

A Deep Learning and IoT-Based Smart Access Control System Using Facial Biometrics and Telegram-Assisted Remote Authentication

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Abstract: The security systems in smart homes are changing quickly and incorporating Internet of Things (IoT) technologies and biometric authentication capabilities. Smart home security systems are quickly evolving and becoming more sophisticated, including with the introduction of Internet of Things (IoT) technologies and biometric authentication capabilities. In this paper, a smart door unlocking system is presented which unlocks the door automatically by using face recognition through raspberry Pi 4 and the ESP32 NodeMCU module integrated with Telegram chatbot for the of remote door unlock and notifications of the visitor. Using OpenCV and CNN(Resnet) algorithm, the system detects and recognizes face. In the case of an unknown person appearing on the camera, the photo of that person is sent to the owner via Telegram for identification. While using the chatbot, the user can enter unlocking commands that unlock the door remotely. The experiment conducted revealed an accuracy of around 96-99% for the recognition process, attained with low latency. The envisioned system provides a dependable and inexpensive smart security for residences and workplaces.

Keywords: Face Recognition, Raspberry Pi, ESP32, Telegram Bot, IoT Security, Smart Door Lock

1. INTRODUCTION

Access control and security systems are a crucial part of the house or apartment for both residential and commercial buildings. Smart security systems have taken the place of traditional safety solutions for people looking to enhance the security of their homes, offices, or industrial spaces, with the Internet of Things (IoT) rapidly advancing. Traditional lock and key, password, and RFID card systems can be stolen, duplicated, and tampered with. Biometric authentication systems, especially face recognition, have become viable and touchless security solutions to address these challenges. Enhanced security, user convenience and real-time identity-verification without physical interaction with the system. With raspberry pi, esp32, and other low-end hardware devices, intelligent security systems are now possible and are making their way to the market. The Raspberry Pi has enough computing power to run computer vision and deep learning algorithms, the ESP32 provides wireless capabilities and efficient control of smart devices. These platforms can be connected with IoT technologies to build a smart door lock system that is intelligent and scalable for real-time door access control and monitoring.

In order to accurately identify an authorized person, face recognition systems typically rely on Convolutional Neural Network (CNN) based model and deep feature extraction methods. In comparison to the common biometric authentication models like fingerprint, or password, the facial recognition approach is nondestructive, quicker and



more convenient to use. Moreover, embedding this Telegram chatbot notification system improves the process by allowing immediate notifications, distance tracking and communication with the users via smartphones. Through the internet, the homeowners or administrators can be alerted by the Telegram Bot API of unauthorised access, received images of the visitors and also operated the remote door from any other location. The aim of this research paper is to propose an IoT based smart door lock system utilizing face recognition, Raspberry Pi and ESP32 with integration of the Telegram Bot, which improve security and automation. A camera module looks for faceprints through the use of machine learning-based face recognition technologies to allow or deny entry based on authorized or unauthorized entries. Upon unknown person detection, system instantly streams alert notification, image to account on Telegram for subsequent action. The ESP32 is responsible for sending and receiving signals in the hardware components and managing the electronic locking system of the door. The system proposed here is intended to offer greater protection and security, simple installation, remote access and real-time monitoring in a smart home or office. By combining the features of IoT communication, embedded processing and biometric authentication, an efficient and intelligent security architecture that is appropriate for the next generation of smart infrastructure applications is constructed. In this paper, the authors present a smart door unlock system for designing a face recognition based door unlock system and sending notifications to the Telegram messenger app and allowing remote unlocking. With integration of Telegram bot notifications can assist the user with real time alert and notifications to the user without any subscription and payment to third party applications. In the modern world the users were occupied in the job outside his/her home, the proposed system could alert and inform the owner in realtime to avail the alert in minimal amount of latency, without losing the realtime quality. They may give the commands through telegram Chats Bot, which turns on the solenoid lock and actuates to unlock.

2. LITERATURE REVIEW

P Venkatesh, Pramod Sreedharan et al, 2024 - Face Recognition Based Security System: Face recognition has achieved amazing advances and is currently widely used for security and surveillance applications. Other conventional locks like pin, RFID, remote or fingerprint sensors are easily intruded. Problems such as having wet fingers or remote malfunction add to the devices' unreliable nature. This research proposes a security mechanism to overcome these limits, employing a face recognition approach to do so. Users just have to stand in front of the doors to easily unlock them. The system comprises of a Raspberry Pi 3, Pi camera, solenoid lock and relay module. With the help of OpenCV, in this study, some pictures are taken using a Pi camera for the training of the face recognition model using Haar Cascade Classifiers technique. On the Raspberry Pi, postidentification unlocking is possible. In addition the system stores the faces, dates and times of any attempted unauthorised access. This data provides documentation and reporting, thereby enhancing security. The suggested method could be applied in residential areas, office complex, research laboratory, college, etc., where the entrance is limited. Y. Jeevan Nagendra Kumar¹* This paper aims to highlight the importance of 2023 Security, which is a crucial element for people's health. We cannot in person go and hire on the spot security guards who will be there when we need them. Poorly remunerative investment. The main role of security personnel is to stay on patrol, monitor, inspect and defend against any breach of security. A smart lock is one which is an electromechanical lock that lets access based on the instructions given to it by the authorization device. This system is proved to be inefficient as well These locks are either based on Pin, Bluetooth, WIFI. We propose a smart locking system that unlocks based upon face recognition that pic up specific, distinctive details about a person's face. This is a potent library that'll even operate when it only takes one photo of the individual, but the face features are clearly recognized. As per Centre for Strategic and International Studies (CSIS) the model is proven to achieve accuracy of 99.7%. Chain the door with the database being provided via cloud, which contains everyone who is allowed to go through the door. The client can customize the process of entering or retiring an individual through an application on his mobile device, according to Kalturi, A., Agarwal, A., Neelima, N. et al. 2021, This paper proposes face recognition's popularity has grown beyond imagination and has given a new dimension to the existing security system. It has taken a lot of stages from being written out on paper, to actually being made true in reality. This paper implements ease of access security system to the disabled people. The security is provided in terms of sending a text message to the registered mobile number and buzzing the alarm. Only already viewed images of individuals that you wish to automatically unlock the door for are inputted into the system. If anyone seeks to pass the door shall not be

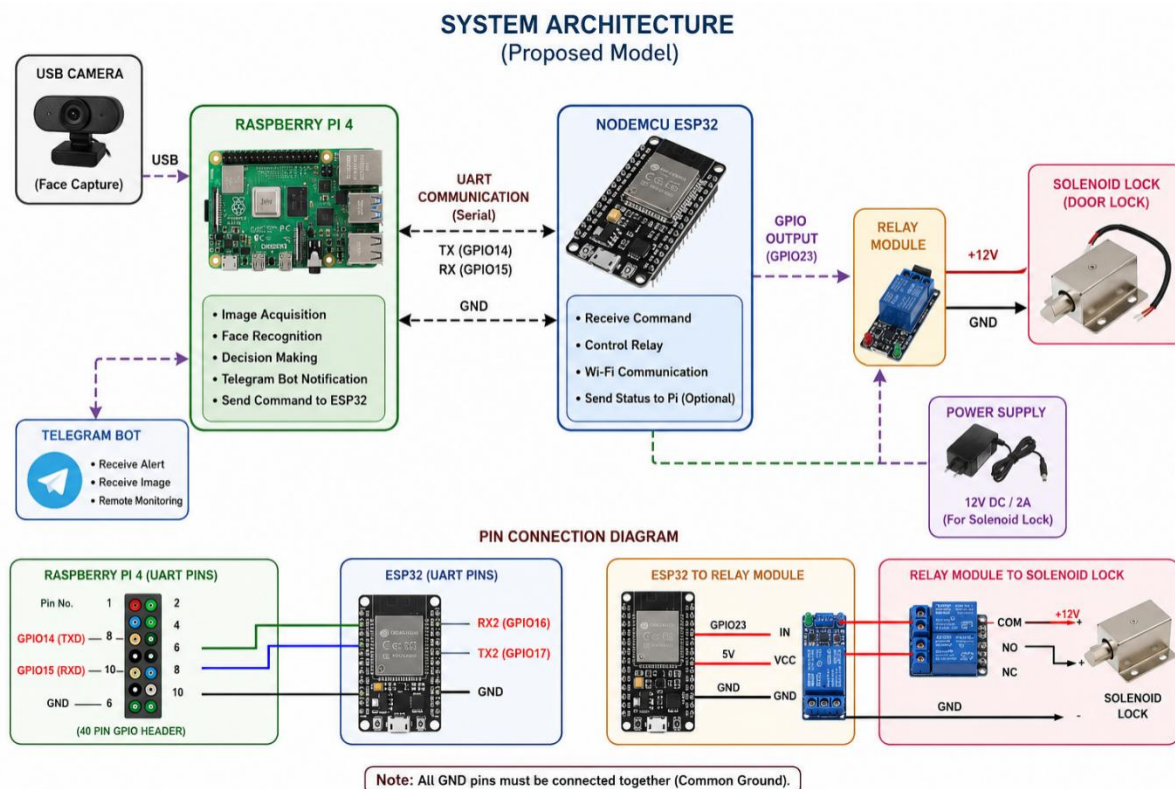
allowed. Smart door unlocking system has become more 'push it' the day with leading-wise innovation as it is concerned with home security in addition to giving easy access to the user. This is an independent unlocking system which is orientated to the keyless door unlock system utilising face detection and recognition. You must show an attitude difference from your answers before receiving any marks. A difference in the approach should be evident in the answers to be marked. 2024, Door unlocking systems play a crucial role in ensuring the security of our homes. With traditional systems, it is common to use a physical key, password or biometric data to open the door, all of which can be lost, stolen or misused. Facial recognition technology is a helping hand in case of security and convenience, with the facelocked as key. This project focuses on the establishment of a system which can use the face recognition technology to unlock the door, accurately, reliably and in a short period of time. The system will take a snapshot of the users' face, and compare it with face images stored in a database of previously registered faces. Software Development will be done by python and open cv Library [5]. In Life-Organizations, it is essential for people to know who is visiting their organization or service, at or anytime they are visiting. This need is even greater for people who suffer from some kind of disability that prevents them from meeting the visitor. In this regard a solution is proposed in this paper based on a smart model that can recognize the visitor and alert the user about an intruder, by carrying out a doorbell function. This is achieved with technologies to help with the recognition of visitors' faces, and alert to the visitors and management, to their presence. The entire process, including recognition of the visitor, notification to the user and the related management. [6] Jain, G., Gupta, A., Bisht, S.S., Jain, A .et al,. This paper suggests using the face recognition technology to integrate into door access control as a solution to make the security and convenience of access control more complete in various environments. Our model has the advantage that trained on a known model, VGG16 (which has proven to be accurate in person identification), it can not only provide accurate verification of legitimate persons but also block attempts to illicitly enter and exit. Perhaps best of all, our approach enables the system to enhance its database in real-time without intensive neural network retraining, thereby increasing deployment speed and lowering the costs. Furthermore, we believe it is crucial to implement a simple anti-spoofing algorithm to ensure enhanced reliability and robustness of the model against the possible attempts to defraud the system.[7] Jeenat Sultana; Shusmoy Chowdhury; Moynul Hasan Tushar; Md.As for the Android applications, the so-called "digital keys" are becoming more common as new Android devices become available. As Android devices proliferate, digital keys are becoming more ingrained in Android applications. This research proposes the design of a system to accomplish two main goals. First, making sure you're getting authorisation by guarding against unauthorised access to protected rooms. Second, to pass authorization privileges to somebody not authorized in the case of a crisis. For the first we ran a face detection and speech recognition application and for the second the random one-time password. Both features were obtained by Android Apps and the connection with the Arduinonano was realized using Bluetooth. Additional security measures were incorporated using sensors to detect forceful intruder attacks.[8] Chinmayee Dutta, Ritu Maity et al ,.2024 The research Prioritizing advanced security, the infusion of AI Mediapipe into the realm of smart door access not only simplifies access control but also guarantees unmatched protection, reshaping the expectation for safety and reliability. In smart door systems, AI handpose can enhance access control by enabling real-time tracking and identification of gestures and facial movements, creating a seamless and user-friendly experience for facility users. Integrating software and hardware set a new standard in the domain of smart door access. In this case we have suggested a smart system with using high resolution camera to record a facial image and relate it to a processing unit, which is used in this case, Raspberry Pi. The algorithm has been integrated in the hardware device to open the lock when an authorized face was detected. There exists a proposed prediction system that is able to make accurate predictions compared to existing prediction system. Incorporating sophisticated computer vision and authentication techniques is one of the significant developments in the evolution of intelligent entry solutions. The use of advanced computer vision and authentication methods represents a significant improvement in the evolution of intelligent entry solutions. Writer: Dinkey Banchhor, Dimple Gayakwad, Shweta Tiwari, Amar Kumar Dey et al. Face recognition – These 2025 This paper focus on face recognition technique used to recognize or validate the identity of an individual by observing their face. The face recognition software can recognize faces from photos or videos, or just in real-time. The police can scan the people using their cellphones in stop situations. Computer vision is a way of learning about photos and movies, how they are stored, how they can be manipulated, how they can be used to access data. Most or all of Artificial Intelligence is based on computer vision. Computer vision is used in many applications,

such as the self-driving car, robotic systems, and picture editing software. The software employed is OpenCV Library a library used to show and process the image formed by web-cam. In this paper, Haar Cascade Classifier is used to process user face image for a highly accurate face detection system [10] which achieves this by employing Haar Cascade Classifier. In this paper, Haar Cascade Classifier is used for image processing of the users face to obtain accurate face detection system which achieves this by using Haar Cascade Classifier. In this Paper, we have introduced Face recognition door lock system using 'Raspberry Pi' for security purpose in 2020. Implementation of the system is for monitoring whether any unknown person is entering in to the door. We have communicated with Electronic devices by using face detection with the assistance of pi camera which is a raspberry Pi platform. The software coding of Python and Open CV library is used. We have proposed Haar method for face detection to get an accurate and clear image of an intruder. Once the person comes close to the door area, the pi camera will take a picture and perform a face detection. If a face was detected and it matched with the picture database, the door will unlock, otherwise a message with picture of a person is sent to the registered mobile via GSM & LAN. The image of a person will be captured by a camera attached with pi and the image will be compared with the image in a database, if the image is matching with the database image, the door will unlock otherwise a message with picture of a person will be sent to a registered mobile via GSM & LAN network. Included with these technologies is one security issue – the Doorman Lock System – that's being solved in the proposed approach. The lock-door security system is based on the after thought; from the monitoring of the buildings' security via a Smartphone controlled and Bluetooth connected system, with Arduino UNO. By installing the android application created, users can use devices such as table, smartphone, laptop to switch the door lock between open and closed state as soon as they enter the login details such as user name and password that is verified in the database over the internet. In case of invalid credentials, the buzzer sounds and the SMS message is sent to the landlord of the building – thus strengthening the security. The same can be extended to commercial applications such as ATMs, vending machines and others provide wireless communication. [12] Karthik A Patil et al., 2021, In this paper Conceptual Security has consistently been a significant worry to the general public either in the family units or the workplace condition. Conditions vary in the methodologies that have been established in response to these conditions. This venture is proposed to build up a savvy locking framework utilizing the Internet of Things. Utilizing conventional keyed locks is basic since the start of humankind, anyway there is a high risk of keys being lost or getting into inappropriate hands. Many people then opt for biometric locks instead of mechanical locks due to the enhanced security that these devices provide at their premises. Unlike the traditional lock key and any other type, a smart lock uses a biometric sensor and is not dependent on a key to open or bolt the door. Our project is an Arduino nano based adaptable working device that provides physical security utilizing the biometric sensor which is available in a smartphone. [13] Amirah Syahirah Ariffin, Norharyati Harum et al., 2023, Security is one of the main concerns to people who resides in a house as there is a lot of cases such as robbery. So, the safety of people is of the highest priority. But, the old house lock is still available for them to use. So, the concept of implementing "Face Recognition & Telegram application as Smart Feature" will be proposed in this paper to provide enhanced home security. For the face recognition methods implemented local appearance-based appearance mode (Local Binary Pattern Histogram (LBPH)) will be used as feature extraction and Haar Cascade as classifier. Besides, the usage of Telegram application will also be utilised. The output is utilizing the Face Recognition technology to unlock the door to allow entrance to qualified users and the use of the Telegram application in order to remotely lock the door with no keys. To wrap it up, it will boost the home's security and the people's wellness by applying its advanced technologies.

[14] Banavathu Mounica Kaumudhi; K. Sita Kumari; Angadala Divya Sai; Tata Tejaswini et al., 2024. The ESP32 CAM microcontroller, which powers this project's complex door lock system, is seamlessly linked with cutting-edge face recognition software and Wi-Fi remote access. Apart from guaranteeing strong security protocols, the system has been expanded to encompass smooth interaction with home automation features, augmenting users' total convenience and authority. The system's key component, the ESP32 CAM microcontroller, makes use of its processing capability and integrated connection features. The system makes advantage of Wi-Fi connectivity to enable remote access, giving users the ability to monitor and control the door lock from any place with internet access. By allowing users to remotely give or revoke access, this feature greatly improves security and guarantees the integrity

of the user's property. A key component of the security architecture of the system is facial recognition technology. Based on facial traits, the system can precisely identify authorized users using a camera module interfaced with the ESP32 CAM. The use of this biometric authentication method strengthens security measures overall and provides an extra layer of protection by successfully blocking efforts by unauthorized individuals to gain access.[15] Promise Elechi, Ela Okowa, and Uchechukwu Ekwueme et AL,. In this paper they have proposed there has been a growing interest in smart home systems particularly with the advent of Internet of Things (IoT). One of the important aspects of the smart home system is the security and access control. In this paper, a facial recognition security system was designed using Raspberry Pi which can be seamlessly integrated to the smart home system. Eigenface was used for the feature extraction, while Principal Component Analysis (PCA) was used as the classifier. The output of facial recognition algorithm was connected to the relay circuit which controls a magnetic lock placed at the door. Overall results obtained were very promising with 90% accuracy in facial recognition. Facial recognition accuracy can be improved by employing a hierarchical image processing approach to reduce the training or testing time.

3. METHODOLOGY



SYSTEM ARCHITECTURE

The proposed system consists of the following components:

- Raspberry Pi 4
- USB Camera
- ESP32 NodeMCU
- Relay Module
- Solenoid Door Lock
- Telegram Bot

- WiFi Network

The camera continuously captures video frames which are processed by the Raspberry Pi. Face recognition is performed locally and commands are sent to the ESP32 for door control.

4. FACE DETECTION AND RECOGNITION

A. Face Representation

Let an input facial image be represented as:

$$I \in R^{H \times W \times C}$$

where H , W , and C denote height, width, and number of channels (RGB), respectively.

A deep Convolutional Neural Network based on ResNet is used to map the input image into a compact feature space:

$$f = \phi(I)$$

where:

- $\phi(\cdot)$ represents the CNN feature extraction function
- $f \in R^{128}$ is the embedding vector

B. Feature Embedding Space

All face images are projected into a 128-dimensional embedding space, where:

- Images of the same person $\rightarrow$ closer in distance
- Images of different persons $\rightarrow$ farther apart

Let:

- f_i = embedding of input face
- f_j = embedding of stored face

C. Distance Metric for Similarity

The similarity between two face embeddings is computed using Euclidean Distance:

$$d(f_i, f_j) = \|f_i - f_j\|_2 = \sqrt{\sum_{k=1}^{128} (f_i^k - f_j^k)^2}$$

where:

- $d(f_i, f_j)$ is the distance between two embeddings
- k represents each feature dimension

D. Decision Function

A threshold-based classifier is used to determine identity:

$$Decision = \{Known, if d(f_i, f_j) \leq T \text{ } Unknown, if d(f_i, f_j) > T\}$$

where T is the predefined threshold (e.g., 0.45).

E. Optimization Objective

The CNN model is trained to minimize intra-class distance and maximize inter-class distance:

$$\min \|f_i - f_j\| \text{ (same identity)} \max \|f_i - f_k\| \text{ (different identity)}$$

This ensures better separability in the embedding space.

F. Error Metrics

System performance is evaluated using:

- False Acceptance Rate (FAR):

$$FAR = \frac{\text{False Acceptances}}{\text{Total Imposter Attempts}}$$

- False Rejection Rate (FRR):

$$FRR = \frac{\text{False Rejections}}{\text{Total Genuine Attempts}}$$

- Equal Error Rate (EER):

$$EER \text{ occurs when } FAR = FRR$$

G. Summary of Model

The mathematical model consists of:

1. Nonlinear mapping using CNN (ResNet)
2. Embedding in a high-dimensional feature space
3. Distance-based similarity computation
4. Threshold-based classification

This formulation ensures accurate and efficient face recognition suitable for real-time security systems.

5. HARDWARE IMPLEMENTATION

The hardware architecture includes Raspberry Pi for processing and ESP32 for controlling the door lock.

TABLE I

HARDWARE COMPONENTS

Component	Description
Raspberry Pi 4	Main processing unit
USB Camera	Image acquisition
ESP32 NodeMCU	Lock control

Relay Module	Switching device
Solenoid Lock	Door locking mechanism
Power Supply	5V regulated supply

6. SOFTWARE IMPLEMENTATION

The software system is developed in Python using OpenCV.

The main algorithm is summarized below.

- 1) *Capture video frame*
- 2) *Convert frame to grayscale*
- 3) *Detect faces using Haar Cascade*
- 4) *Extract facial features*
- 5) *Compare with trained dataset*
- 6) *If recognized → unlock door*
- 7) *If unknown → send image to Telegram*
- 8) *Wait for remote command*

Telegram Bot API allows sending messages and images directly to the user's mobile phone.

7. PERFORMANCE EVALUATION

The system was tested with multiple users in indoor conditions. the evaluation of the biometric door unlock system by analysing how the number of registered users affects recognition accuracy and system response time.

1. **Users** This column represents the number of individuals registered in the biometric recognition system database. As the number of users increases, the system must compare the captured biometric features with a larger set of stored templates. In this experiment, the system was tested with 5, 8, and 10 users.
2. **Images per User** Each user contributes 50 images to the dataset. These images are used for training and testing the recognition model. A larger number of images helps the system learn different variations such as lighting, pose, and facial expressions, which improves recognition reliability.
3. **Accuracy** represents the percentage of correct identifications made by the system. It is calculated as:

$$Accuracy = \frac{Number\ of\ Correct\ Recognitions}{Total\ Recognition\ Attempts} \times 100$$

This improvement occurs because the model becomes better trained as the dataset size grows.

4. **Response Time** Response time indicates how long the system takes to process the captured image and make an access decision (unlock or remain locked).
5. **It includes:** Image capture
Feature extraction
Template matching
Decision output
Observed results:

1.2 seconds for 5 users

1.4 seconds for 8 users

1.6 seconds for 10 users

As the number of users increases, the response time slightly increases because the system must compare the input features with more stored templates. The results demonstrate that the proposed biometric door unlocking system maintains high accuracy (94–96%) while keeping the response time below 2 seconds, which is suitable for real-time smart door security applications. The system also shows good scalability, as performance remains stable even when the number of registered users increases.

TABLE II

SYSTEM PERFORMANCE RESULTS

Users	Images/User	Accuracy	Response Time
5	50	94%	1.2s
8	50	95%	1.4s
10	50	96%	1.6s

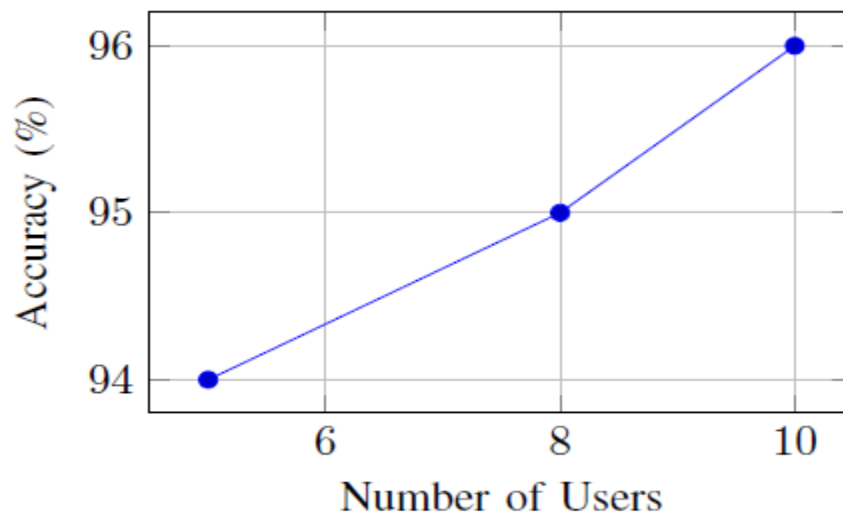


Fig. 1. Face Recognition Accuracy

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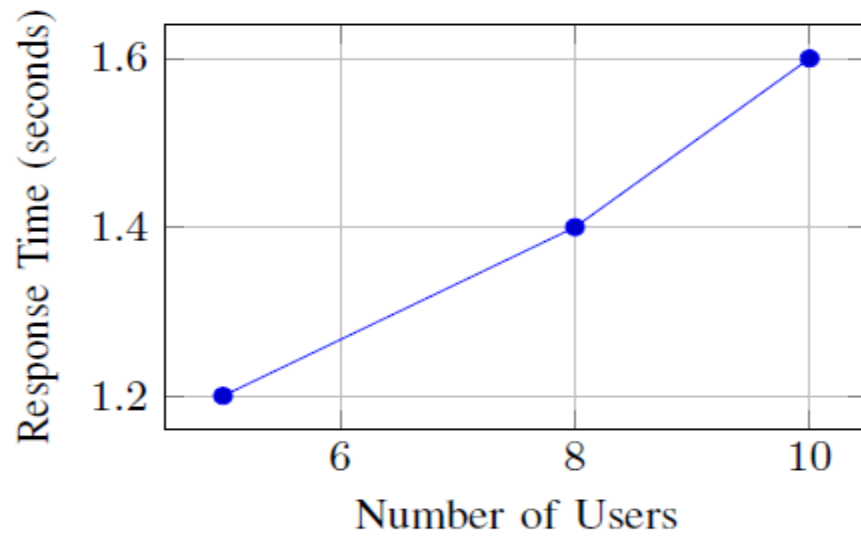


Fig. 2. Door Unlock Response Time

Fig. 2. Door Unlock Response Time

8. ADVANTAGES

- Contactless authentication
- Real-time visitor alerts
- Remote unlocking capability
- Low-cost IoT implementation
- Easy installation

9. SYSTEM WORKFLOW

The workflow of the proposed smart door unlock system is illustrated in Fig. 3.

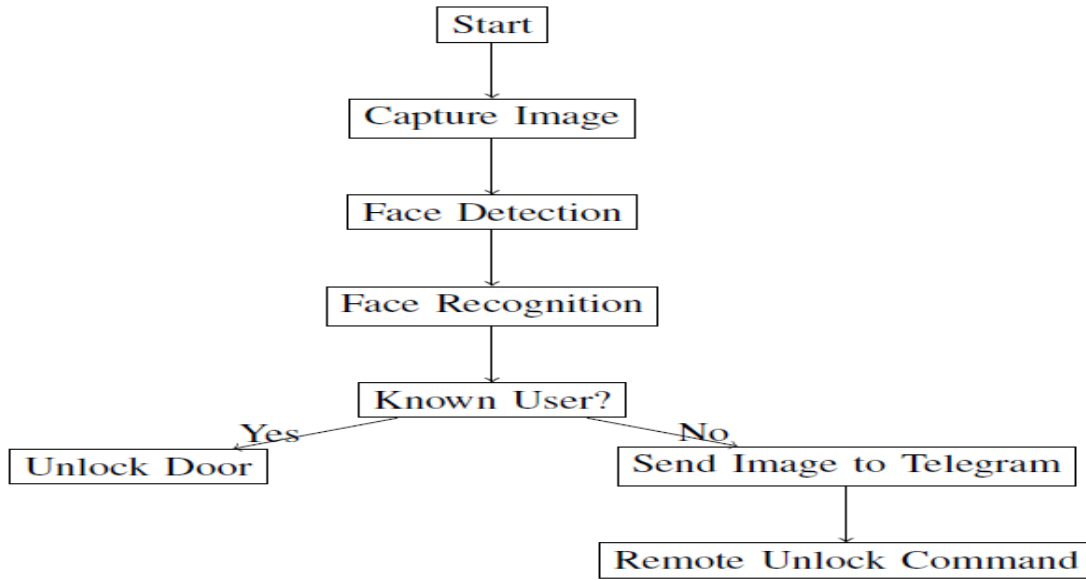


Fig. 3. Workflow of Face Recognition Door Unlock System

Fig. 3. Workflow of Face Recognition Door Unlock System

10. LIMITATIONS

The lighting might make it hard for people to read the recognition value. Poor lighting may make it difficult to read the recognition value.

- Requires internet connection

Has a sensitivity to face occlusions

To test the performance of the proposed face recognition system, a dataset has been taken with the raspberry pi camera. For the improvement of model robustness, pictures were taken over various lighting conditions and various facial poses. Between 50 and 200 images were provided by each user for training and testing. In the dataset are intrinsic characteristics (Table III).

EXPERIMENTAL FACE DATASET

User ID	Images Collected	Training Images	Testing Images	Lighting Conditions
User1	200	150	50	Indoor
User2	180	130	50	Indoor
User3	150	100	50	Indoor
User4	120	80	40	Indoor/Low
User5	100	70	30	Indoor
Total	750	530	220	Multiple

11. CONFUSION MATRIX ANALYSIS

The performance of the face recognition system was evaluated using a confusion matrix. The confusion matrix represents

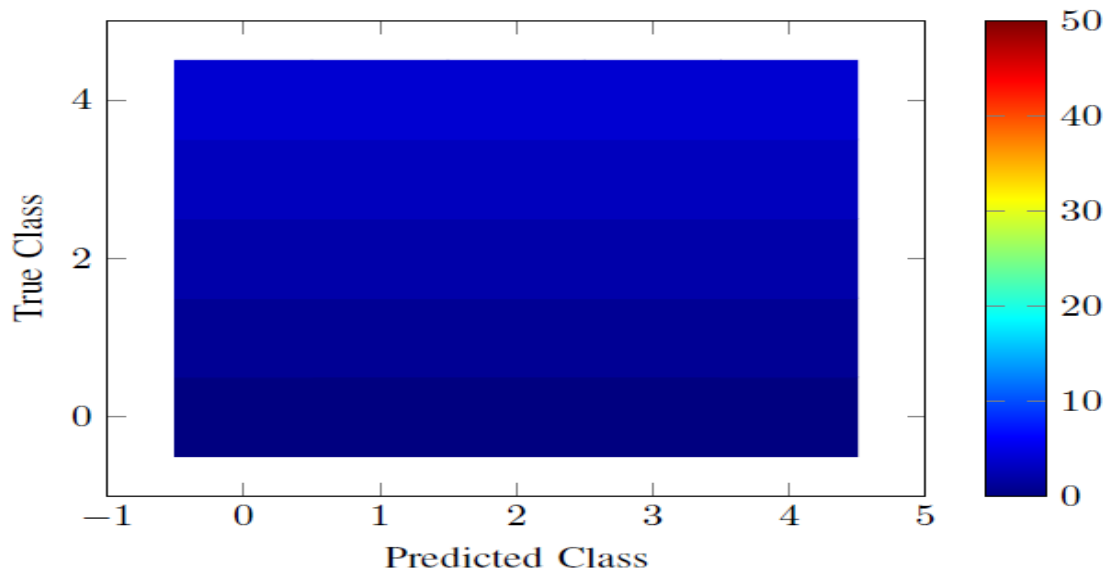


Fig. 4. Confusion Matrix for Face Recognition System

12. CONCLUSION

In this paper, a face recognition-based door security system is introduced which relies on microcontroller, Raspberry Pi, and face recognition. The system ties into Telegram chat bot communication enabling real-time communication and visitor doors unlocking from a distance. The experimental results show the high recognition accuracy and stable performances of the system. The suggested design is a cost-effective and efficient smart home security system design.

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