Face Identification Lock

ECE 445 Design Document

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Group 69

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1 Introduction

1.1 Objective

It is quite annoying when we are at the front door of our houses with hands full of things from the supermarket, but we can not enter in since we still have to take out the key from our packet to unlock the door. Just like we have different approaches to unlock our phone other than entering pins, physical keys can be more and more replaceable now. A face-identification lock is one solution to the problem of finding keys and losing keys. Instead of putting things on the ground and then use our free hand to get the key and unlock the door, we can easily stand in front of a camera and then the door will automatically unlock after it identify us.

The project we propose seizes the achievement of turning a cheap camera into an intelligent guard. Nowadays, face identification has been an active area with many deep learning methods. Specifically, a neural network approach is good to tackle the face detection while maintain a relatively high accuracy. According to a research conducted by Stanford University, their neural network algorithm is able to produce a 0.0884% false positive rate and overall 91% accraucy [1]. Even though the system does not necessarily seem more secure than a regular lock, it does provide us a much more convenient way to open the door when our hands are full while the tradeoff of security is in an acceptable level.

1.2 Background

At present, people are paying increasing attentions to home securities. The market of home security products will possibly reach 12 billion USD by 2025 [2]. In particular, the image processing technology has made more and more security solutions possible such as smart monitor systems or motion triggered cameras. As an alternative to traditional security systems that use passwords, cards, or keys, face recognition lock is one of the image processing technology that both offers users great convenience of hands free operation and ensures the sensitive area to be monitored and controlled[3]. However, we have to agree that there is no exact formula or rule to define one person's face. Thus we can not directly tell a computer to recognize a human being's face. Instead, we choose machine learning to approach such problem. We let the computer to learn from the experience by feeding with input and hand-designed features or multiple layers of features. By mapping from those features, the computer is able to provide us the output. Particularly, in our algorithm, we will use a fully-connected layer and a dropout layer

Our project only requires simple cameras, so it is cost effective and reliable compared to the average price of 400 USD of existing products in the market.

1.3 High-level Requirements List

- The false negative rate of our face identification system must be below 1%, which implies intruders have little chance to lock the door. Besides, overall accuracy rate must be above 85%, which means the lock works as intended at more than 85% of the time.
- The lock will respond to the user within 5 seconds. That is, either a led shows the face identification fails or the door unlocks.
- The microphone should be able to detect a voice command "open" and activated face identification system in the correct situation.

2 Design

Our design is make up of four components: a power unit, a recognition unit, a actual lock system and a printed circuit board (PCB). A power unit ensures the power supply to all of the other components so that the door lock system can work continuously all day. A recognition unit is the core of computing our convolutional neural network algorithm and feeding back our face identification outcome to the control unit in PCB. The PCB contains multiple chips and helps connect the other components. It detects sound and receives image signal if activated. Besides, it process the image into data we need for the computing part. It also contains a microprocessor to receive signals from the recognition unit and send to the lock system unit. The lock system unit contains a motor driver which helps unlocking the door if it receives a signal from the PCB.

In our design, the camera, will firstly take multiple pictures of the users and then transmit them to the recognition unit. The recognition unit has a pre-processed training model stored in a SD card which uses a convolutional neural network algorithm. Our camera data will go into the recognition unit as test inputs and the unit generates a true/false signal back to the control unit indicating whether the face identification success or failure. Here is a flow chart of the design, please refer to the state diagram to see more about how decision is made in the last step.

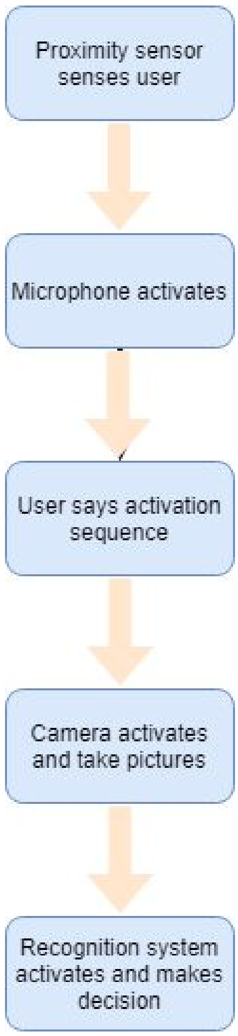

Figure 1.   Flow Chart

Block Diagram:

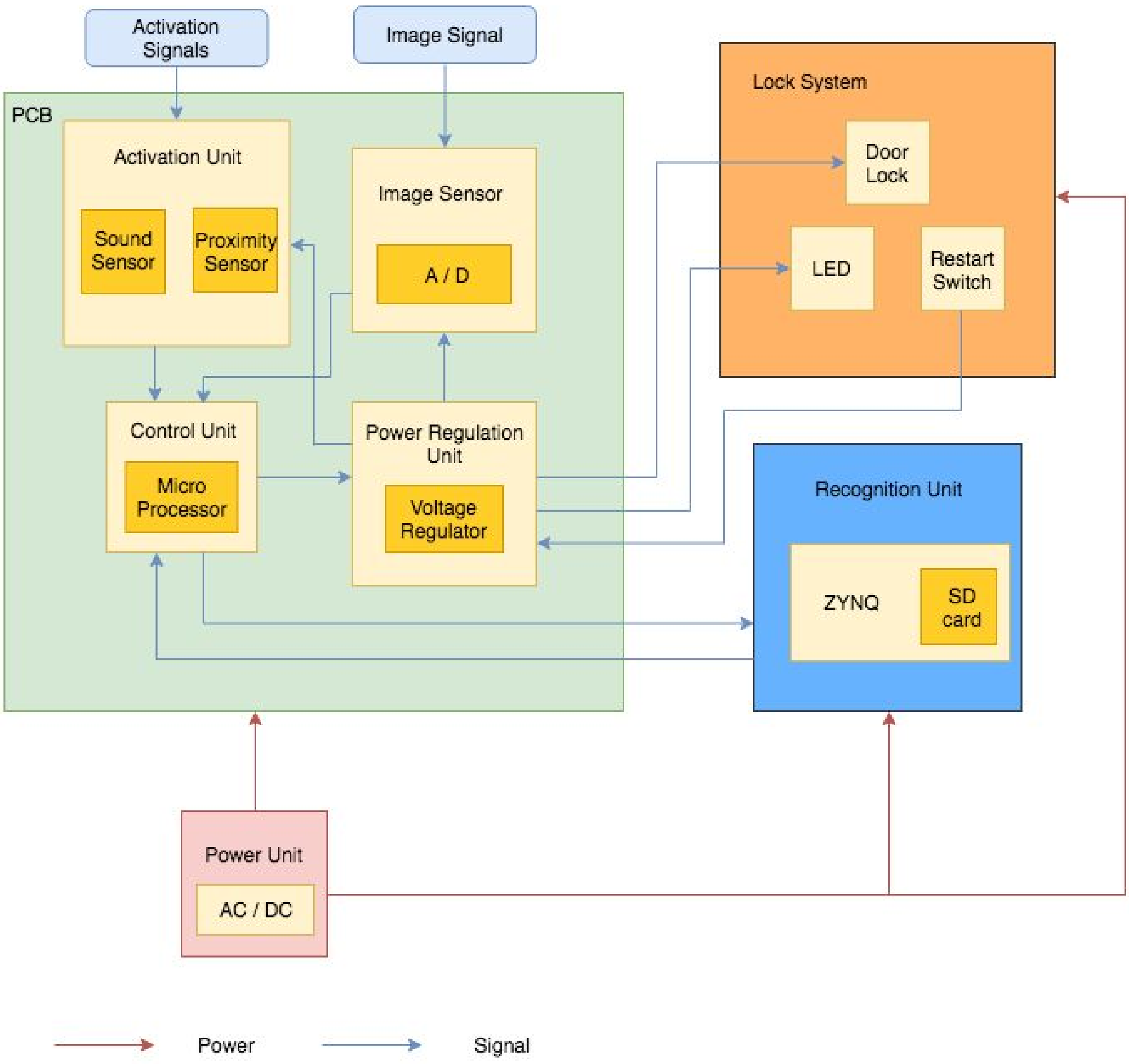

Figure 2. Block Diagram of the System

State Diagram:

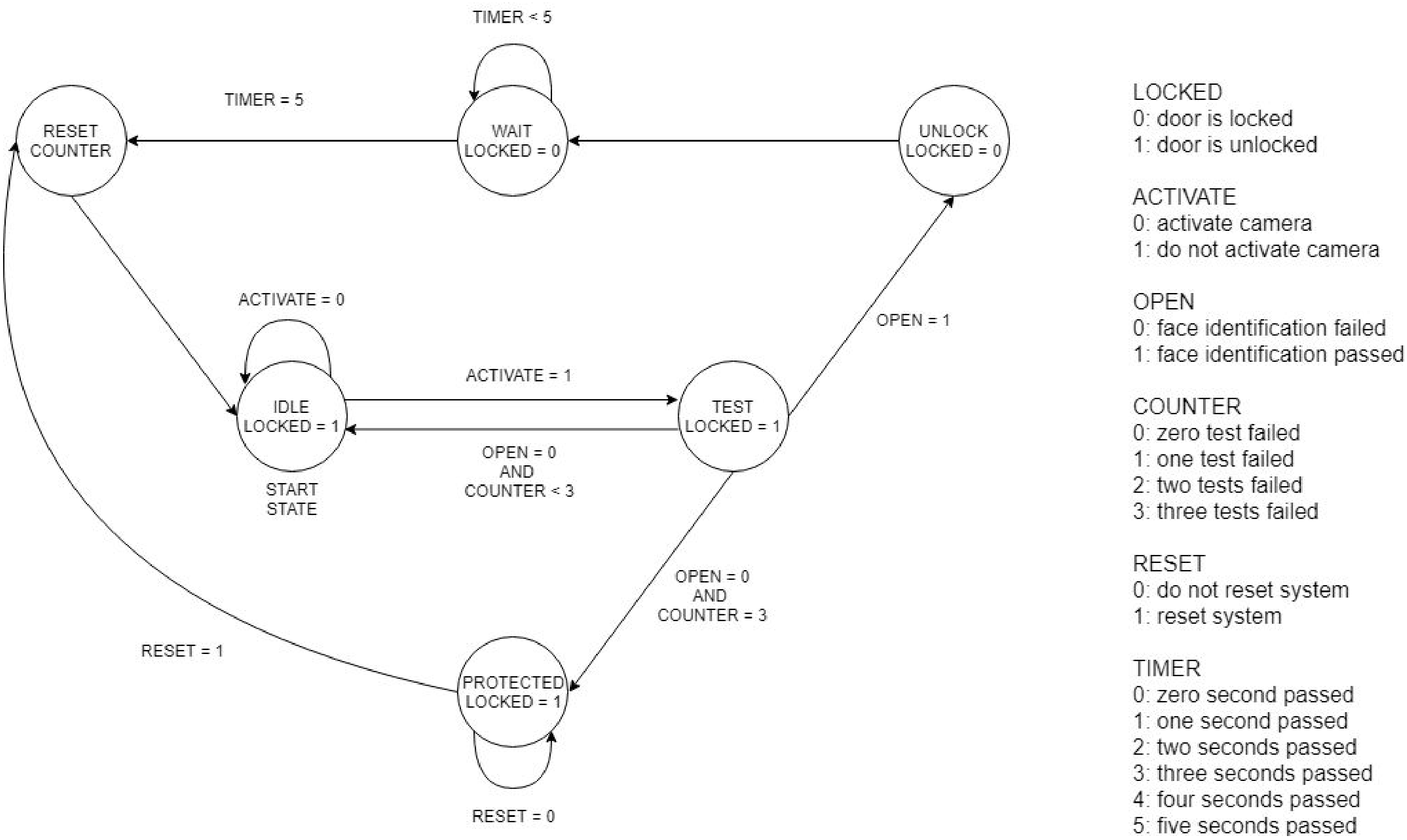

Figure 3. State Diagram of the Door Lock System

Please refer to 2.5 Tolerance Analysis for more discussion of the state diagram.

2.1 PCB

2.1.1 Image sensor

We plan to use OV7725 CMOS sensor as our image sensor. The sensor must be able to capture a picture where the camera faces and output the data into digital signal processor. We chose this camera because its operating voltage requirement is 5V , which is standard and same as our lock module. Besides, we want the camera be able to produce at least 30 images of 640*480 image in one second so that we can receive enough data to process in our face identification algorithm.

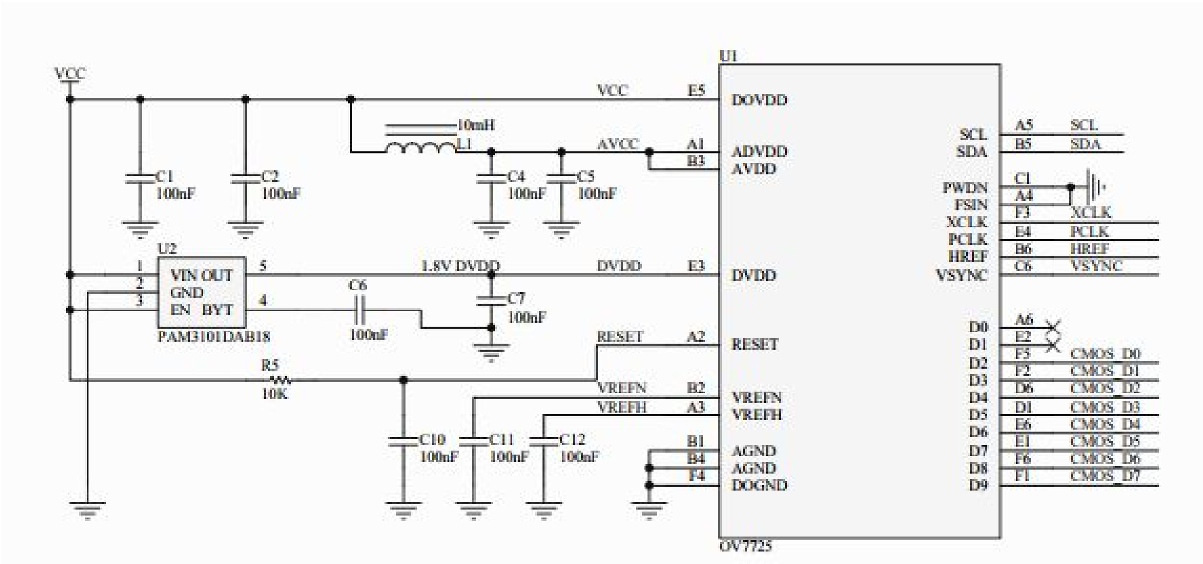

Figure 4.   OV7725 Image Sensor Circuit Schematic[9]

Requirements	**Verification**
1.Its activation flag is set only when it receives a signal from the control unit, otherwise it would be activated all the time without actual user being present, causing waste of power. 2. Outputs at least 30 images of 640*480 pixels in one second.	1.We use oscilloscope to check the activate signal pass into the image sensor. We observe when it turns to high and if the image sensor begins to take pictures simultaneously. 2. We generate the camera output into a computer and see how many images it has generated in five seconds. Therefore we can calculate the fps. Also we check the image property to see if it meets 640*480.

2.1.2 Activation Unit

We are going to use a microphone and an ultrasonic sensor for the activation unit. The ultrasonic sensor helps to detect whether there is a person standing in front of the door and then the microphone will be activated to receive voice. If the voices detects a human voice command “open” , the image detector will finally be activated. In this way, we help to avoid a problem which some noises accidentally activate our face identification system.

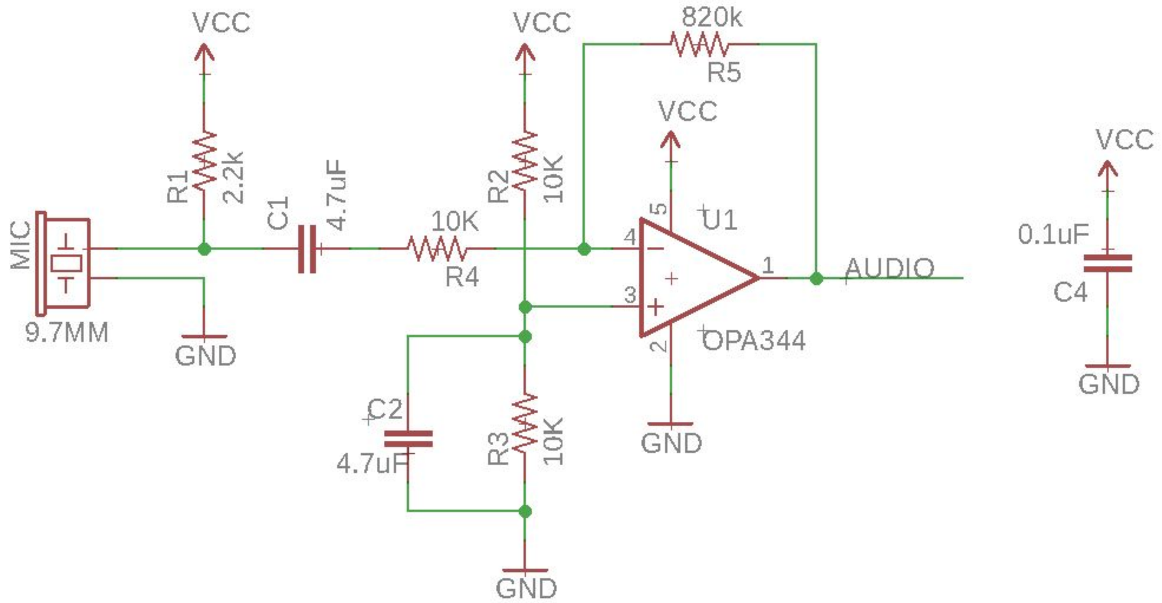

Figure 5.   Microphone Circuit Schematic

The designed circuit above has a voltage gain of 82V/V, which is approximately 80dB. And we place a decoupling capacitor near to OPA344 to prevent some circuit interference. The output AUDIO has a voltage of half the supply voltage, which is ready to input to the ADC of our microcontroller.

Requirements	**Verification**
1. The ultrasonic sensor should only detect an object within a range of 0.45~0.55 meters and a height of ~1 meter.	1. We use the sensor to test if it detects an object within the certain range and also test it does not detect it without the range.
2. The microphone is able to detect the sound command “open.”	2.We test with different sounds and see if the microphone filter works as intended.

3. It requires a voltage of 3~3.6V.	3.We gradually increase the DC source from 3V to 3.6V and check if the sound sensor is working during the time.

2.1.3 Microprocessor

We plan to use ATMega328P microprocessor that controls the operation of the whole system: activation of image sampling, signal of computing algorithm on face identification, and the control of motor driver. The microprocessor has processing power of 20 MIPS at 20MHz.

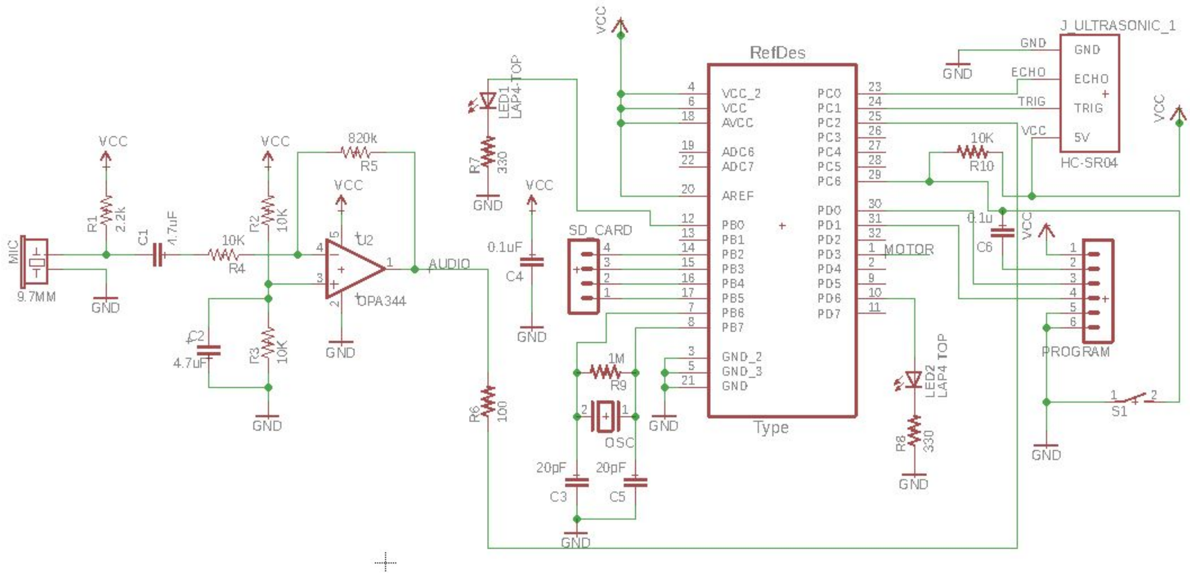

Figure 6. Microcontroller Circuit Schematic

Figure 5 above shows the input and output from or to other modules of our circuit. We will need a crystal oscillator built inside as a generated clock signal to synchronize the circuit. We will first build this design with our dev board, and then program it using kit in the lab.

Requirements	Verification
1. It should be able to perform in voltage 3-3.6V.	1.We gradually increase the DC source from 3.0V to 3.6V and check if the microprocessor is working during the time.
2. It correctly accepts and delivers the flag signals to other parts as described in the block diagram.	2. We use oscilloscope to check if the signals are transmitted as expected, meaning signal should be correct and in time.

2.1.4 Power Regulation Unit

We plan to use LM317 voltage regulators to manage out voltage supply for different components on PCB as they have different voltage input requirements.

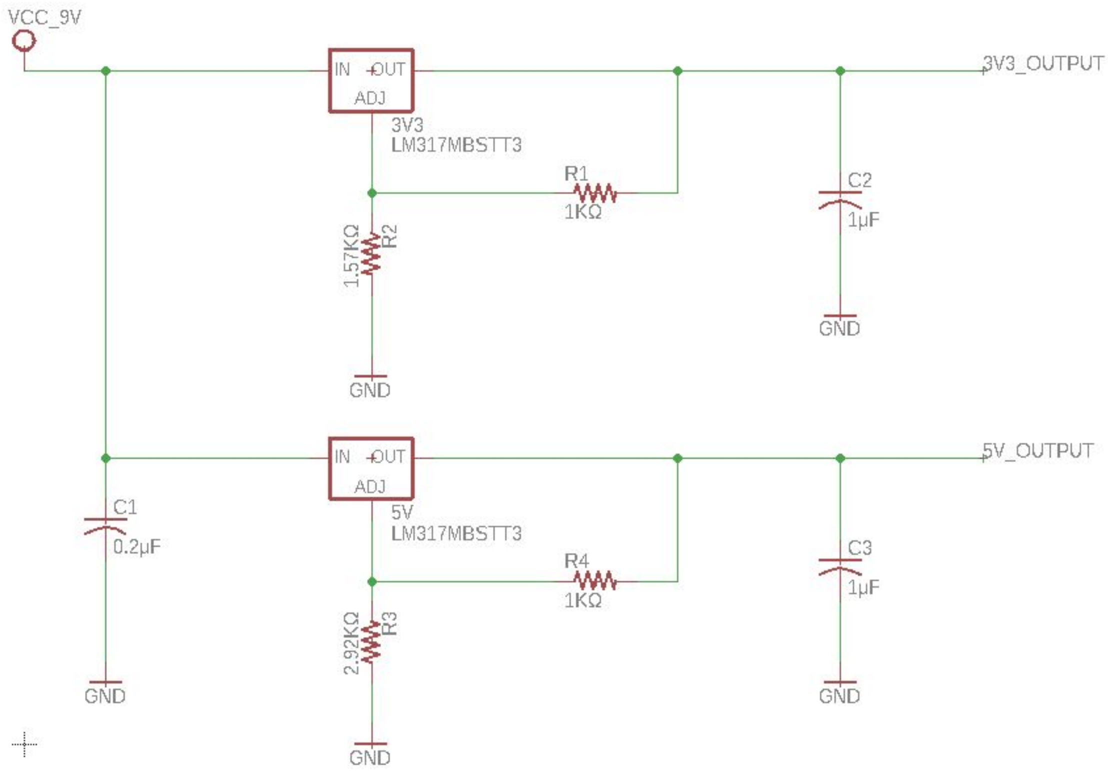

Figure 7. Power Regulator Unit Circuit Schematic

Requirement	Verification
It should be able to take an input of 9V and output stable voltage that works for microcontroller (3.3V), sound sensor (3.3V), image sensor (3.3V) and ultrasonic sensor (5V).	After the circuit is complete, we can set Vcc to 9V and test voltage output on two output lines.

2.2 Lock System

2.2.1 Motor Driver

The motor receives an PWM signal sent by aforementioned microprocessor. Then it sends an unlock signal to the door lock. The door lock we choose does include a motor driver inside.

2.2.2 Door Lock

We plan to use FC MXBB DC door lock. Upon receiving the unlock signal, it rotates to unlock the door. It will remain unlocked for a short amount of time and tries to relock the door.

Requirements	Verification
After receiving the PWM signal, it unlocks within one second and it will relock after 4.5s~5.5s.	We use a function generator to manually gives a PWM signal to the door lock and check if it works as intended.

2.2.3 LED

The LED takes signal input from MCU, indicating whether the facial recognition failed or passes. When the recognition process failed, it blinks red light; when passed, it blinks green light.

Requirements	Verification
1. Output represents the control signal (ie. red for fail identification and green for success) 2. The brightness should be strong enough that we should see it even under the sun.	1. We manually give a control signal and check it it matches the LED output. 2. We gives power to the LED and see if it meets the condition.

2.3 Power Unit

Power unit supplies DC power to all the other units. It is connected to a AC wall plug, with a AC to DC converter. We also need to design a regulator that stabilizes the circuit.

All of the input voltage to the chips and units should be strictly controlled within limit range. We need a range from 11.5~12.5V converted from AC wall power.

2.4 Recognition Unit

Face identification runs on a PYNQ FPGA board. Its inputs are the raw images from the image sensor. The input test image should be tested by the pre-trained neural network, and the recognition unit should be able to output identification result that is either true or false. The output signal will go back to the control unit.

2.4.1 PYNQ

PYNQ board is based on ZYNQ chip. We choose this board because it has BNN framework implanted which supports convolutional neural network [4]. We will use Vivado to implement the SoC design.

Requirements	Verification
1.We require PYNQ to perform given algorithm within 3 seconds so that the user would not be waiting for too long.	1.We run our current algorithm on PYNQ using sample pictures to see if its running time matches our expectation.

2.4.2 SD card

SD card can be used as memory once formatted. It should be big enough to store about hundreds of images as trainned data.

Requirements	Verification
1.We require a storage of ~16GB to store the photos as training data. 2. To respond quickly, we require a data transfer (write) rate of at least 20MB/sec, since pictures taken by OV7725 CMOS sensor in one second is around 55MB.	1.We plug the SD card into laptop and right click its properties to see its actual storage. 2. We manually send a package of 55MB to the SD card multiple times and calculate average time it takes.

2.5 Tolerance Analysis

Since our project is a security device, lowering the error rate is extremely essential. There are two types of error: a false negative and a false positive. A false negative will lock the user from entering the door, but could be simply solved by a key. Just like the face id system of iPhone 10: a negative result of recognition would prompt the password option. A false positive, however, is way more dangerous. It would allow intruders to use this glitch to unlock the door.

With our current algorithm and design, the total error rate is less than 15%. False negative rate is estimated around 10%, therefore, false positive rate is less than 5%. Our OV7725 CMOS sensor will take 60 pictures in one second. We will first rule out bad inputs like blurred pictures. Then we will randomly pick 10 out of the good inputs to test. If 9 out of 10 good inputs match the pre-stored data, the door unlocks. Also, the user has three chances to unlock the door, if all three failed, the system will enter protected state, which disables the face identification system. The user can only unlock the door using a key.
The probability for an intruder to pass a test is $5\%^9$. We assume this probability to be independent of the others because each sample will be randomly chosen by our algorithm.

The probability of an intruder successfully breaks in should be: P = first test passed + first test did not pass but second test passed + first and second tests did not pass but third test passed. Since there is 5% false positive rate and 85% true positive rate, we can calculate P like this:

$$P_{BreakIn} = (5\%)^9 + (85\%)^2 * (5\%)^9 + ((85\%)^2)^2 * (5\%)^9 = 4.384 * 10^{-12}$$

We will also continue to try to improve our facial recognition algorithm to reduce false positive and false negative rate.

On the other hand, we have to also make sure the completion time for one operation cycle is short enough. It is clearly not a good idea to let the user wait for a couple of minutes before they can enter their place.

First user activates the system using voice command over 60 decibels, which is the average level of human voice volume. Since the SEN12642 sound detector uses analog signal, we consider it to be real time.

After the activation signal is sent, OV7725 CMOS sensor starts to take pictures. It takes one picture in around 0.01667 second. For aforementioned reason, we would like it to take more than a few pictures. So we would give it one second to take pictures.

The pictures are sent to SD card in PYNQ module. The write speed and read speed of our SD card, according to the datasheet, should be around 50MB/sec and 90MB/sec. The amount of data we write and read is:

$$D = 3 * 640 * 480 * 60 / 10^6 = 55.629MB$$

Thus the total read and write time is 1.73 seconds.

Then we want to make sure the computation time of our algorithm is acceptable for a real-time face identification system. Since we have not implemented the code completely, we can only offer an estimation based on our experience. With trained model, our algorithm should respond as quickly as 0.01- 0.1 second per picture. Thus an estimation of total response time should be 0.1 - 1 second.

At last the MCU sends unlock signal to motor driver, which we tested: it takes less than one second to unlock.

Consider propagation delay, MCU operation time, a close estimation of one operation cycle (unlock attempt) is:

$$t = 1.73 + (1 - 0.1) / 2 + 1 + 0.5 = 3.68 \pm 0.45 \textit{ seconds}$$

It does not take much longer than finding the key in your pocket or bag, take it out and unlock the door.

2.6 Software

2.6.1 Face Detection

One important process before the face identification would be the image pre-processing. For image inputs that have too much noise, unclear or contains no actual face, we do not want them to be considered during the test process. To achieve that, we will need face detection on every raw image.

We will be using Adaboost with image integral to detect and select valid face in the images. The boosting algorithm will help us on strengthening our neural network classifiers by adjusting weights in the image. The detection process could be done using image integral that helps to find face features, or Haar-like features.

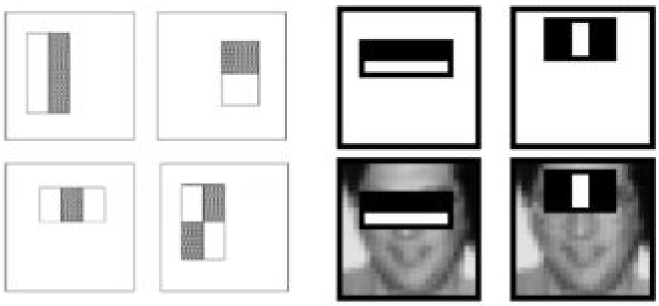

Figure 8. Rectangular Filters [11]

The feature output, as shown below, is the difference between two adjacent regions. One way of implementing fast computation of such difference is the image integral, so that every pixel is the sum of its neighbors to the upper left. Adaboost is used to choose the right and robust filter among various rectangle filters.

$$value = \sum(pixels\ in\ white) - \sum(pixels\ in\ black)$$

Formula 1. Feature Output Value[11]

Once this process is done all of the qualified face image data will be sent to the recognition algorithm for face identification.

2.6.2 Convolutional Neural Network

The software in our project is essential to accomplish our goal of face identification. We use a Convolutional Neural Network algorithm to approach the problem. We can build multiple layers called "feature maps" to map our image input to a simple output like "yes" or "no" representing as 0, 1.

The Convolution method help holds meaningful features in small spatial regions. It is particularly useful as it requires less storage, better statistical characteristics and faster training. However, it may require multiple layers for wide receptive field.

Within the algorithm, we want a fully-connected layer since we not only want to convolute the data but also want to resample and make sure that accuracy does not decrease. We may need an additional dropout layer or cross validation to control the success rate and the problem of overfitting.

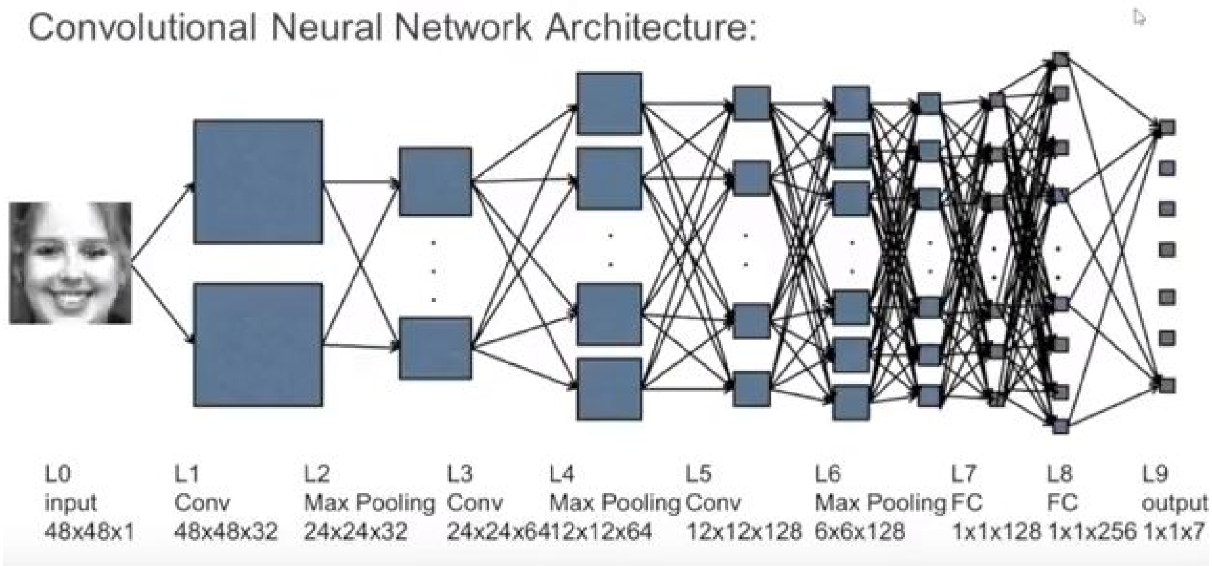

Figure 9. A example of CNN architecture [10]

As shown in figure above, our pre-processed data will feed in as a test input to the trained neural network, which consists of three convolutional layers, three pooling layers, two fully connected layers and one output layer. Inside convolutional layer, randomly generated square weight patch will convolute over the input image to that layer, the patch could have a size of 10 by 10, and we still need to test which size gives the best result. The max pooling layer basically extracts the most important message (highest weight pixels) from its previous convolutional layer, and down scale the image with most of the unuseful data (low weight pixels) dropped. The fully connected layer and the output layer do the job of connecting all of the input volumes and outputs them into N classes. In our case, the face ID will only have two classes ("Is you" or "Is not you"). Softmax layers are commonly used for multiclass situations, but we can still use it here on two-class classification. For any other parameter, such as number of neurons, size of batch that needed to be frequently adjusted for better performance, we are not able to provide a fixed value.

3 Costs

3.1 Labor:

Our estimation of hourly wage is estimated based on majors.

Name	**Estimated Hour**	**Estimated Labor Cost**
Kaiji Lu	90	$3600
Zan Chen	90	$3600
Zekun Hu	90	$3150
Total	270	$10350

Table 1. Labor Cost

3.2 Parts:

Part Number	**Part Name**	**Manufacturer**	**Description**	**Quantity**	**Cost**
OV07725-V28A	OV7725 CMOS Sensor	Spinal USA	Image sensor on PCB	1	$28.00
CEM-C9745JAD462P2.54R	Microphone	SparkFun	Electret Microphone	1	$11.95
SEN13959	HC SR04 Ultrasonic Sensor	SparkFun	Proximity sensor on PCB	1	$3.95
ATMEGA328P-AU	ATMEGA328P-AU	MICROCHIP	Microprocessor on PCB	1	$13.00
ROB-09065(Sub-macro size)	Servo	SparkFun	Lock system	1	$8.95
PC6	DC Power Converter	Schumacher	Power unit	1	$18.39

ZYNQ XC7Z020-1CLG400C	PYNQ-Z1	Digilent	Recognition unit	1	$229.00
16G UHS-1 U3 Class10 TF	Micro SDHC U3 Card	Amplim	RAM for ZYNQ	1	$13.92
FD-5WSRGB-A	10mm Diffused RGB LED	FEDY	LED in lock system	2	$4.00
LM317MBSTT3	LM317	TI	Power Regulation Unit	2	$9.40
ECS-160-20-3X-EN-TR	Crystal Oscillator	ECS	CLK for PCB	1	$0.46
KS-01Q-01	Switch	E-Switch	Reset system	1	$0.53
Total Cost	$341.55				

Table 2. Parts Cost

3.3 Grand Total:

Grand Total = Labor Cost + Parts Cost = $10690.32

4 Schedule

Date	Objectives	Kaiji	Zan	Zekun
Feb 19 - Feb 25	Write design document	Revise design document	Write cost and schedule	Finish circuit diagram
Feb 26 - Mar 4	Revise design after design review, order parts	Revise design document, prepare PCB design	Prepare PCB design, order parts online	Prepare PCB design
Mar 5 - Mar 11	Design and order PCB, test arrived parts	Test individual parts	Design PCB	Design PCB with Zan, prepare coding
Mar 12 - Mar 16	Coding and test other parts	Testing other parts, help with coding	Coding, help in testing other parts	Testing algorithm
Mar 26 - Apr 1	Coding / Debugging, assemble all parts	Start assembling all parts	Debug to finish the coding part, help in assembling design	Debug to finish the coding part, improve accuracy
Apr 2 - Apr 8	Test, debug and improve design performance	Debug the design on hardware level	Improve design performance	Debug and improve the design on software level
Apr 9 - Apr 15	Debug and finalize design	Continue debugging if necessary	Finalize design, prepare final papers	Finalize design, prepare final papers
Apr 16 - Apr 22	Write final report, prepare mock demo	Prepare mock demo and presentation	Write final report	Collect statistics from demo for final report
Apr 22 - Apr 29	Summarize, finish final report	Summarize design, help in revising final report	Revise final report	Revise final report with Zan
Apr 30 - May 3	Prepare final presentation, wrap up	Prepare final presentation, finish final report	Prepare final presentation, finish final report	Prepare final presentation, finish final report

Table 3. Schedule

5 Ethics and Safety

There are some ethical concerns with our project. As our project includes a facial identification, we inevitably need to process people's photos. We here promise that all the information through our technology is confidential as we should not go against the IEEE code of Ethics. As #1 and #9 mentions, we have to "disclose promptly factors that might endanger the public or the environment " and "avoid injury other's property" [5]. We not only need to make sure we do not misuse the data but also we have to carefully protect our data.

Since our project relates to a door lock , we have to try our best to improve the accuracy of our algorithm. As following the IEEE code of Ethics #7 , we humbly accept helpful advices or criticisms from all sources and we ensure that we credit these contributions properly. Besides, according to the IEEE code of Ethics #3, even if our final project does not come to be as accurate as we expect initially, we promise to report the true result and give justified claims. [5] We will truly report the outcome and statistics of our final project and compare them with our requirements.

The safety of our physical design is relatively high. We may have potential overheat for several chips and a motor which controls the lock. However, we do need to pay attention to our data safety when we use convolutional neural network to accomplish the goal of face identification. We have to watch out whether the data are going somewhere else when we did not intend. That's a big safety concern and an ethical issue as we talked before.   All cloud services based on the US, the UK, France and other jurisdictions known to be tolerant of NSA-style snooping, which means the data we store on the cloud services all have potential danger of being accessed by others [6]. Thus, it is important for us to protect these identifiable information that we collect during our trials. One potential way to keep our data safe is to encryption and avoid storing too much data on the cloud services.

Finally, we aim to create good, safe and convenient intelligence system for others. To meet ACM Code of Ethics and Professional Conduct #1.1 , we dedicate to create a "safe social environment" as well as a "safe natural environment" [7]. That's why our product aims to be lower cost than a surveillance camera but also high-accuracy promised intelligence system.

6 References

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