Auxiliary Combination Lock Based on Door Knocks and Door Knob Turns

ECE 445 Design Document

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1 Introduction

1.1 Problem

Getting locked out of one's apartment or house happens frequently, especially when living alone. Many large apartment buildings have security at the entrance, meaning people often do not feel the need to lock their apartment door, and as such do not carry a key. The number of high-rises continues to grow [1] and as such, the number of buildings with entrance security will grow.

In order to combat this problem, many people hide a spare key or install a keypad lock. Hiding a spare key is a security risk, as it can easily be found by somebody trying to gain entry. Yet in a variety of settings, this unideal solution is used nonetheless, such as for Airbnb rentals. While keypad locks are a somewhat superior alternative, they are often large and unsightly (Figure 1), while obviously conveying a secondary path of entry.

Figure 1: Keypad door vs example Knock Turn Lock implementation

1.2 Solution

Our proposed solution offers a unique approach to the problem of getting locked out of a home or apartment. As previously mentioned, a spare key may be hidden somewhere or a keypad lock may be installed, but both solutions involve several security risks. More generally, the problem of authenticating access without a physical key remains inadequately solved. The auxiliary combination lock based on door knocks and door knob turns offers a secure and convenient alternative.

The combination input space is simple to use, yet complex enough to avoid unwanted access. The lock can be programmed with a unique combination of door knob turns and knocks, making it unlikely for someone to guess the correct combination. Additionally, the lock can be easily reprogrammed in case the combination is shared with someone or becomes known to others.

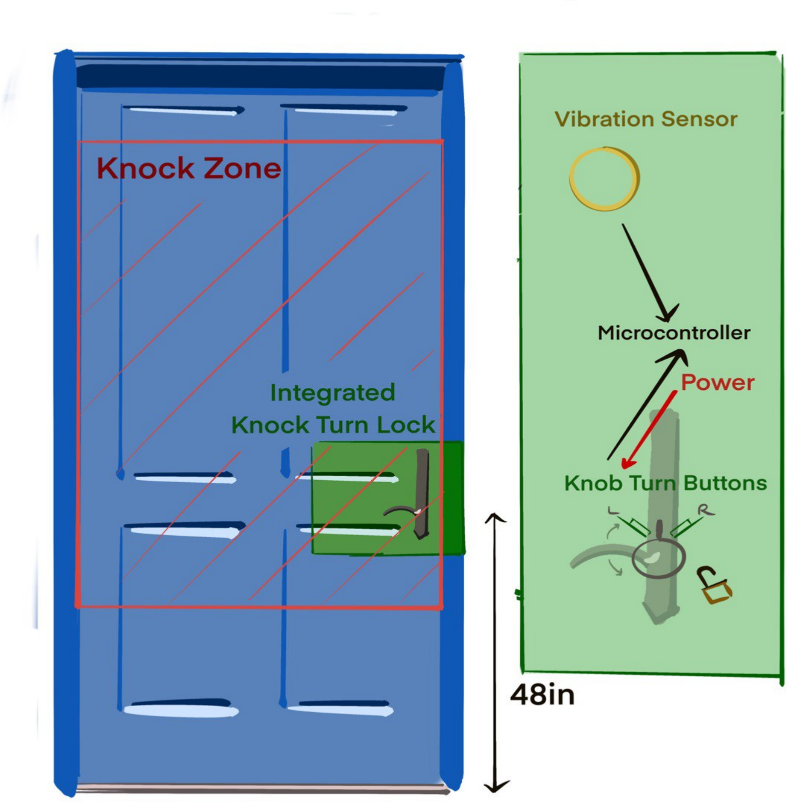
The lock is designed to be hidden from the outside, making it appear as if someone was let in by a roommate. This provides even more security, as it is unlikely that someone would attempt to break in if they believe someone is already inside. Additionally, the discrete design of the lock makes it an ideal solution for those seeking a more aesthetically pleasing option for securing their home or apartment.

In terms of versatility, the lock can be used in a variety of settings. Whether it be for an Airbnb rental, a shared living space, or any other situation where a physical key might not be the best solution, the combination lock provides a secure and convenient alternative. The complete Knock Turn Lock system will aim to satisfy ADA requirements, maximizing the implementation space of the final product. Knocks will be registered as low as 48 inches from the ground, for wheelchair users.

In short, The Knock Turn Lock is easy to use, reprogrammable, and provides a unique approach to home security.

1.3 Visual Aid

Figure 2



1.4 High-Level Requirements

1.4.1 Consistency

The combination must be able to be input consistently by an authorized user when input correctly. This would avoid situations where the existence of the combination becomes apparent due to repeated knock and turn combinations from outsiders. A practiced entrant should be able to input the combination 10 times in a row without failure.

1.4.2 Discreteness

One of the advantages of not having a keypad or RFID reader is strangers are unable to tell there is a way to enter other than having a key, and as such are unable to figure out a way to bypass it. The entire design should be able to fit inside of a door in order to avoid this outward display of a second entry point, as well as potential unsightly electronics. The widths of most doors are between 1-¾ and 2" wide, so the design should be 1-½ in. in thickness.

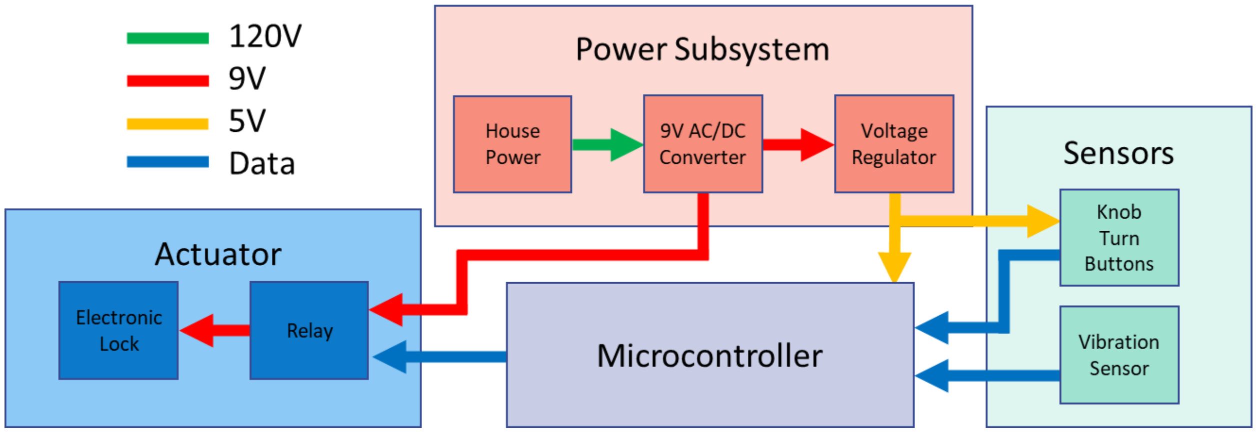
1.4.3 User Programmability / Security

The lock should have a user-friendly interface for programming and changing the combination. This would allow the user to customize the combination to their preferred sequence of knocks and turns, and also change the combination in case it is shared or spread. Changing the combination should be a simple and intuitive process. Additionally, the lock should allow for multiple combinations to be programmed for different users for potential HIPPAA compliance. Finally and obviously, the programming interface should be secure and prevent unauthorized access.

2 Design

2.1 Block Diagram

Figure 3



2.2 Subsystem Overview

2.2.1 Power Subsystem

The power subsystem will provide power to each of the modules based on their needs. The highest power requirement is the electric lock, which requires 9V, and as such the AC/DC converter will convert to 9V [3]. However, the microcontroller requires anywhere between 3.3V and 5V, so there will have to be a voltage regulator in order to drop the voltage down to an acceptable level [9]. The button will also be connected to the microcontroller through this voltage level. The vibration sensor behaves as a capacitor when it senses a force, so this will not need to be connected to power to generate a signal [4].

Table 1: Power Requirements and Verification

Requirements	**Verification**
• The AC/DC converter should be able to output enough voltage to run the highest voltage requirement, and have enough current to ensure there will not be failure due to lack of power.	• The AC/DC converter should output 9±0.5 V even with varying loads, and be able to provide at least 750 mA in order to ensure there are no power failures when supplied with regular outlet AC power. This can be tested by cycling the lock, which consumes the most power, twice a second and ensuring there is no failure due to lack of power nor voltage drops outside of acceptable range [3].
• The voltage regulator should be able to output a voltage acceptable for the microcontroller specifications, in order to not damage the part.	• The microcontroller VCC and I/O pins are rated for 1.8-5.5V, so the regulator will be rated for 5V and should always remain in the range of 2-5.4V even while the lock is cycling twice a second [9]. • The typical rating for the microcontroller is 0.8 mA, but has an absolute maximum listed at 200mA. As such, the voltage regulator should remain within the 2-5.4V even when driving a 200mA load [9].

2.2.2 Sensors Subsystem

The sensors used in this lock will be able to detect knocking on the door as well as turning the door knob. The knock detection will be done by the vibration sensor, which is a piezo sensor able to detect forces. The turning of the door knob will be detected by buttons within the door knob. By placing a button on either side of the knob when fully turned, each button will correspond to a separate direction and can be used individually in the combination.

Table 2: Sensors Requirements and Verification

Requirements	**Verification**
• The buttons should have fast reaction times so each turn gets read.	• Upon a turn to the left or the right, the input should be read within 0.1 seconds.
• The piezo sensor should be able to reliably detect knocks at a regular volume.	• Knocks as quiet as 60dB should be detected 95% of the time.
• The piezo sensor should not detect knob turns as knocks.	• Knob turns should not trigger the knock input to be read.
• The piezo sensor should be able to detect knocks in quick succession.	• Knocks separate by as little as 0.2 seconds apart should be read as separate knocks.

2.2.3 Microcontroller

The microcontroller will collect data from the sensors and make decisions whether to unlock the door based on the current combination programmed into the lock.

Table 3: Microcontroller Requirements and Verification

Requirements	**Verification**
• The microcontroller will need 3 I/O lines for communication between the sensors and the relay.	• Run a simple test program verifying inputs received on input lines and outputs received on output lines.
• The microcontroller will need enough memory to store a simple program that determines if a sequence of inputs is the correct combination.	• Program is less than 8KB and receives sensor inputs, processes inputs, and sends unlock signal [9].
• The microcontroller will need enough processing power to analyze inputs at human speeds.	• Program keeps track of all knocks and turns as fast as human input (~0.1s) and sends unlock signal within 0.1s of correct input [9].

2.2.4 Actuators

The only actuator in this design is the electronic lock. However, the microcontroller cannot power it because it requires too high current. In order to remedy this, a relay will be implemented using a MOSFET. The microcontroller will output a high signal to the relay, which allows the power from the AC/DC converter into the electronic lock and opens it.

Table 4: Actuators Requirements and Verification

Requirements	Verification
• The power ceases quickly enough in order to show the entrant they have correctly input the combination	• The power ceases through within 1 second of a LOW output from the microcontroller.
• The power enters quickly enough to lock the door, and not allow unauthorized entrants in	• The power reenters within 1 second of a HIGH output from the microcontroller.
• The lock draws low enough power to run off the AC/DC converter	• The lock runs off as low as 8.5V, and does not draw more than 1A [3].
• The lock closes quickly enough to not allow unauthorized entrants in.	• The lock closes within 1 second of receiving power from the relay.
• The lock opens quickly enough to make the entrant realize they have entered the correct code.	• The lock opens within 0.5 seconds of power stopping from the relay.

2.3 Tolerance Analysis

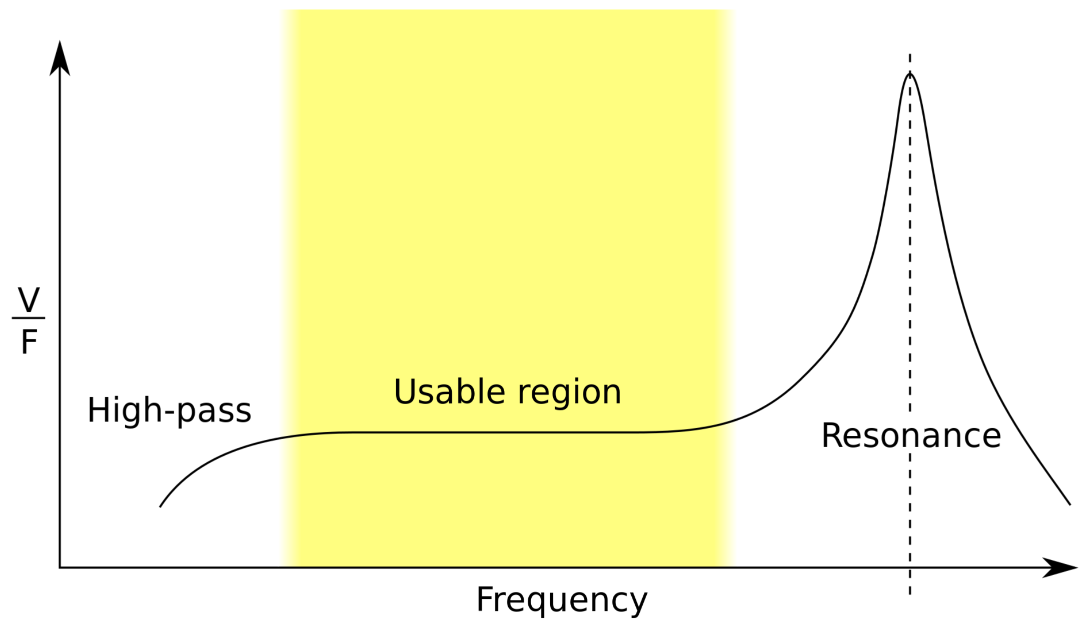
Vibration Sensor Thresholds

In order to make the combination not obvious, all knocks must be done at a reasonable volume, which means around 60 decibels. However, these vibrations will not be much stronger than vibrations in the door due to the door knob turning. If the vibration sensor cannot differentiate between the two, it would mean that any combination without distinct sections of knocking and turning (ie. knock once, turn left, turn right, knock again), would read multiple knocks and keep the person locked out. Further, differing door types, background noise and other local factors must also be considered to avoid this outcome, violating the high-level requirement of being able to consistently unlock the door upon first attempt.

Preliminary investigations indicate that an amplitude high-pass filter would be the most effective filter for this use case, conducive to the operation of a piezo sensor (Figure 4). Unintentional inputs, from the door knob or the environment would be ignored, given the signal amplitude does not reach the set threshold value. This must be tested in order to determine the precise numeric threshold which correctly interprets sensor outputs as knocks/noise – exact figures cannot be provided until then.

If no sensitivity threshold can correctly differentiate knocks and noise, then physical deafening to the vibration created from turning the door knob may be necessary.

Figure 4



The frequency response of a piezoelectric sensor

There will have to be resistors used for the buttons and the MOSFET relay for the lock. These will have values that can range anywhere from 1.1-2.2kΩ, as they are pull-up resistors for the buttons and a current limiting resistor for the MOSFET relay. With such a high range, these can be selected to be ±10% variation to reduce cost.

Similarly, the voltage regulator does not have to be precise. The microcontroller can run on anywhere from 3.3-5.5V, and the button inputs are binary so they just have to have a voltage over 1.5V in order to have a HIGH input [9]. This means the 5V voltage regulator can vary 10% from the rated value and cause no problems with the microcontroller.

3 Cost and Schedule

The total cost of parts is $53.99. Shipping costs are around 5% and sales tax is around 10%. This brings the total cost of parts delivered to be $62.09. Labor costs run $50/hr * 2.5 * 60 hrs = $7500 per team member. All three members including the parts bring the total to $22562.09.

3.1 Cost Analysis

Table 5: Cost Analysis

Part	Manufacturer	Quantity	Total Price
Solenoid Lock	Adafruit	1	$14.95
Piezo Element	Adafruit	2	$1.90
Piezo Element	Adafruit	2	$1.90
Piezo Element	CUI Devices	2	$1.96
Piezo Element	CUI Devices	2	$4.16
Power Supply	CUI Inc.	1	$15.79
ATtiny85	Microchip	1	$1.56
Button	SparkFun	2	$1.10
Wire	general	10 ft	$0.10
N-Channel MOSFET	Fairchild	1	$1.97

Resistors	general	20	$2.00
Voltage Regulator	onsemi	1	$1.60
PCB	PCBWay	1	$5.00

3.2 Schedule

Table 6: Schedule

Week	Task	Involved
Feb 20 - Feb 26	Order first round parts	Adam
	Finish design document	Everyone
	Finish team contract	Everyone
	Start PCB design	Jack
Feb 27 - Mar 5	Meet with shop	Vishal
	Design review	Everyone
	Finalize PCB design	Everyone
Mar 6 - Mar 12	Order second round parts	Jack
	Begin software program	Adam & Vishal
	Order PCB	Adam
	Finalize software program	Jack
Mar 13 - Mar 26	Assemble PCB	Adam & Vishal
	Test PCB	Everyone
	Revise PCB	Jack
	Receive doorknob from shop	Vishal
Mar 27 - Apr 2	Order second PCB	Adam
Apr 3 - Apr 9	Assemble second PCB	Jack

	Revise software program	Adam & Vishal
Apr 10 - Apr 16	Test PCB	Jack
	Team Contract Fulfillment	Everyone
	Full test of Knock Turn Lock	Everyone
Apr 17 - Apr 23	Mock demo	Everyone
Apr 24 - Apr 30	Final demo	Everyone
	Mock presentation	Everyone
May 1 - May 4	Final Presentation	Everyone
	Final paper	Everyone

4 Ethics and Safety

Given our position as computing professionals, our actions and the resultant products of our intellectual property have the potential to change the world, in both positive and negative ways. As such, a careful analysis of all the ways in which our work could be used is warranted. What follows is a thorough overview of the Knock Turn Lock in its relation to the ethical standards proposed by the IEEE and ACM. While both codes differ in their minutiae, the overarching themes are largely congruent, and all the main themes relevant to the Knock Turn Lock will be covered.

With regards to IEEE, the main relevant code is “to uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities,” specifically “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others.” ACM emphasizes that we must " design and implement systems that are robustly and usably secure" and "use care when modifying or retiring systems."

Our product being a novel lock that aims to replace existing tried and tested systems, we must abide by this ethos in a very literal sense. Through rigorous testing, we shall ensure that our lock is robustly prepared to handle the actions of bad actors whilst also allowing easy access to authorized users. Beyond this, before our product comes to market we will apply for ANSI/BHMA commercial hardware certification, ensuring without a doubt that any consumer of our product is properly informed of the security grade of the Knock Turn Lock.

In addition to the Knock Turn Lock abiding by the relevant ethical standards as proposed by IEEE / ACM, it is equally important for the product to abide by the safety standards put into place by the relevant regulatory authorities [2]. Given that the Knock Turn Lock is designed for residential, not commercial use, we could sidestep many regulations aimed exclusively at the latter, especially given that residential door lock regulations are largely non-existent. However, since we aim to allow the Knock Turn Lock to be used in as many places as possible, its design will attempt to follow commercial regulations as well, whether or not we officially advertise this compliance. What follows is a thorough overview of the Knock Turn Lock in its relation to the safety standards outlined by the ADA and HIPAA. While all commercial locks must abide by the ADA, HIPAA applies to specific industries where patient privacy is in question. Again, since the Knock Turn Lock aims to be used in as many places as possible, all efforts will be made in this pilot product to satisfy as many regulations as possible, and official compliance can be established by a later version.

Regulations exist for both doors and locks. Our product will be assumed to be installed on a compliant door. Thus this discussion will be limited to the scope of lock regulations. The ADA requires:

- All locks and handles attached to your doors must be operable with one hand and not require any extreme grasping or twisting
- Any lock or handle hardware must be mounted no more than 48 inches above a finished floor; this ensures that those in wheelchairs are able to reach door locks as needed.

The Knock Turn Lock will use a lever handle, and allow knocks from below 48in of height. Easy egress will also be implemented automatically by the lever handle. The additional stipulation placed by HIPAA is an access control system. We could abide by this through the use of different combinations for each user.

5 References

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