyless locks. Ultimately, the biggest downside of the keyless lock is cost. Since it is a new technology, keyless door can be expensive. Fingerprint locks may be a better solution compared to keyless locks, but they also have few downsides, one of them is reliability. Some of the low-quality locks will fail to recognize an authorized user if his fingers are oily or sweaty. But like the keyless lock, the fingerprint locks biggest shortcoming is cost; they are very expensive.

The biggest flaws that these new technologies have in common is their usability for a person with a disability. They both require some kind of physical maneuver. A better door lock will be one that does not require any physical maneuver while still ensuring the security.

A Better Door Lock: Certain door locks, such as the tradition mechanical door lock, or the keyless and fingerprint door locks often require some kind of physical maneuver from the user. For individuals with disabilities, this can be a problem. Design a door lock that allows a person to enter his home without having to perform any action on his way in.

The following is a list of preliminary criteria for a better door lock.

- *The design must require minimal physical maneuver*
- *The design must be functional*
- *The design must be easy to implement*

- *The design must be secure*
- *The design must be reliable*
- *The design must be cheap*

Gather Pertinent Information

The formerly established problem has already been addressed and partial solutions have been found. Companies like August and Lockitron currently have Door locks that require no action from the user in order to unlock a door. Whenever a phone with Bluetooth capability is nearby, these locks will identify its digital key and if it is an authorized user, the door will automatically unlock itself. One problem with the August and Lockitron locks is cost: $200 for an August lock and $179 for a Lockitron lock. Those costs can be improved. Another problem with them is that they are not fully autonomous. They user still need to push in order to open and pull in order to close the door.
There are automatic doors for public buildings, but nothing for residential buildings. They would open whenever it senses something and do not provide any type of security. Certain buildings with card readers would allow authorized personnel to enter. The aim of this project is to create a system that will automatically unlock and open a door for certified users. Currently there isn't a product that fulfills our requirements. When it comes to cost, the objective is a solution that will cost no more than $100. For such a product and cost, it will attract many people.

Generate Multiple Solutions

The solution to our problem can be broken down into 2 major parts:

- Identification (Identify authorized users)
- Execution (lock, unlock, open and close)

There are different methods that could be used in order to identify a user and its distance from the door. We could choose to identify a user by an RFID card or through his phone using Bluetooth or through WI-FI

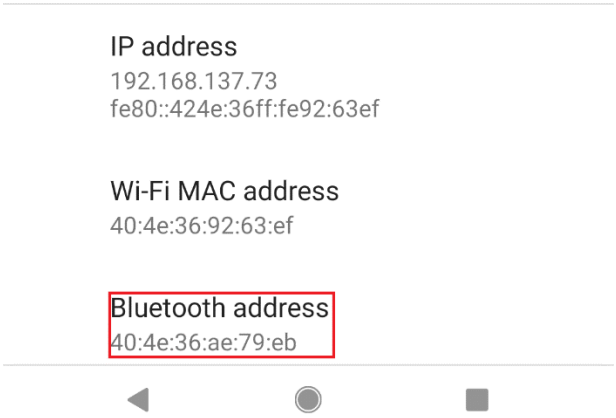
Identification

Bluetooth

Our system can identify a user through his phone. This method involves scanning the area for Bluetooth devices. When a device is within range, our system will identify it using the device's Bluetooth address. Every device with Bluetooth capabilities will have a unique Bluetooth address. To access your phone Bluetooth address:

1. *Go to "Settings"*
2. *Then go to "About Phone"*

Here is an example:



Our system will scan for predetermined addresses. When a device has been found, the system will attempt to establish a connection. With a successful connection, we'll be able to determine an RSSI. The Received Signal Strength Indicator or RSSI is an estimated measure of the power level that a device is receiving when connected to another device (can also be a router or access point). The further the device, the weaker the RSSI. This can give us a rough estimation of the device distance. This method requires that the user's Bluetooth is enabled and made discoverable at in order for our system to find it. The user's address needs to be known by our system and a manual connection is necessary beforehand.

RFID Card

This path will require an RFID card and RFID card reader. Radio Frequency Identification (RFID) uses electromagnetic fields to automatically identify tags which contain electronically stored information. An RFID card is a passive tag which collects energy from a nearby RFID reader's interrogating radio waves ("What Is RFID and How Does RFID Work? - AB&R®."). This method requires the user to scan his card. All tags need to be registered to the system.

RFID Tag

RFID Reader

RFID Reader

Wi-Fi

We can also choose to identify a user when his or her phone connects to the Wi-Fi. This approach requires our system to perpetually scan the network for any new connections. This approach has two major downsides. The first regards iPhone users. Whenever an iPhone device is not in use, its software shuts down all unnecessary activities including Wi-Fi connection. Consequently, our system will not detect an iPhone user until the user accesses his or her device. The other major downside to this approach is that there is no way for our system to determine how far a user is to the door.

Before we can identify and determine a user's distance, we first need to determine a controller that will manage our system. For that we can either use a Raspberry Pi or an Arduino Uno. There are other microcontrollers on the market, but they are just variations of the former two. Raspberry Pis and Arduinos are very popular and great documentations of projects using them can be found online.

Controller

Raspberry Pi 3

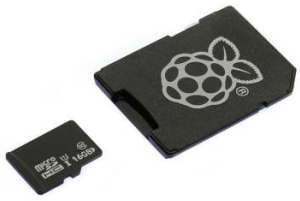
A Raspberry Pi is a low cost, credit-card sized computer. It is capable of performing everything one would expect from a desktop, from word processing and browsing the internet to playing games and streaming high-definition videos. The raspberry pi 3 sports a 1.2 GHz quad-core 64-bit ARM cortex A53. It has built-in Wi-Fi (802.11n Wireless LAN) and Bluetooth 4.1.

Required

- **Raspberry Pi 3**
- **Power Supply**
- **SD Card**

Raspberry PI 3

Power Supply



Micro SD Card

Arduino Uno

The Arduino Uno is an open-source microcontroller board developed by Arduino.cc. The board is equipped with a set of digital and analog input/output pins that can interface with diverse circuits and expansion board (Frost, Sandra L). To use an Arduino for our project, we'll need to acquire a Bluetooth module.

Required

- **Arduino Uno**
- **Power Supply**
- **Bluetooth Module**
-

Arduino Uno

HC-05 Bluetooth Module

Power Supply

Execution

The second part of the solution requires our system to perform two different actions:

- ***Lock & Unlock***
- ***Open & Close***

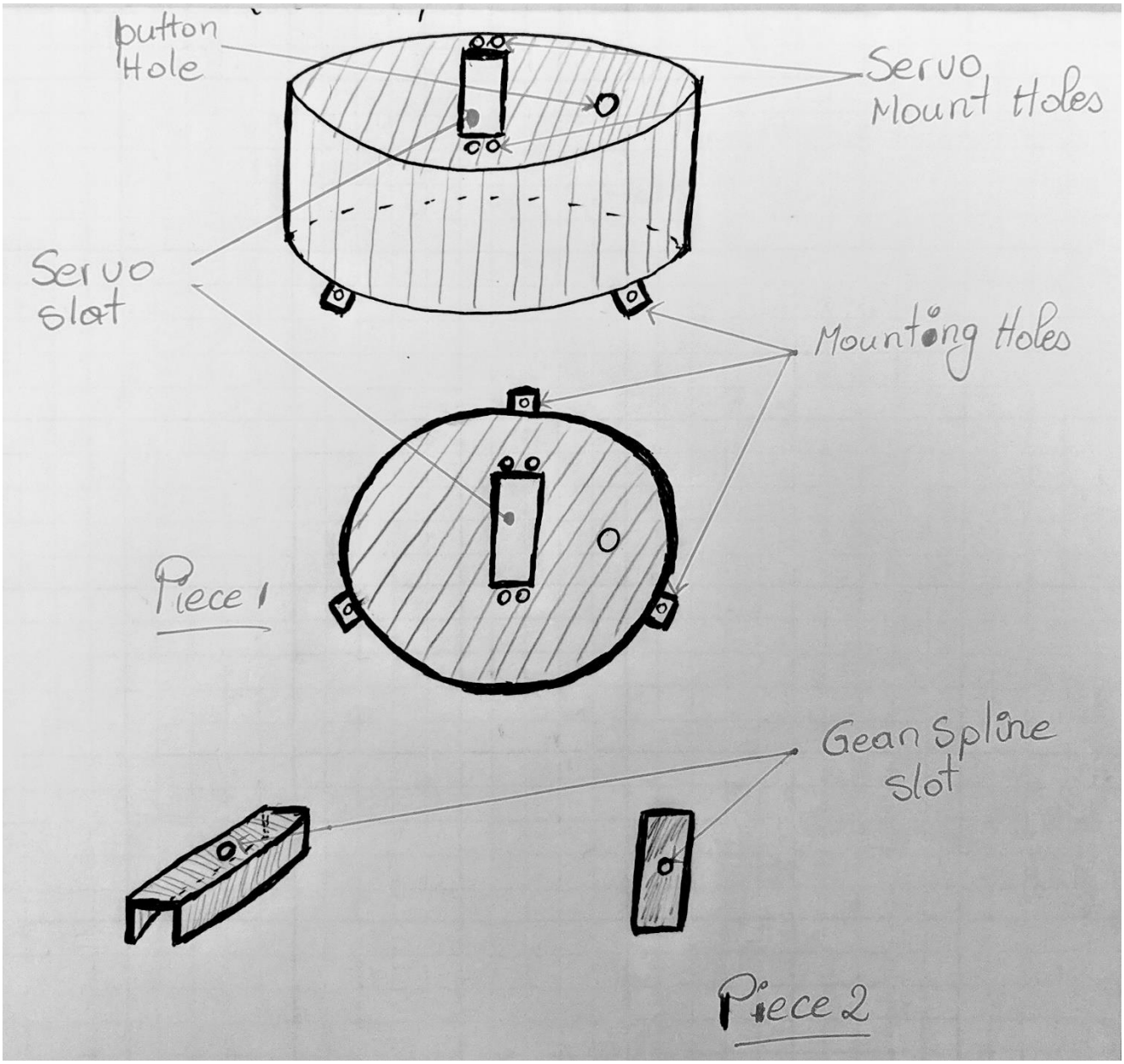
Lock & Unlock

Alternative 1

One option to Lock & Unlock, is to use a servo motor. A servomechanism or servo is an automatic device that incorporates a DC motor, a potentiometer, an integrated circuit and an output shaft. The shaft can be positioned at a specific angle based on the coded signal the servo receives. We'll need a high torque servo to be able to perform our task. The Tower Pro MG995R is a good candidate because it has metal parts and can deliver 8 Kg-cm of torque at 5 volts.

Tower Pro MG995R

To implement this alternative, we'll need to construct 2 pieces. One is needed to hold the servo to the door lock. It should have a cylindrical shape with a length no greater than 5 cm and a radius of 2 mm greater than our door lock. It has 3 mounting holes at the bottom to attach the piece to the door, a slot at the top for the Tower Pro, 4 mounting holes for the servo and a button slot at the top for manual operation (Piece 1). A second piece has a slot for the servo output shaft at the top. The bottom will be constructed to fit the lock knob (Piece 2). We can choose to build the pieces using a 3D-printer or by using wood. The following is a rough illustration of the desired product.



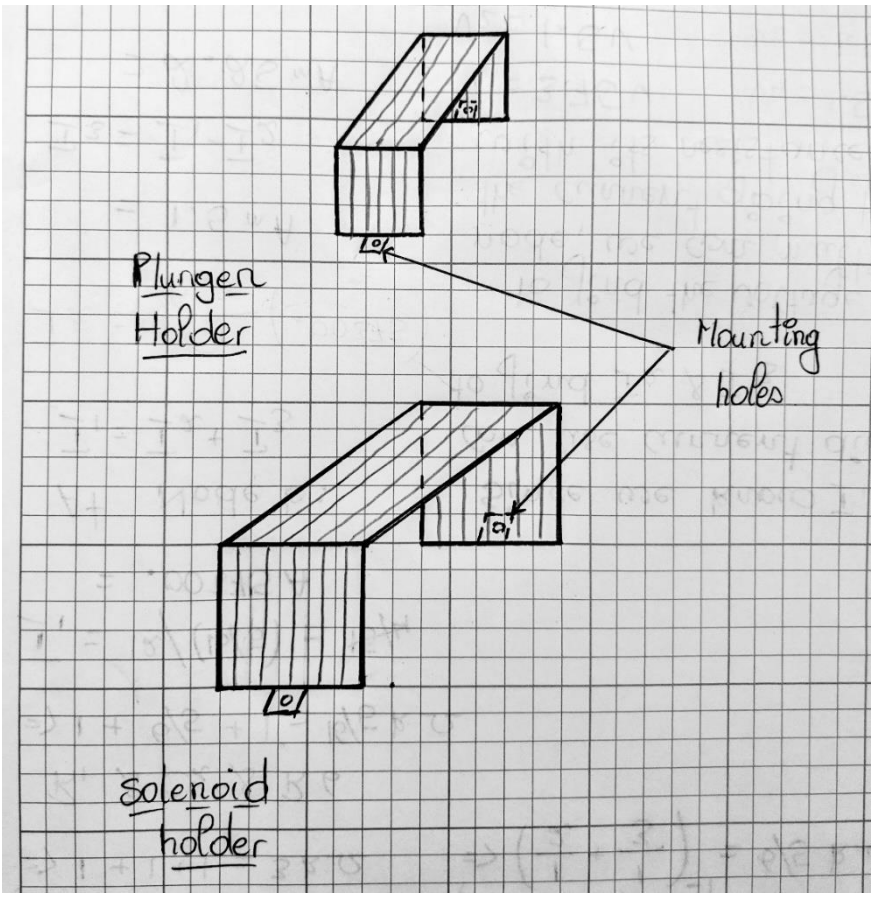
Alternative 2

This alternative requires the construction of a lock. To do so, we'll need a Push Pull solenoid. A solenoid is a device containing a large coil with a plunger going through it. When a large current is delivered to the coil, the plunger is pulled/pushed. The solenoid requires a huge amount of current, therefore we'll need a relay module that basically acts as a mechanical switch to control an external power source.

Relay Board

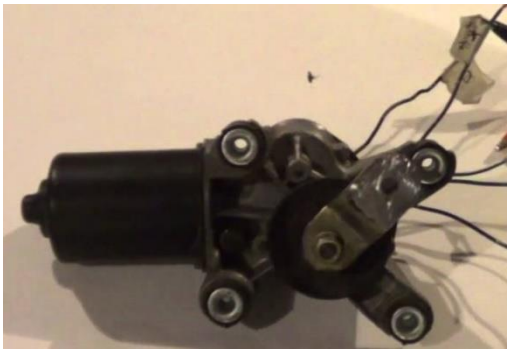
Push Pull Solenoid

This alternative also requires the construction of two pieces; one to hold the solenoid against the door and another similar but slightly smaller piece to hold the plunger to the door frame.



Open & Close

This will require an electric motor. It is very important that the motor has a high torque and a low speed. There is an array of electric motors that fulfill our requirements, but for the purpose of this project, we can recycle an old windshield wiper motor. It has a lot of torque, low speed and very inexpensive. Alongside this piece, we will need a door closer.



Old 2003 Toyota Highlander Windshield Wiper

Door Closer

Analysis of Design Solutions

In this step of the design process, we will analyze each alternative solution against the selection criteria defined in step 1. After a thorough evaluation of the pros and cons of each alternative, you'll decide the best combination of alternatives.

Identification: Bluetooth

Nowadays, cellphones have become a necessity for everyday life. They can be used for many activities such as watching movies, listening to music, reading news and e-mails, social media, shopping etc.…and essentially everyone has one in their pocket. Identifying a user via Bluetooth is a great alternative due to the many advantages it holds.
It is easy to use because it would only require that the user's Bluetooth is enabled and made discoverable. It is functional, reliable and easy to implement. Security would be the only critique worth mentioning about Bluetooth. In case the user loses his phone, anyone with it could gain access to your home, but this security flaw also exists with a mechanical keep. When it comes to cost, we may need to purchase a Bluetooth module (HC-05 $8) if we are to use an Arduino board as the controller but will cost nothing with a raspberry pi.

Identification: WI-FI

Wi-Fi is easy to use but has many flaws, functionality being the first. Through this alternative, we won't be able to determine how far a user is from the door. Typically, when the user is

approaching his or her home, their phone will automatically connect to their router and our system won't be able to access an RSSI. We could overcome this problem by making our controller an access point, but this would be difficult to implement and would require many wires dangling from your door. Everyone knows what it's like to come home and their Wi-Fi is down and that is a major reliability issue with this alternative. It upholds the same security as the Bluetooth alternative. This alternative requires a router, an RJ45 Ethernet cable, a Wi-Fi module (Arduino Uno as the controller) and an Ethernet LAN module (Arduino Uno as the controller).

Identification: RFID

The use of RFID is a functional, reliable and an easy to implement alternative. However, it loses points when it comes to its ease of use. It requires the user to scan his or her card. Ease of use is a crucial factor for this project because we're aiming to create a system that would let the user enter their home with minimal physical movement. This alternative also requires the purchase of an RFID tag and reader. Security is of the same standard as the previous alternatives.

Controller: Arduino Uno

Compared to a raspberry Pi, using an Arduino Uno has many advantages such as low power consumption, easy interfacing with sensors, easy data collection, cost, great online support, open-source, etc.… It is reliable and easy to use, as well as a secure and capable controller for this project. It is cheaper than a Raspberry Pi (Arduino Uno: $22, Raspberry Pi: $35) but requires additional shields for networking.

Controller: Raspberry Pi

Using a Raspberry Pi for our project is a bit of an overkill. It demands more power and a good knowledge of Linux Systems. Nonetheless, using one isn't totally out of the question because it offers more functionalities, more computing power and memory for later development. Using a Raspberry Pi for the implementation of our project will require more work than an Arduino Uno but still it is certainly achievable. It offers great security and reliability.

Execution: Alternative 1

This alternative comes with a few challenges. The required pieces can be tough to create. A good knowledge of 3D-printers or carpentry skills is imperative. One benefit of this alternative is a manual operation. A user can still access his home using a key, making this alternative more reliable. This alternative requires a high torque servo (Tower Pro: $25). The estimated cost of implementation does not include the construction cost (required pieces).

Execution: Alternative 2

The construction required for this alternative is less of a challenge due to the simplicity of the pieces. Simple carpentry will be more than enough. One major difficulty is the fact that the user

will not be able to gain entry to their home without their phone. In such situations, he or she will have to use a back door. A solenoid ($19) and a single channel relay ($8) is required.

Both alternative 1 and 2 offer ease of use from the user's point of view. They are both functional and secure alternatives. For opening and closing the door, the alternative listed above is the most convenient option. A more efficient and better suited motor could be purchased, but a windshield wiper motor is a cheap and a very capable option.

Decision Process

Decision Matrix Evaluating Identification Alternatives

Criteria	Weight (%)	Bluetooth	RFID	Wi-Fi
Ease of use	40	9	5	7
R x Weight		360	200	280
Functionality	20	7	9	3
R x Weight		140	180	60
Implementation	30	9	7	1
R x Weight		270	210	30
Security	10	7	7	7
R x Weight		70	70	70
Reliability	20	8	9	4
R x Weight		160	180	80
Cost	10	9	6	2
R x Weight		90	60	20
Total	**100**	**1090**	**900**	**540**

Decision Matrix Evaluating Controller

Criteria	Weight (%)	Arduino Uno	Raspberry Pi
Ease of use	40	8	7
R x Weight		320	280
Functionality	20	9	9
R x Weight		180	180
Implementation	30	8	7
R x Weight		240	210
Security	10	7	7
R x Weight		70	70
Reliability	20	7	7
R x Weight		140	140
Cost	10	7	8
R x Weight		70	80
Total	**100**	**1020**	**960**

Decision Matrix Evaluating Execution Alternatives

Criteria	Weight (%)	Alternative 1	Alternative 2
Ease of use	40	9	9
R x Weight		360	360
Functionality	20	8	9
R x Weight		160	180
Implementation	30	5	7
R x Weight		150	210
Security	10	7	7
R x Weight		70	70
Reliability	20	8	6
R x Weight		160	120
Cost	10	6	7
R x Weight		60	70
Total	**100**	**960**	**1010**

The combination of Bluetooth, Arduino Uno and Alternative 2 has been determined to be the best design due to the rating assigned for each criterion. Ease of use is the most important criteria and has been assigned a value factor of 40. Implementation comes in second with a value factor of 30. Functionality and reliability both share 20. Since all the alternatives have the same security level, security was assigned a value factor of 10, alongside cost, which was not an important factor.

Test and Implementation

Since we're not building anything yet, this step of our design process will be a reiteration of the chosen design. From the previous steps, the following parts are required for implementation:

- Arduino Uno Rev 3
- Reversible 12V Motor
- Push Pull 12V Solenoid
- HC-05 Bluetooth module
- 24 V DC Power Supply (Solenoid + Motor)
- 24V to 12V – 5V step down converter
- Dual and Single Relay Modules (One of Each)
- USB 2.0 Cable (to program Arduino)
- Door Closer
- Holding Pieces (to be Built)
- Jumper Wires

The cost of acquiring all the necessary parts is $110 (tax excluded).

Connections

Bluetooth to Arduino

Supply 5V to the module using VCC and GND. RXD and TXD will connect respectively to pin 0 and 1 of the Arduino.

Power Converter to Arduino

Supply 5V to the Arduino using the external power supply.

Relay 1 (Single Channel Module)

Supply 5V to Relay 1. Connect one wire from the solenoid to the NC pin (Normally Close) of Relay 1 and the other to the a GND pin of the power supply. The COM pin will be connected to the power supply (12V output). The IN pin connects to pin 12 (Arduino).
At normal state, the plunger is pushed out by a spring into the frame piece which means that the door is locked. To unlock it, the Arduino will output some voltage through pin 12, which will alter the position of the switch inside the relay to allow current to flow through the NC pin.

Relay 2 (Dual Channel Module)

In order to be able to reverse the direction of the motor, a dual channel relay is necessary. Supply

5V to Relay 2. Connect Both wires of the motor to the COM pins (Common) of Relay 2. Supply 12V to both NO pins (Normally Open) of Relay 2. IN1 and IN2 will connect to pin 10 and 11 of the Arduino.
The same logic is applied here. When there is no voltage at IN1(pin 10) and IN2(pin 11), the motor is not moving. When IN1 is HIGH (Voltage) and IN2 LOW (No Voltage), the motor will spend in one direction and the other direction when IN1 and IN2 interchange values. The rotation of the motor causes the door to either open or close.

Algorithms

Search

All algorithms are object to changes in the implementation stage for better functionality.

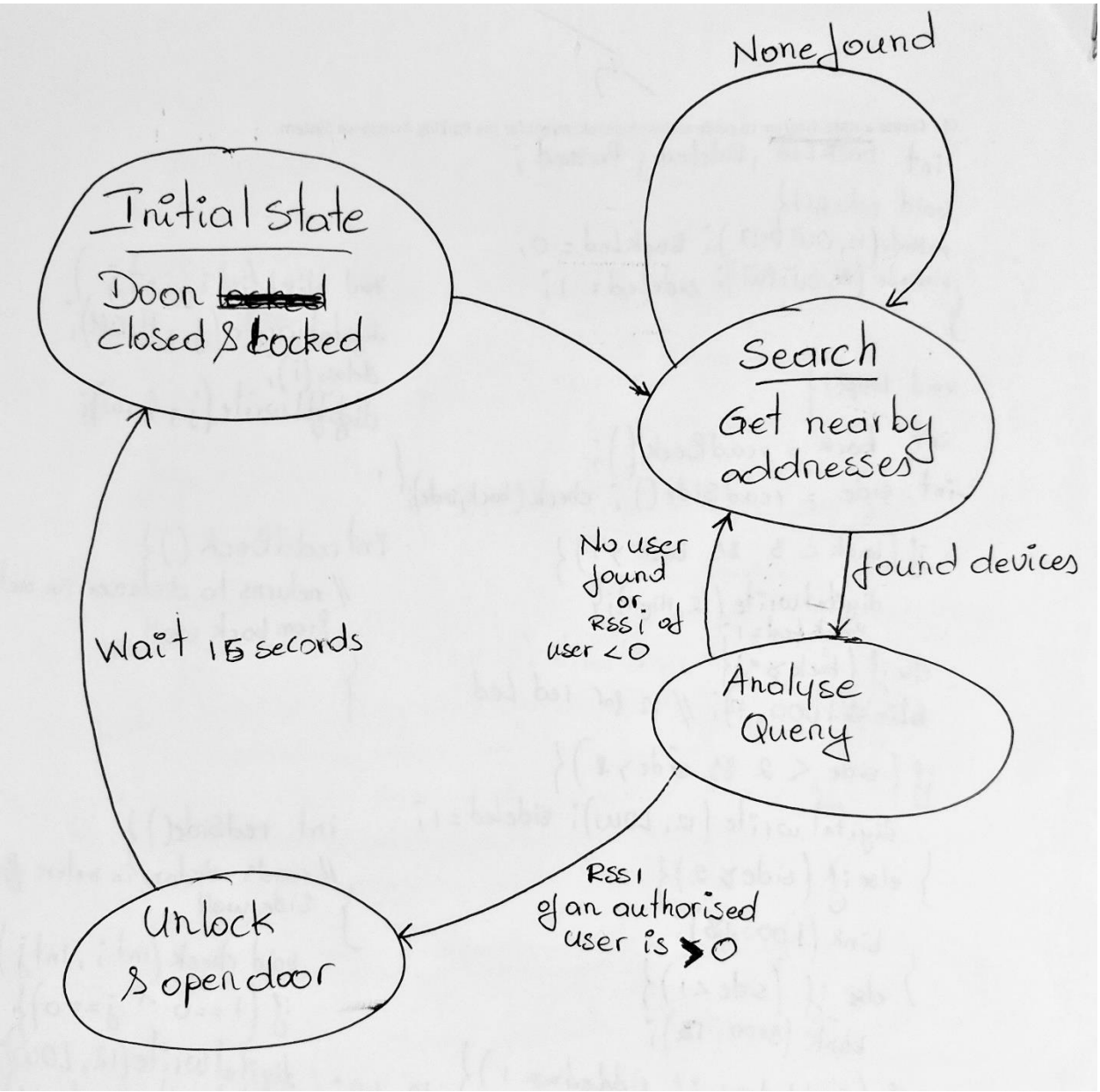
1. Setup HC-05
2. First send an INQM command specifying RSSI access mode, maximum number of devices to be discovered and a time out value.
3. Then query nearby discoverable devices using AT+INQ
4. The result from the previous step will generate lines of strings contain the address, a type field and a RSSI value of nearby devices.
5. If an RSSI value associated to an authorized is greater than 0 (device must be about 2 feet or less), proceed to opening door.

Opening and Closing (Pseudo Code)

//Initial State:
//pin 12 is LOW (Locked)
//Both pin 10 and 11 are LOW (Motor Not spending)

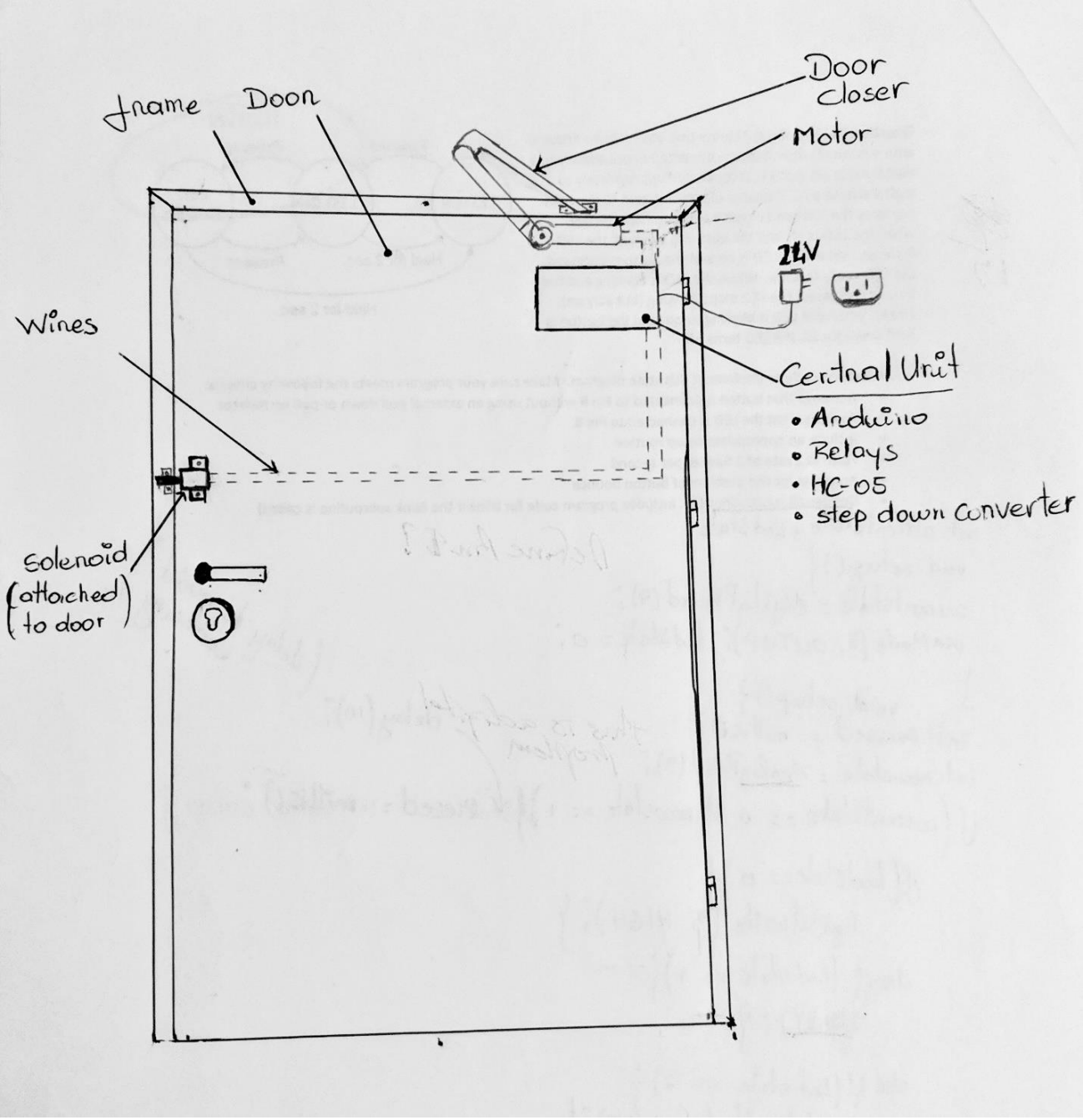
1. Make pin 12 HIGH *// (Unlocked)*
2. Wait for 1 second
3. Make pin 10 HIGH *// (Motor spends in opening direction)*
4. Wait for some time T *// (T represents how long it takes for the door to open or close)*
5. Make pin 10 LOW *// (Motor is not spending)*
6. Wait for 15 seconds *// (user to enter)*
7. Make pin 11 HIGH *// (Motor is spending in opposite direction)*
8. Wait for T
9. Make pin 11 LOW *// (Motor is not spending)*
10. Make pin 12 LOW *// (locked)*

State Diagram



Mounting

The 12V motor will be attached to the door about a third of the length of the door from the hinges. One end of the door closer will be attached to the door frame slightly above where the motor is attached, but not directly above. Of the constructed pieces, the small one will be attached to the door frame and the other to the door, with the solenoid in between.


frame
Doon
Door closer
Motor
24V
Wines
Central Unit
• Arduino
• Relays
• HC-05
• step down converter
Solenoid (attached to door

Citation

"MAC Address." P2P (Peer To Peer) Definition, techterms.com/definition/macaddress. https://techterms.com/definition/macaddress.

"What Is RFID and How Does RFID Work? - AB&R®." AB&R, 6 Feb. 1970, www.abr.com/what-is-rfid-how-does-rfid-work/.

Frost, Sandra L. "Introduction to Arduino Uno." 2017, doi:10.2172/1412918