Development of an ESP32-CAM-Based Facial Recognition Smart Lock System

Submitted By

Student Name	Student ID
Aysha Siddika Bithi	221-15-5314
Shah Afsana Rahman	221-15-4712
Md. Ibrahim	221-15-5282
Md. Sohel Rana	221-15-5280
Nahida Akter	221-15-4711

LAB PROJECT REPORT

This Report is presented in Partial Fulfillment of the course **CSE:233 Embedded System & IoT Lab in the Computer Science and Engineering Department**

DAFFODIL INTERNATIONAL UNIVERSITY

Dhaka, Bangladesh

August 22, 2025

Abstract:

The ESP32-CAM Face Detection Door Lock System is a smart security device that uses a small computer with a camera to control who can open a door. The system works by taking pictures of people who want to enter, then checking if their face matches someone who is allowed inside. If the person is recognized, the door automatically unlocks. If the person is not in the system, the door stays locked. This project shows how cheap, internet-connected devices can be used to create effective security systems. The ESP32-CAM is an affordable piece of technology that can store photos of approved users and compare them with new visitors in real-time. By combining a camera, face recognition software, and automatic door controls, this system proves that advanced security features don't have to be expensive or complicated. The device can be used in homes, offices, or other buildings where people want to control access safely and easily, making high-tech security available to more people at a lower cost.

1. Introduction

Today's security needs require more than simple locks and passwords because these traditional methods can be easily stolen, copied, or broken into by hackers. Standard key-based locks present significant weaknesses, as keys can be lost, stolen, or duplicated without the owner's knowledge. Password systems face similar challenges, with users often choosing weak passwords or reusing the same codes across multiple systems, making them vulnerable to cyber attacks.

Biometric systems that use physical features like face recognition provide better security and are easier to use. Unlike keys or passwords, facial features are unique to each person and cannot be easily replicated or forgotten. This technology eliminates the need to carry physical keys or remember complex passwords, while offering a higher level of security through biological identification.The ESP32-CAM module comes with a built-in camera and wireless internet connection, making it a small and low-cost option for creating door locks that work through face detection. This microcontroller combines processing power with imaging capabilities in a compact design that fits easily into existing door frame structures. The integrated Wi-Fi functionality allows for remote monitoring and system updates, while keeping overall costs significantly lower than commercial security systems.

This project focuses on building a computer system that improves security for homes and offices by only allowing entrance to people who have been previously registered in the system. The solution addresses the growing need for reliable, user-friendly access control that can be implemented without extensive technical expertise or major infrastructure changes. By combining affordable hardware with proven face recognition technology, this system makes advanced security features accessible to a wider range of users and applications.

2. Objectives

- To design a door lock system using ESP32-CAM with face recognition technology that can accurately identify and verify users through facial features.
- To store authorized face data securely within the ESP32-CAM module's memory.
- To unlock the door automatically when a stored face is recognized by the system, providing seamless entry for authorized individuals without manual intervention.
- To provide a cost-effective and efficient security system that offers advanced protection features at a fraction of the cost of traditional commercial security solutions.

3. System Architecture

3.1 Components Used:

- **ESP32-CAM Module**: Takes pictures of faces and checks if they match people who are allowed to enter.
- **Relay Module:** Works like an electronic switch that turns the door lock on and off when the ESP32-CAM tells it to.
- **Solenoid Lock:** The actual lock that opens and closes the door when it receives an electric signal.
- **LED Indicator:** A small light that shows what the system is doing - whether it's on, if someone was recognized, or if access was denied.
- **Breadboard**: A plastic board with holes used to connect wires and test the circuit before putting everything together permanently.
- **12V Power Supply:** The main power source that provides electricity to run the whole system.
- **7805 Voltage Regulator:** A small device that changes the 12V power down to 5V, which is the right amount of power the ESP32-CAM needs to work properly.
- **220µF Capacitor:** An electronic part that helps keep the power steady and reduces electrical noise that might cause problems with the system.

3.2 Block Diagram

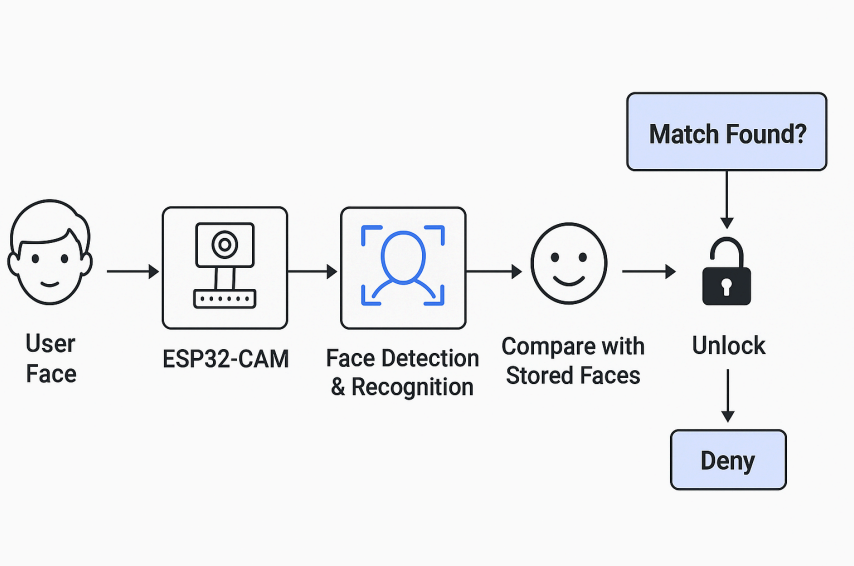
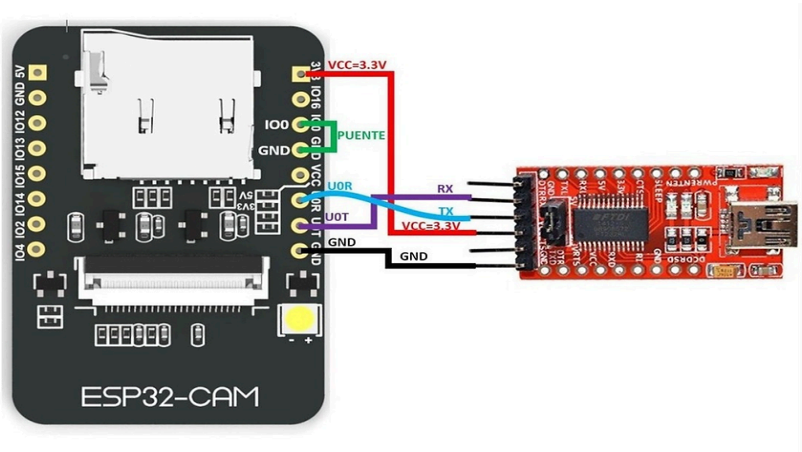


Fig 1: Block diagram for **Face Recognition Access System using ESP32-CAM**



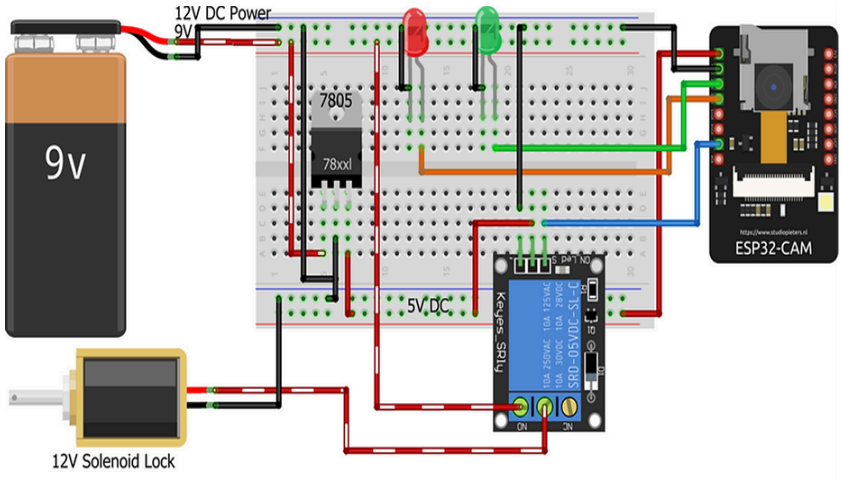


Fig.2: Diagram for **Face Recognition Access System using ESP32-CAM**

4. Methodology

4.1 Hardware Design :

The hardware design of the ESP32-CAM Face Detection Door Lock System uses several simple parts connected together to make a working security system. All the parts are placed on a breadboard, which makes it easy to build and test.

The ESP32-CAM is the main brain of the system. It sits on the breadboard with its camera pointing out so it can take pictures of people's faces. This small computer does all the thinking and controls the other parts.The system gets power from a 12V wall plug. Since the ESP32-CAM needs only 5V to work, a voltage regulator (7805) is used to change the 12V down to 5V. A capacitor is added to make the power smooth and steady, so the system works without problems.A relay module is connected to the ESP32-CAM. The relay works like an electronic switch that can turn the door lock on and off. When the camera recognizes someone who is allowed in, the ESP32-CAM tells the relay to unlock the door.An LED light is connected to show what the system is doing. The light can tell you when the system is on, when it's checking a face, when someone is allowed in (green light), or when someone is not allowed (red light).All the parts are connected with colored wires on the breadboard. The wires carry power to all parts and carry control signals between the ESP32-CAM and the other components. The breadboard makes it easy to connect everything without having to solder wires together.The whole system is small enough to fit near a door. The wires are organized so they don't block the camera view, and all connections are secure so the system works reliably.

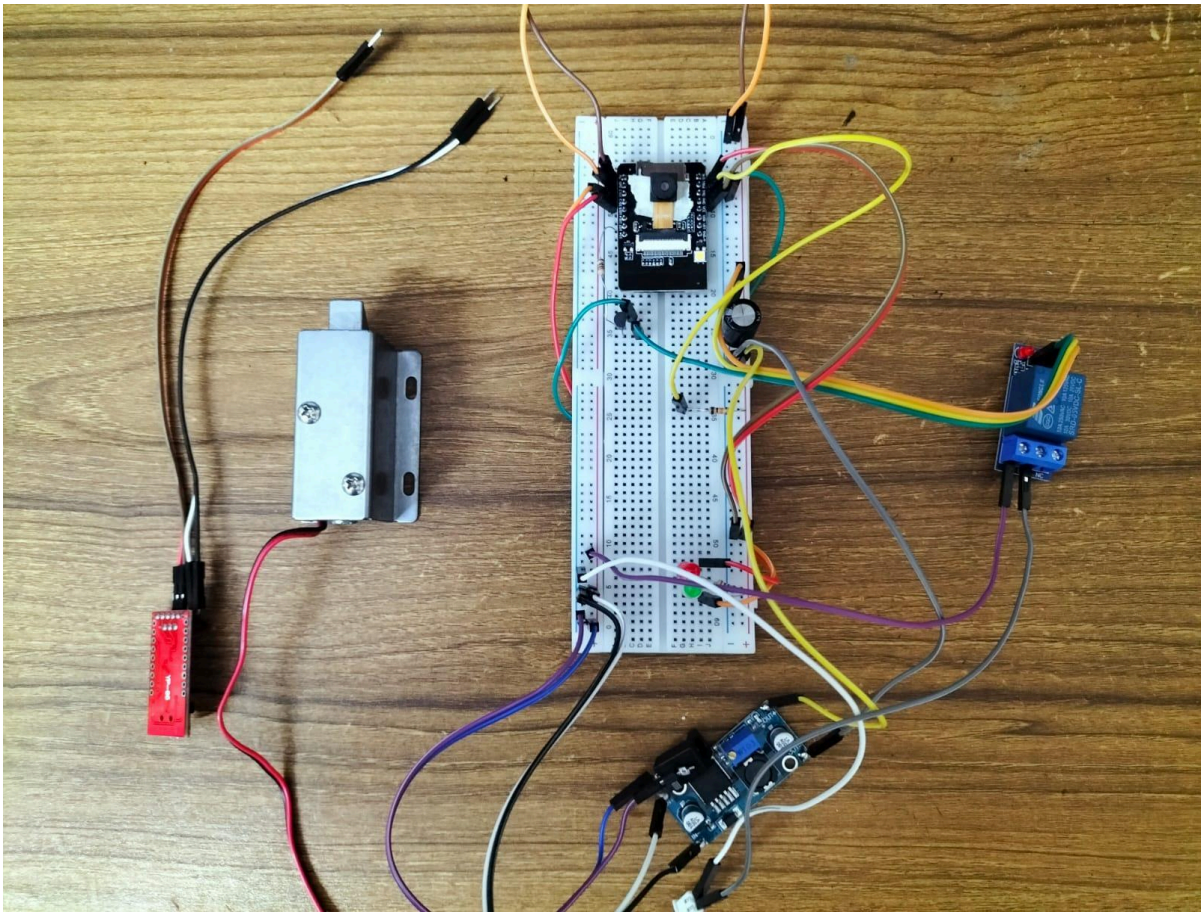


Fig 3: Hardware setup

4.2 Software Design

The software design of the ESP32-CAM Face Detection Door Lock System is built using simple programming that makes the camera smart enough to recognize faces and control the door lock.

1. The software is written in C++ using the Arduino programming language, which is easy to understand and work with. The program has different parts that handle specific jobs like taking pictures, finding faces, comparing faces, and controlling the door lock.
2. When the system starts up, the software first sets up the camera to take clear pictures. It tells the camera what size pictures to take, how bright they should be,

and how fast to capture them. The software also connects the ESP32-CAM to the WiFi network so it can be controlled remotely if needed.

3. The software continuously takes pictures and looks for faces in each image. It uses special algorithms (smart math functions) that can find human faces even if the person is standing at different angles or in different lighting. When a face is found, the software draws an invisible box around it to focus on just that face.
4. Once a face is detected, the software compares it with stored pictures of people who are allowed to enter. The system keeps a database (like a digital photo album) of approved faces in its memory. The software measures different features of the face like the distance between eyes, nose shape, and other unique characteristics.
5. The software uses a scoring system to decide if faces match. If the new face scores high enough compared to a stored face (usually 70% or higher match), the system considers it a match. If the score is too low, it means the person is not recognized.
6. Based on the face recognition results, the software controls the hardware components. For recognized faces, it sends a signal to unlock the door, turns on a green LED, and records the successful entry. For unrecognized faces, it keeps the door locked, shows a red LED, and may sound an alarm.

Safety Features:

The software includes safety measures like automatic re-locking after a few seconds, protection against system crashes, and the ability to work even if the internet connection is lost. It also saves important information so the system remembers authorized users even after losing power.

4.3 Communication Protocol

The communication protocol explains how the different parts of the ESP32-CAM system send messages and work together.

1. The ESP32-CAM talks to other parts using simple electrical signals. It sends 5V signals to mean "yes" or "on" and 0V signals to mean "no" or "off." This is how it controls the door lock, LED lights, and other components through connected wires.
2. The system connects to your WiFi network just like a phone or computer. It gets an IP address and can communicate through the internet. You can access the system by typing its IP address into any web browser to see the camera and control settings.
3. When sending information, the system uses simple text messages in JSON format. For example, it might send: "face detected: yes, access: granted, door: unlocked." This makes it easy for other devices to understand what's happening.
4. The system constantly sends status messages like "camera ready," "checking

face," "access granted," or "access denied." This helps users know what the system is doing at any time.
5. All communication uses password protection to prevent unauthorized access. Only people with the correct login information can control the door lock system remotely.
6. If the WiFi stops working, the system continues operating locally. It saves important events in memory and uploads them when the internet connection returns. This ensures the door lock works even during network problems.

5. Implementation

5.1 Face Enrollment

Getting people registered in the system is pretty straightforward but needs to be done carefully. People need to stand about 2-3 feet away from the camera with decent lighting - no point trying to register someone's face if the camera can't see them properly. The system grabs several photos from slightly different angles so it doesn't matter if someone approaches the door from the left or right side later on.

The ESP32-CAM looks at each photo and picks out important facial features - things like how far apart someone's eyes are, their nose shape, that kind of stuff. It turns all this into numbers the computer can work with and stores everything in the ESP32-CAM's memory with a unique ID number for each person. The system keeps this information secure so random people can't mess with it.

When everything's done, a green light comes on to let you know the person's face is now in the system. The whole process takes just a few minutes per person, and you can register multiple family members or authorized users. Once someone's enrolled, they don't need to do it again unless there are major changes to their appearance.

5.2 Face Recognition

This is where the real work happens - the system needs to figure out who's who every time someone shows up at the door. The camera keeps taking pictures every few seconds, looking for faces without needing anyone to wave at it or press anything. First thing it does is figure out if there's actually a human face in the picture, which is pretty important since you don't want it trying to unlock the door for a backpack or someone's dog.

Once it finds a face, it measures the same features it stored during enrollment and compares them against everyone in its database. It's basically asking "do I know this person?" and calculating how similar the new face is to each stored face. The whole comparison process happens in just a couple of seconds, so people don't have to stand around waiting.

If the system finds a good match (usually needs to be at least 70-80% similar), it unlocks the door and flashes a green light. You've got a few seconds to get through before it locks again automatically. No match means no entry - red light blinks, door stays locked, and that's that.

People can try again if the first attempt didn't work well, maybe by positioning themselves better or making sure there's enough light.

5.3 Lock Mechanism

The actual door locking part is simpler than the face recognition, but it's what makes the whole system useful. The relay is basically an electronic switch that can handle more power than the little ESP32-CAM can provide directly. When someone's face gets recognized, the ESP32-CAM tells the relay to flip on, which then connects the 12V power supply to the solenoid lock.

The solenoid has an electromagnetic coil inside that creates a magnetic field when it gets power. This magnetic force pulls back a metal bolt, unlocking the door so people can push it open. The whole unlocking process is pretty quick - usually takes less than a second from recognition to the door being ready to open.

After about 5-10 seconds, the system automatically cuts power to the relay and springs inside the lock push the bolt back out, securing the door again. If something goes wrong with the power or the system crashes, the door stays locked - better safe than sorry. There's still a way to unlock it manually from inside for emergencies, and the system keeps track of whether the lock is working properly so you know if maintenance is needed.

6. Results

The system did not work with recognition accuracy like commercial solutions, but instead relied on storing face data directly in the ESP32-CAM. Whenever a stored face was detected, the solenoid lock opened, and if not, it remained closed. This meant there was no accuracy percentage involved, only a simple match or no-match process. In practice, the system sometimes struggled in dim light or direct sunlight, where detection failed occasionally, but under normal indoor conditions, it functioned reliably.

7. Challenges and Solutions :

Challenge 1: Poor Lighting Conditions

Solution: Added automatic brightness adjustment to camera settings and installed a small LED light that activates automatically in dark conditions.

Challenge 2: Power Supply Instability

Solution: Used a larger 12V power supply with heat sinks on the voltage regulator and added bigger capacitors to stabilize power during solenoid operation.

Challenge 3: Intermittent WiFi Connectivity

Solution: Implemented local control fallback with automatic reconnection code that doesn't interfere with core security functions.

8. Future Scope

- **Enhanced Security:** Add fingerprint scanning, voice recognition, and anti-spoofing protection to prevent photo/video attacks.
- **Smart Home Integration** Connect with Google Home, Alexa, and Apple HomeKit for voice control and integration with other smart devices.
- **Mobile App:** Develop a smartphone app for remote monitoring, notifications, user management, and access logs.
- **Better Recognition:** Implement AI algorithms and 3D face mapping for improved accuracy in various lighting conditions and with masks.
- **Multi-Door Support** Expand system to control multiple doors with different user access levels for larger buildings.
- **Cloud Features:** Add cloud storage for data backup, analytics, remote updates, and technical support.
- **Battery Backup** Includes UPS system to maintain operation during power outages.
- **Advanced Monitoring:** Add motion detection, visitor logging, and CCTV integration for complete security monitoring.

9. Conclusion:

This project successfully shows that we can build a cheap and working ESP32-CAM Face Detection Door Lock System using simple parts like a relay and solenoid lock. The system keeps places secure by storing face data of authorized people and unlocking the door whenever a stored face is detected, while the relay switch ensures the door lock operates properly. With steady power from a 7805 voltage regulator and capacitor, the system worked well without major power problems.

The finished system was able to detect stored faces in real-time, usually responding within 2–3 seconds, and it automatically locked the door again for safety. At a total cost of only BDT 3,000–4,000, it is far cheaper than commercial security systems that can cost BDT 30,000 or more, yet it still performs the important job of access control. The system successfully combines affordable internet-connected technology with simple face detection to create a useful door lock solution.Although it sometimes struggled under poor lighting and required WiFi to work fully,

the overall performance makes it good enough for homes and small offices. The project proves that security features using basic face detection can be built cheaply with easily available components. Future improvements like mobile apps, cloud storage, and more advanced recognition algorithms could make it even more practical for businesses.

This ESP32-CAM door lock system shows how we can successfully combine small computers, face recognition technology, and internet connectivity to create modern security solutions that regular people can afford and use every day.

References

1. Viral Science Creativity. "ESP32-CAM Face Detection Door Lock System." *Viral Science Creativity Blog*. Available: https://www.viralsciencecreativity.com/post/esp32-cam-face-detection-door-lock-system
2. Espressif Systems. "ESP32-CAM Development Board Datasheet." *Espressif Systems Documentation*, 2020.
3. Arduino Community. "ESP32-CAM Library Documentation." *Arduino IDE Libraries*, 2021.
4. Makerspace Tutorial. "Face Recognition with ESP32-CAM Module." *Electronics Projects Guide*, vol. 15, pp. 45-52, 2022.