ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Project Proposal: Fingerprint Recognition Door Lock

Team Members

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1 Introduction

1.1 Problem

In our Residential College, each student has own dormitory, and the dormitory door can only be opened by the student's own IC card. Sometimes it is possible that you forget your IC card inside the dormitory room, or lost it somewhere by mistake, so that you must go to the front desk of the Residential College to get a temporary card, or go to the IC card service center and get a new card. And if it is in the midnight, it will be harder to get staff in touch. So it is better that students can use more methods to open the door except for swiping the IC card. We are thinking of other ways to unlock the door using other personal identification information. Even if you didn't lose your IC card, with more ways to open the door brings a little more joy in daily life.

1.2 Solution

Some popular way to unlock the door is password, facial recognition and fingerprint recognition. Considering the difficulty and portability, we decide to develop our own fingerprint recognition lock for our Residential College. However, replacing all the door lock in the Residential College is quite challenging. we propose a device which can be easily attached to the existing door lock, and turn it into a fingerprint recognition door lock, without assistance from the professional installation workers.

In addition to fingerprint recognition, we also intend to integrate other approaches to our smart door lock. Some basic functionality includes unlocking the door using Software App with the help of remote control through Wi-Fi. Besides, we will also apply Bluetooth technology to open the door lock automatically when the bonded mobile phone is approaching. In order to save energy, the device will turn into low energy mode, and we will add an infrared detection part to our device, which will wake up the device when people come back. Furthermore, we will try to implement more advanced features including unlocking the door through facial recognition, and voice recognition, which can make our device more convenient and intelligent. In general, we intend to develop a portable device with integrated ways to unlock doors, which can be managed easily through our mobile phone application and promise the security.

1.3 Visual Aid

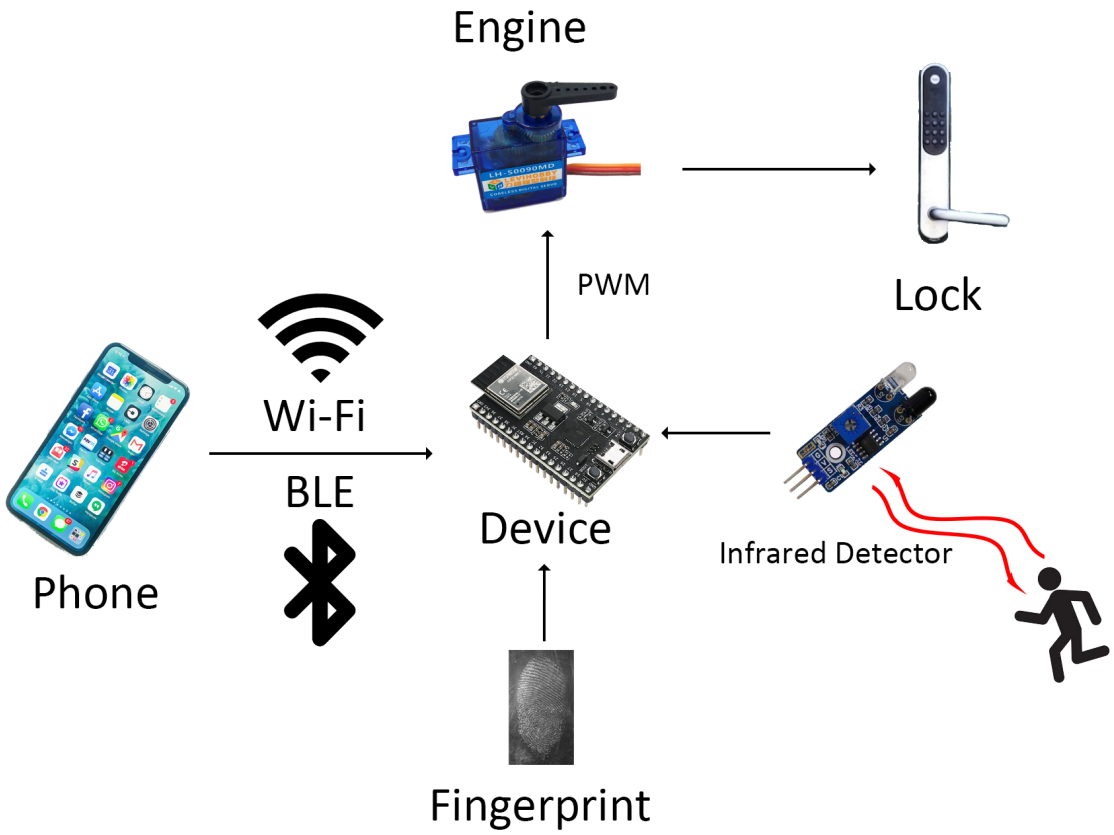

Figure 1: Visual Aid

1.4 High-level requirements list

- Enable the authorized users to open the door lock using their fingerprints, the controller should be able to store at least 5 different fingerprints and the success rate should be above 95%. Besides, the infrared detector can wake up the device when people stand in front of the door within a 120° sector area with radius 1m $\pm$ 0.2m.
- Allow remote control using the software app with delay time at most 3 seconds. And the BLE module of device can identify the neighboring mobile phones when approaching inside the range of 0.5m $\pm$ 0.1m.
- The mechanical subsystem can reliably open the door, the servo motor with a torque of at least 25 kg·cm is necessary.

2 Design

2.1 Block Diagram

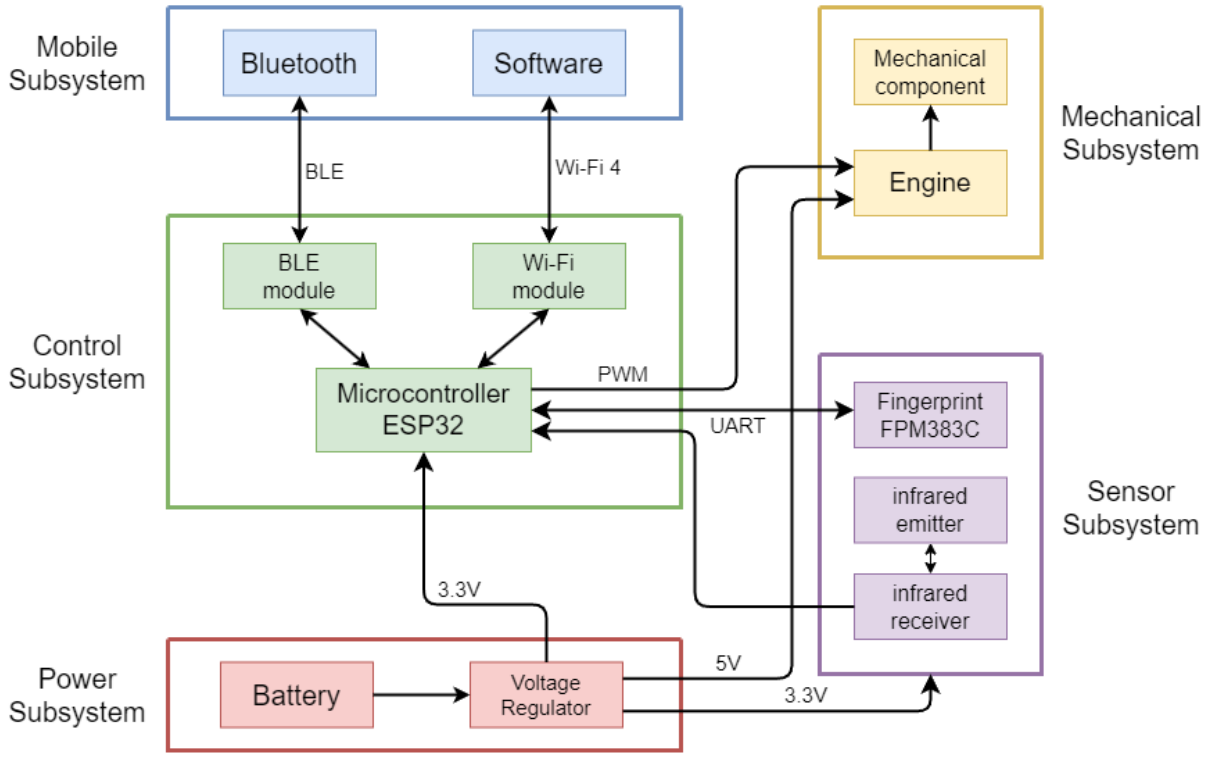

Figure 2: Block Diagram

2.2 Subsystem Overview

2.2.1 Controller Subsystem

This subsystem consists of a micro-controller that manages the operations of the device, including processing fingerprint data, controlling mechanical subsystem, and coordinating with the mobile app and BLE signal designed to interact with mobile phone. Besides, it will be waked up by infrared signal, which enables the device rests when people have left and works when someone is approaching.

2.2.2 Sensor Subsystem

This component comprises an infrared detection module and a fingerprint recognition module. The infrared module signals the ESP32 board to activate the Bluetooth and WiFi

modules when someone enters a predetermined range, allowing the system to conserve power by operating in a low-power state when unoccupied. The fingerprint module consolidates fingerprint scanning, storage, and identification into a single, efficient unit.

2.2.3 Mobile Subsystem

It contains front-end and back-end. The front-end will be a simple app page on the phone with buttons which allow users to unlock the door, add new fingerprints or delete fingerprints. It also contains a simple user login page. The software also provides one-to-one control to every device. The back-end contains two part, one is databases which containing data of fingerprint and keep a recorded unlocking history of the door. The other part uses Wi-Fi to communicate with ESP32. Specifically, ESP32 will act as the client and phone will act as the server and they will communicate using TCP protocol. Bluetooth protocol will also be implemented to connect to the BLE module of ESP32.

2.2.4 Mechanical Subsystem

The Mechanical Subsystem consists of a servo motor and an mechanical actuator which can push the handle of the door lock from the inner side and thus open the door. This subsystem is installed near the lock, inside the door. The servo motor is directly wired with the Controller Subsystem, and accepts PWM signal from the micro-controller as a trigger. Then the servo motor drives the actuator, and the actuator can push or pull the door handle inside, to complete the action of opening the door.

2.2.5 Power Subsystem

The Power Subsystem contains a battery set and some voltage regulators. It is used to power up our Controller Subsystem, Mechanical Subsystem and the Sensor Subsystem. We plan to use a 5V lithium battery as power source. The voltage regulators will regulate the voltage to different levels so that we can power up different parts of the device.

2.3 Subsystem Requirements

2.3.1 Controller Subsystem

We may choose an ESP32 develop board with Wi-Fi module and BLE module as the platform. For the sensor subsystem, it will manage the fingerprint information we collect from the sensor, including add, delete and match fingerprint information from the database. For the Mobile Subsystem, it will receive the message from software app through Wi-Fi module when the user want to control the lock remotely; it will also deal with the strength of BLE signal when the bonded device is approaching. For the Mechanical Subsystem, it will use PWM signal to control the behavior of the engine.

List of Requirements:

- Identify the strength of BLE signal when devices approach 0.5m $\pm$ 0.1m.

- Store more than 5 different fingerprint information.
- Interacting with mobile app with error rate less than 5%.

2.3.2 Sensor Subsystem

This section encompasses both an infrared detection module and a fingerprint recognition module. The infrared detection module is designed to emit a signal to the ESP32 board, which activates the Bluetooth and WiFi modules upon detecting a person within a predefined proximity. This functionality ensures the system conserves energy by operating in a low-power state in the absence of individuals.

We utilize the FPM383C capacitive fingerprint sensor as our chosen fingerprint recognition module. This module stands out due to its compact size and low power consumption, making it an ideal match for our battery-operated door lock system. It operates on a 3.3V power supply and communicates with our ESP32 micro-controller via the UART serial communication protocol. Designed with a touch-to-wake feature to minimize power usage, the module can store up to 60 fingerprint records in its flash memory. It seamlessly integrates fingerprint scanning, storage, and recognition capabilities, rendering it suited for our application.

List of Requirements

- Able to collect and store the fingerprint of at least 5 users.
- Able to wake up when people stand in front of the door within a 120° sector area with radius 1m $\pm$ 0.2m.
- Identify the user fingerprint on touch in less than 2 seconds with a minimum accuracy of 80%.
- Able to interact with the ESP32 micro-controller to indicate the identity of the user via UART protocol.

2.3.3 Mobile Subsystem

This subsystem mainly interacts with the Controller Subsystem, as it provides a connection between the user and our device. Specially, we will use Wi-Fi and Bluetooth API in our backend of ESP32 to interact with the controller. Espressif provides detailed API documentation for us to achieve wireless communication.[1]. For the front-end of our software, we will use some widely used framework such as React and Vue. The Bluetooth is used to connect to the BLE module of ESP32. The challenging part of this subsystem is to maintain a stable and secure connection between our software and our device.

List of Requirements:

- Software shows the status of the device and records of fingerprints.
- A button on front-end page which allows the user to unlock the door in less than 3 seconds.

- The phone can control the device remotely.

2.3.4 Mechanical Subsystem

The servo motor are used to drive the actuator when it gets the signal to open the door. It is wired with the micro-controller, and uses PWM protocol to contact with the micro-controller. So it can get a PWM signal from the Controller Subsystem as a trigger. When the PWM signal requests to open the door, the servo motor will turn a particular angle and drive the actuator to move to some extent. By estimation, our door handle need around 25N to open, consider the arm of force in about 8∼9cm, we need a servo motor with its torque above 25kg·cm. TD-8125MG digital servo motor can be a candidate.

The actuator is directly contacted with the door handle. There are many possible designs for the actuator. One possibility is a hammer hanging above the handle inside, when the servo motor moves, the hammer can drop down and push the door handle to the appropriate angle so that we can open the door from the outside. Another strategy is to use a thread to pull the handle inside down, thus the servo motor should be installed at the bottom of the lock.

List of Requirements:

- A powerful enough servo motor to drive the mechanical actuator, approximately with its torque larger than 25kg·cm.
- A reliable mechanical actuator with links strong enough to move the door handle to the certain angle.

2.3.5 Power Subsystem

The power subsystem is the crucial part for powering up other subsystems, it should provide stable power to support the normal work of the entire device. The power can be provided by a 5V battery, which can be easily replaced when it dies out. Then for the voltage regulator circuit, we can use some adjustable voltage regulators to produce different stable voltage output, like LM317 3-terminal adjustable voltage regulator. The micro-controller and the fingerprint recognition subsystems need to work under 3.3V, but the 25kg·cm servo motor should work in about 4.8∼7.2V, and the ones with larger torque may need higher voltage. The voltage regulators should provide stable voltage for them and ensure that they can work normally.

List of Requirements:

- Provide at least 200mA, stable 3.3V power supply for the Controller Subsystem and the Sensor Subsystem.
- Provide at least 200mA, stable 5V power supply for the servo motor to work normally.

2.4 Tolerance Analysis

The common reason for failing to open the door might be that the torque provided by the servo motor was insufficient to overcome the limiting friction. To ensure the selection of a motor with adequate torque to smoothly rotate the door handle, we utilized an electronic dynamometer from the lab to measure the forces involved in rotating the handle. We operated the dynamometer slowly to mitigate any experimental errors caused by acceleration. As shown in the figure below, the data indicates that the peak force is approximately 24 N and the force stabilizes at 16 N, indicating that the maximum force we need is around 24 N. Considering that the distance from the attachment point to the axis of rotation is 8.5 cm, and using the formula $\tau = \vec{r} \times \vec{F}$, we calculated the required torque to be $\tau = \frac{24\text{N}\cdot 8.5\text{cm}}{9.8\text{N/kg}} = 20.8\text{kg}\cdot\text{cm} < 25\text{kg}\cdot\text{cm}$. Consequently, we selected the TD-8125MG digital servo motor with a nominal torque of $25\text{kg}\cdot\text{cm}$ to fulfill our requirements.

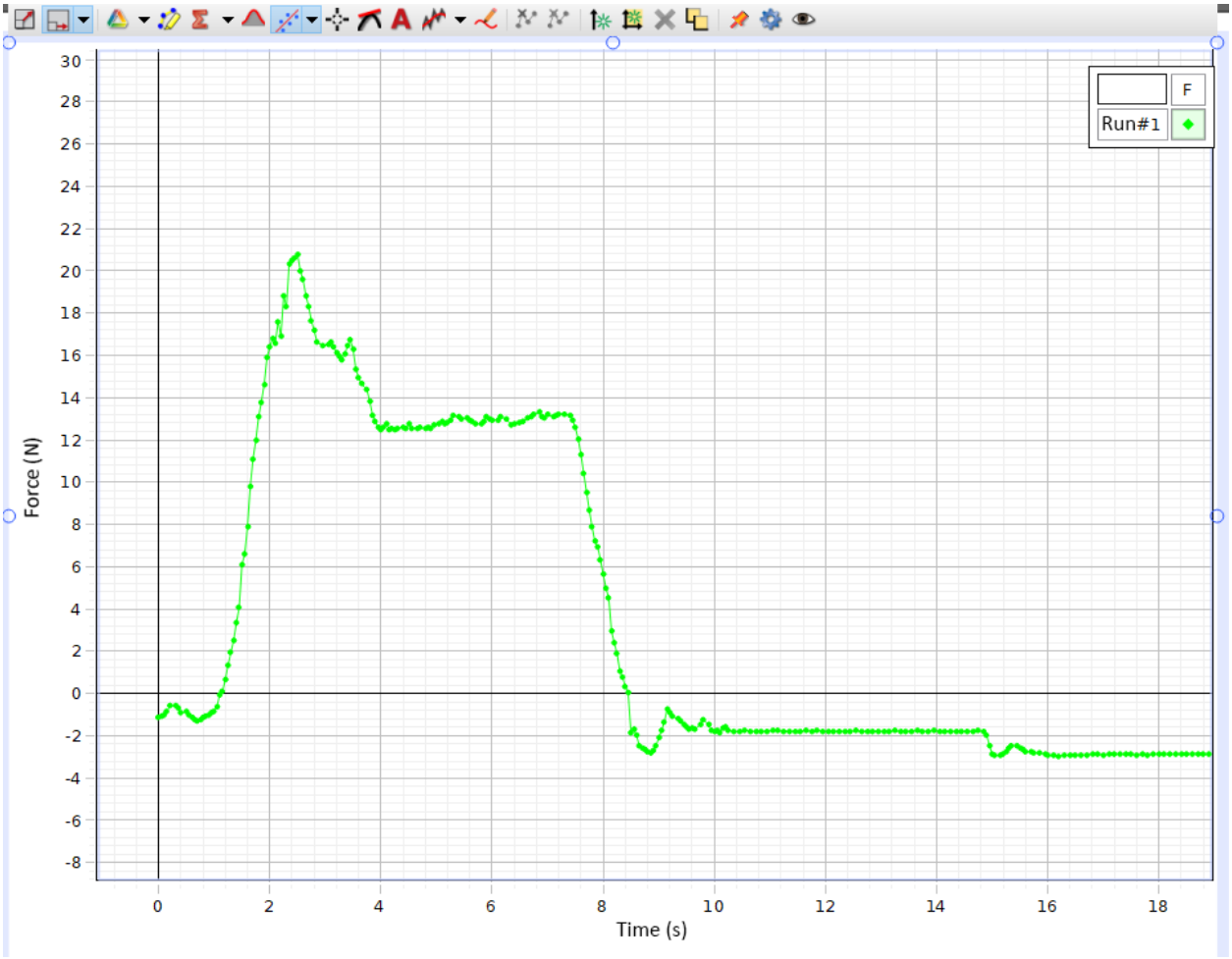

Figure 3: Force-Time Plot for Opening the Door

3 Ethics and Safety

3.1 Ethics

We intend to do experiments on doors inside our campus Residential College, which means we need approval from Residential College. IEEE Code of Ethics request avoiding real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist.[2] So we need to corporate well with Residential College and if we can't reach an agreement, we should try to do experiments on doors which are allowed.

ACM code of ethics[3] requests that we should avoid harm. While our project doesn't involve any organic living things, we still need to do experiments on doors. If not dealt in an appropriate way, we may cause damage to the door, which include stressing too much weight on the door knob, opening or closing the door in a rude way etc. In all cases, we should take full consideration before we start to do any experiments.

ACM code of ethics[3] requests that we should be honest and trustworthy. Our device's basic functionality includes unlocking a door using fingerprint and phone. We can achieve fingerprint recognition using specialized fingerprint sensors but we should achieve that using a simple touching sensors, which means not everyone can unlock the door. Also, for the remote control, we can use Wi-Fi, Bluetooth, SIM card or any other way. But in any cases, we must be transparent about our ways to achieve remote control.

3.2 Safety

As our fingerprint recognition door lock system requires electricity to work, we must pay attention to the usage of battery and follow ECE 445 safety guideline: Any group charging or utilizing certain battery chemistries must read, understand, and follow guidelines for safe battery usage.[4]. Battery is necessary for our project as we need to attach our device to a door. As our device is intended to be small and not having too much weight, we will use lithium batteries. However, lithium batteries are substantially more flammable.[5]. So we must pay attention to the usage of battery and we will use charger from laboratory to charge the battery. All team members have attended fire extinguisher training and there's fire extinguisher in our Residential College. In anyway, when we do experiments inside laboratory or on doors, we must be careful with the battery problem.

References

[1] ESPRESSIF. "Wifi api – arduino esp32 latest documentation." (2024), [Online]. Available: https://docs.espressif.com/projects/arduino-esp32/en/latest/api/wifi.html (visited on 03/07/2024).

[2] IEEE. ""IEEE Code of Ethics"." (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 03/07/2024).

[3] ACM. ""ACM Code of Ethics and Professional Conduct"." (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 03/07/2024).

[4] course staff. "ECE 445 safety guidelines." (2024), [Online]. Available: https://courses.grainger.illinois.edu/ece445zjui/guidelines/safety.asp (visited on 03/07/2024).

[5] course staff. ""Safe Practice for Lead Acid and Lithium Batteries "." (2016), [Online]. Available: https://courses.grainger.illinois.edu/ece445zjui/documents/GeneralBatterySafety.pdf (visited on 03/07/2024).