SMART HOME
NFC LOCK SYSTEM

DESIGN REVIEW

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ECE 445
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1 Introduction:

1.1 Statement of Purpose:
Smartphones are becoming more and more prevalent in modern society, serving as our most valuable and versatile tool in a technological era. Almost everyone owns a smartphone and enjoys the convenience of wireless connectivity. Following the fast growing trend of smartphones and Internet of Things, we would like to introduce a smart lock system that takes advantage of the NFC capabilities of smartphones as a replacement for the traditional keys used to lock and unlock doors. The smart lock we are proposing is easier to use than similar products on the market because it does not require the user to pair to their lock via Bluetooth or make drastic and expensive changes to their current door setup. Instead, the user can get started with the product by simply downloading an app and installing the smart lock module on to one of their doors. The system reduces the hassle of carrying many keys around and subsequently forgetting them. Additionally, the product allows for an administrator to quickly and remotely grant and terminate access to family members and guests. As a redundancy, the lock mechanism does not inhibit the user from using their keys to open the lock, in other words, it only adds a secondary method of entry while not interfering with the key and lock system.

1.2 Motivation:
The inspiration for this product comes from the idea that using smartphones as universal keys has the potential to make unlocking doors much more convenient. The product is perfect for people with tight budgets who cannot afford other, more expensive, commercial products that usually require customized doors. We found that there are some retrofits that use Bluetooth rather than nfc as an unlocking technology, but these products rely on a frustrating and unreliable pairing process. In contrast, our project targets affordability, mobility, reliability. It also serves as a platform for expansion into other methods of entry, such as fingerprint or voice analysis. Last but not least, the project falls in line with the recent 'Internet of Things’ trend.

1.3 Objectives:

1.3.1 Goals:
• Lock/unlock doors correctly
• Reliability through redundancy, to operate for a time even when the main power source is down
• Easy setup and compatibility with many types of doors
• Expandable to have more types of credential checking such as fingerprint and voice

1.3.2 Benefits:
• No need to many carry keys or afraid of losing keys
• Fits well for granting access to temporary guests, especially those who are in Airbnb business
• Very affordable price and no door modification required
1.3.3 Functions and Features:

- Read NFC tags and perform lock/unlock
- Allow to open doors with keys.
- Low power consumption
- Powered from home grid and has a battery as a backup source of power
- Mobile application to communicate with the lock system through NFC
- Desktop application to manage many smart lock systems and access to each system
- User-friendly interface applications and an easy setup process.
2 Design:
2.1 Block Diagram:

![Block Diagram Image]

Figure 1 Overall Design
2.2 Block Description:

2.2.1 Lock:

- **Atmega328:**
  The central control unit of the project is the ATmega328. It serves three purposes; the first is to read the data that the NFC module sends it when a user swipes their NFC-enabled phone over the reader. The second is to communicate with the backend server through the esp8266 WiFi module to verify the identity of the phone and determine whether or not it should be granted access. Finally, if it is determined that the phone has access to the door, the atmega328 unlocks the door by sending pulse width modulated (PWM) signals to an H-bridge circuit which rotates the motor. Communication with the WiFi and NFC modules is done with the UART interface. The ATmega is powered by the 3.3v rail coming from the regulator.

![Diagram of ATmega and connected components](image)

- **WiFi Module (ESP8266):**
  The WiFi module facilitates communication between the ATmega and the server. It sends the NFC ID of the phone being read by the NFC reader to the server over a the network using tcp/ip protocol, and receives a 'yes' or 'no' response which it relays to the ATmega328. This information is used to determine whether or not the lock should be opened.
Motor (SG27RS370 3V):
We use the motor to interface our circuit with the door lock. It receives pulse
width modulation signals from the ATmega328, and gets its power from the
power block via the H-bridge circuit.

In order to arrive at an approximate torque value that the motor would need to be
able to provide, we conducted a simple experiment on a door lock by tying a
string to the end of the lock latch and adding weight to the end of that string until
the latch turned enough to unlock the door. The weight that opened the latch was
1kg or 9.81N of force. The distance from the axis of rotation that the string was
attached was 2.5cm, and the angle between the string and the plane of the latch
was 45 degrees. Using these values, we have the following calculation:
\[ \tau = 2.5 \text{ cm} \times 1 \text{ kg} \times \sin(45^\circ) = 1.768 \text{ kg} \cdot \text{cm} \]
We used this torque specification to select the motor.

H-bridge Motor Driving Circuit:
In order to drive this high voltage motor, we have implemented an H-bridge
design that consists of four N-channel power MOSFETs (RFD3055) that are
driven by 2 pulse width modulated signals from the ATmega328.
NFC Reader (PN532 RFID Module):
The NFC module is responsible for reading the phone NFC identifier and relaying that information to the ATmega328. This information is used to decide whether or not to open the lock. The NFC module is powered by a 5v rail from the power block. Because the ATmega328 only has one pair of UART ports, we have to use software serial ports to emulate the hardware serial ports. Although the NFC module can work through SPI or I²C, the library and the framework available to us use UART. Therefore, we chose to use software serial. This also makes the debugging process easier through the information dumped to the Serial Monitor.
2.2.2 Power:

- **Power Selector:**
  This circuit allows only the wall adapter to power the system under normal circumstances, but uses 1N4004 diodes to switch to the battery when the wall adapter fails, enabling us to use the battery as backup.

- **Power Regulators (2 LM317):**
  In order to provide steady output voltages to the integrated circuits in our printed circuit board, we use two LM317 linear voltage regulators with outputs that are adjusted using resistors. Since our lock requires 5 and 3.3 volts, we calculated the resistor values needed to set each regulator to its respective output level using the following formula as giving in the LM317 datasheet:

  \[ V_{out} = 1.25 \times \left(1 + \frac{R_2}{R_1}\right) \]

  Where \(R_1\) is the output resistor and \(R_2\) is the resistor that connects the adjust pin to ground.

  Using the resistor values derived from these equations, we arrive at the following regulation circuit:
- **Battery Charger (Max1555):**
  The battery charger block uses a MAX1555 linear regulator to charge the single cell lithium ion battery. The input to this block comes from the 6 volt wall adapter, and the output of this block is 4.2 volts with variable current which is used to charge the battery. The chip monitors the battery voltage and automatically decreases its output current to 0 amps as the battery voltage approaches 4.2 volts.
Lithium Ion Battery:
The backup power for our system comes from the lithium ion battery, whose 3.7V output goes to the power selection circuit. From there, it only powers the system when the wall adapter has failed. The input to the battery comes from the max1555, which automatically limits the current as the battery approaches its max capacity of 4.2V.

Wall Adapter:
The wall adapter we are using outputs 5 volts and a maximum of 2000 mA to the power source selector circuit. This voltage is used as input to the two regulators which provide steady 5 and 3.3 volt outputs that source the rest of the lock’s circuitry.

2.2.3 Phone and Mobile Application:
The mobile application will ask the user to set the passcode which is identical to the one that is used to register in the database. The information package that the phone sends to the NFC reader includes the phone’s NFC ID and the passcode. This method enhances the security of the system in case another person tries to replicate the phone’s NFC ID using a MiFare card. In the worst scenario, if both NFC ID and passcode are stolen, the user can simply change the passcode in the database and on the phone to make the phone work again without changing to a new phone.

2.3 Power Analysis:

<table>
<thead>
<tr>
<th>Load</th>
<th>Voltage (V)</th>
<th>Current (Active mode) (mA)</th>
<th>Current (Idle mode) (mA)</th>
<th>Power (Active mode) (mW)</th>
<th>Power (Idle mode) (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>3.3</td>
<td>9.6</td>
<td>2.35</td>
<td>48</td>
<td>11.75</td>
</tr>
<tr>
<td>WiFi module</td>
<td>3.3</td>
<td>6.16</td>
<td>0.15</td>
<td>20.33</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Voltage</td>
<td>Current</td>
<td>Resistance</td>
<td>Power</td>
<td>Efficiency</td>
</tr>
<tr>
<td>------------------</td>
<td>---------</td>
<td>---------</td>
<td>------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>NFC module</td>
<td>3.3</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Battery charger</td>
<td>4.2</td>
<td>280</td>
<td>50</td>
<td>1176</td>
<td>221</td>
</tr>
<tr>
<td>Power Regulator</td>
<td>3.7</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Motor</td>
<td>3.7</td>
<td>600</td>
<td>N/A</td>
<td>2200</td>
<td>N/A</td>
</tr>
</tbody>
</table>

2.4 Software Flowchart:
2.4.1 Checking request from the hardware:
The server runs in background mode and wait for interrupt signals from hardware through WiFi. The signals from the hardware module contain information about the identity of the locks and the NFC tags of the phones. If the information matches with the database in the server, an accepting signal is sent from the server to the hardware module. Otherwise, a rejecting signal is sent.
2.4.2 Access Control (for one lock system):
There are two features in this function: granting new access and terminating existing access. This function manages access in only one lock system.
2.4.3 Lock System Control:
This function allows users to add more lock modules to the system. It also lets users delete existing lock modules. When a lock module is deleted from the database, all the access is also deleted.

Main window: login screen. The user must login in order to proceed using the software. The default login credentials are Username: admin, Password: admin.

View: lets the administrator see access of different locks in the system. The administrator can insert or delete record, or change the passcode of each record.

Manage Locks: allows inserting or deleting locks from the system.

Edit: allows user to change the login credentials.

About: information about authors and versions of the software.
Figure 12 Login Window

Figure 13 View Window
Figure 14 Manage Locks Window

Figure 15 Edit Login Window
NFC Smart Lock System

Authors: Arnav Gulati, Hay Doan
Version: 1.0
2010

Figure 16 About Window
2.4.4 Mobile Application:

Start

Setup

Set passcode from user

Write to NFC tag

End
3  Requirements and Verification:

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall adapter: output must be 12V +/- 0.5V</td>
<td>Plug the adapter to an outlet and measure the output voltage with an DMM</td>
<td>0</td>
</tr>
</tbody>
</table>
| Battery Charger:  
a. must steadily output 220 to 340 mA and 4.158 to 4.242 volts needed to charge the single cell battery. The circuit monitors battery voltage and stops charging when the battery reaches a threshold of 4V at 50mA. | Measure the output voltage and current of the battery charger using a DMM after supplying it with 3.7 to 7 volts and connecting its output to a 12Ω resistor | 5 |
| Power Regulator: must output 5V +/- 0.3V on one line and 3.3V +/- 0.3V on another. | Measure the output voltage levels with a DMM and ensure values are within range. | 5 |
| Microcontroller:  
a. Control servo: output must be PWM signals with the peak-to-peak voltage of 5V +/-0.5V, 50Hz, 2ms pulse width.  
b. WiFi module: output to TX must be 3.3V +/- 0.2V for TTL high.  
c. NFC module: the emulated software serial ports must work as if they were hardware serial ports. | a. Load and run the test code to write the PWM to the ports on the microcontroller connected to the control servo and display the output on an oscilloscope.  
b. Probe the TX pin with an DMM. Run the test code and measure the maximum voltage, which could not exceed 3.5V.  
c. Use the test of the WiFi module to see the result in Serial Monitor. If the PC and the WiFi module can connect through the software serial ports, the right result will be in the Serial Monitor. | 10 |
| NFC reader: the maximum reading distance should be 7cm | Load and run the test code to display data read by the NFC on the serial monitor of the Arduino IDE. Let the phone approach from far to close until stable reading is acquired. Measure the distance from the NFC reader to the phone. | 5 |
| Motor:  
a. Capable of turn the lock into the locked/unlocked position with a minimum torque of 2 kg.cm +/- .2kg.cm. | Mount the motor in a stationary position and attach the shaft to the lock latch assembly, then connect the leads to the h-bridge circuit and tie a string to the end of the 2.5cm latch with a weight of 1.3kg attached to the end. Load and run the test code on the ATmega328 to supply the PWM signal to the motor which turns it in the counter-clockwise direction and observe that the latch rotates into the unlocked position. | 0 |
| WiFi module:  
a. Have the module connected to a serial-to-USB converter with the other side connected | | 10 |
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Connect to the WiFi in the range of 70m</td>
<td>b. Must be able to transmit NFC data to the server through TCP/IP</td>
</tr>
<tr>
<td>b.</td>
<td>to the computer. Stand in the range of 70m of the closest access point. Open the serial monitor in the Arduino IDE. Use AT commands to connect to the WiFi. Check the response on the serial monitor.</td>
</tr>
</tbody>
</table>

b. Put the server in listening mode. Load the test code on the ATmega328 to send data to the server. Then read the response from the server and compare with the expected result.

| Power Selector: the minimum voltage during the switching time must not be below 3V. | Measure the output voltage of the circuit with a digital DMM when both voltage sources are on. Turn the wall adapter off. Display the statistic on the DMM about the minimum voltage. |
| Battery: capacity must be 2000 mAh ± 100 mAh and output voltage should be 3.7V ±0.2V/- 1.0V. | After standard charging, discharge the battery at 0.2A to voltage 2.75V, recording the discharging time. The time should be ≥ 270 mins. |
| Software: must be able to load/store information from the database and response correctly to the client. | Run the application and try to add/edit/delete records. Then open the database to see the updates. Also use another PC to send an unlocking request through TCP and verify the reply from the server. |
| H-Bridge: must be able to supply 50% duty cycle pwm 3 volts +/- .2 volts to the motor in positive and reverse polarities such that the motor is able to rotate in the forward and reverse directions | Connect the motor to the load leads of the h-bridge circuit and run the motor test code on the ATmega328. With an oscilloscope, measure the voltage across the motor with respect to time and ensure that there is a 3 volt drop across the motor. |
4 Tolerance and Analysis:

The most crucial subsystem is the power regulator. This plays the key role in providing the correct voltages to different subsystems with different voltage requirements. The tolerance for this circuit should be in the range of +/-5%. This is because the WiFi module has a target input voltage of 3.3V and its (min,max) input range is (3.0V,3.6V). This gives us a headroom of +/-9% (0.3/3.3 = .0909).

However, we never want to operate our circuit near the tolerance boundary. To ensure that we are always well within the acceptable input range of the WiFi module, we will set up the power regulator circuit to output 3.3 volts using external adjustment resistors (see figure 6). The LM317 has an output tolerance of +/-2% and is therefore well within our output tolerance range of +/-9%.
5 Cost and Schedule:

5.1 Cost Analysis:

5.1.1 Labor:

<table>
<thead>
<tr>
<th>Name</th>
<th>Hours</th>
<th>Rate</th>
<th>Total (Hours * 2.5 * Rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huy Doan</td>
<td>220</td>
<td>$28</td>
<td>$15,400</td>
</tr>
<tr>
<td>Arnav Gulati</td>
<td>220</td>
<td>$28</td>
<td>$15,400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>440</strong></td>
<td><strong>$56</strong></td>
<td><strong>$30,800</strong></td>
</tr>
</tbody>
</table>

5.1.2 Parts:

<table>
<thead>
<tr>
<th>Item</th>
<th>Model Number</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>ATmega328p-pu</td>
<td>2</td>
<td>$14.99</td>
</tr>
<tr>
<td>6V 2A Wall adapter</td>
<td>010-SPS-09476</td>
<td>1</td>
<td>$13.99</td>
</tr>
<tr>
<td>NFC Reader</td>
<td>PN532</td>
<td>1</td>
<td>$20.14</td>
</tr>
<tr>
<td>WiFi Module</td>
<td>ESP8266</td>
<td>1</td>
<td>$11.95</td>
</tr>
<tr>
<td>Charging IC</td>
<td>MAX1555</td>
<td>1</td>
<td>$6.95</td>
</tr>
<tr>
<td>DC converter</td>
<td>LM317</td>
<td>2</td>
<td>$12.24</td>
</tr>
<tr>
<td>3.7V Lithium-Ion battery</td>
<td>PRT-08483 ROHS</td>
<td>1</td>
<td>$17.95</td>
</tr>
<tr>
<td>Motor</td>
<td>SG27RS370</td>
<td>1</td>
<td>$9.19</td>
</tr>
<tr>
<td>Diode</td>
<td>1N4004</td>
<td>5</td>
<td>$0</td>
</tr>
<tr>
<td>Resistor</td>
<td>Assorted</td>
<td>20</td>
<td>$0</td>
</tr>
<tr>
<td>Conductor</td>
<td>Assorted</td>
<td>20</td>
<td>$0</td>
</tr>
<tr>
<td>Capacitor</td>
<td>Assorted</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>$107.40</td>
</tr>
</tbody>
</table>

5.1.3 Grand Total:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$30,800</td>
</tr>
<tr>
<td>Parts</td>
<td>$107.40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$30,907.40</strong></td>
</tr>
</tbody>
</table>

5.2 Schedule:

<table>
<thead>
<tr>
<th>Week</th>
<th>Task</th>
<th>Delegation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/14/2016</td>
<td>Understand components of the system. Complete the block diagram with specifications. Order parts.</td>
<td>Huy</td>
</tr>
<tr>
<td>2/21/2016</td>
<td>Setup NFC module with microcontroller Implement phone card emulation</td>
<td>Arnav</td>
</tr>
<tr>
<td>2/28/2016</td>
<td>Breadboard and test battery and servo Implement and test WiFi module</td>
<td>Huy</td>
</tr>
<tr>
<td>3/6/2016</td>
<td>Continue bread boarding and testing. Start working on the database system</td>
<td>Arnav</td>
</tr>
<tr>
<td>3/13/2016</td>
<td>Design and implement battery charging circuit and power regulation circuits Finish database and desktop application</td>
<td>Arnav Huy</td>
</tr>
<tr>
<td>Date</td>
<td>Task Description</td>
<td>Person</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>3/27/2016</td>
<td>Solder components to PCB. Build prototype.</td>
<td>Arnav</td>
</tr>
<tr>
<td></td>
<td>Test design.</td>
<td>Huy</td>
</tr>
<tr>
<td>4/3/2016</td>
<td>Prepare for Mock demo and Presentation.</td>
<td>Huy</td>
</tr>
<tr>
<td></td>
<td>Test hardware</td>
<td>Arnav</td>
</tr>
<tr>
<td></td>
<td>Finish and test software</td>
<td>Huy</td>
</tr>
<tr>
<td>4/10/2016</td>
<td>Start writing final report</td>
<td>Huy</td>
</tr>
<tr>
<td></td>
<td>Test the whole design</td>
<td>Arnav</td>
</tr>
<tr>
<td>4/17/2016</td>
<td>Reserved for any changes to schedule</td>
<td>Arnav</td>
</tr>
<tr>
<td>4/24/2016</td>
<td>Prepare for demonstration and presentation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Setup software</td>
<td>Huy</td>
</tr>
<tr>
<td></td>
<td>Test hardware and prepare prototype</td>
<td>Arnav</td>
</tr>
<tr>
<td>5/1/2016</td>
<td>Reserved for changes. Relax for presentation</td>
<td>Huy</td>
</tr>
</tbody>
</table>
6 Safety:
- The module contains a Lithium battery. Do not expose the module to extreme heat source.
- When connecting the wall adapter to an outlet, avoid having dangling wires, especially one that may get stuck at the kink in the door.
- The LM317 is a linear regulator that is expected to dissipate some heat as part of regular operation, and therefore precaution should be taken when handling the circuit.
- The H-bridge MOSFETs are switching high currents, so it is imperative that they not be handled when the circuit is in use.
- Do not modify the circuit when it's live.

7 Ethical Issues:
Our project adheres to the IEEE code of ethics as the followed:

1. To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment.
2. To be honest and realistic in stating claims or estimates based on available data.
3. To improve the understanding of technology; its appropriate application, and potential consequences.
4. To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others.
8 References:


