DESIGN AND DEVELOPMENT OF A PROTOTYPE SECURITY DOOR USING FACIAL RECOGNITION SYSTEM

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ABSTRACT

The use of facial recognition for different security systems is increasingly vital in various sectors, even where electronic security systems are prevalent. This project aims to address the need for cost-effective solutions, particularly pertinent due to high funding requirements for facial recognition systems. The prototype, based on a Raspberry Pi 3 system, utilizes locally sourced materials, showcasing feasibility and adaptability within the region. It employs microcontrollers, sensors, and an SD card for data management, with Python programming facilitating system operation. Additional components like a display screen and buzzer enhance user interaction and notifications. The methodology utilized draws from Dennis and Wixom’s prototype methodology (Dennis and Wixom, 2003), encompassing three phases: analysis, design, and implementation. During testing, the system effectively differentiated between authorized and unauthorized individuals, granting or denying access accordingly. However, improvements to the Raspberry Pi module, along with enhancements in memory capacity and camera quality, are recommended for optimized performance, especially for larger-scale deployments. This project also suggests potential expansions, such as integrating voice-based assistance and linking with police databases for enhanced security measures. Leveraging technologies like WhatsApp for notifications and implementing cloud-based storage to manage visitor records efficiently can further streamline operations and reduce costs. Recognizing the limitations of the current hardware, the project underscores the potential for significant improvement with better processing modules. Overall, the project demonstrates the feasibility of locally developed solutions for implementing robust security systems with facial recognition capabilities, offering practical insights for similar initiatives across Africa.

Keywords: Face detection, Python, Security door, Raspberry Pi, Tensorflow, Teachable machine.

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INTRODUCTION
This project helps for the improvement of door security such as the use of keys, RFID, biometrics, passwords, or patterns in sensitive locations by using face detection and recognition. Biometric strategies use a person's body parts for recognition. In password authentication, the users have to choose a specified username and password that they will always remember, these have to be stored on the server database and protected against intruders to avoid being changed. Sometimes, the password/username combinations can be predicted, and choosing a complex password can be troublesome (Osineke et al., 2012). But in facial recognition, the user has nothing to do except stand in front of the camera and authenticate automatically. Though in recent years, other door security systems have been developed deeply none came close to the facial recognition system, hence the proposed system solves all these challenges aforementioned in other security systems including, the need to duplicate keys and security concerns when the key is lost. The automatic authentication solution provided by facial recognition systems can be applied to homes, banks, hospitals, schools, and offices. One of the disadvantages of a face recognition system is its high cost of implementation. Locally sourced materials are used to overcome this challenge in this work. A different method of door access is proposed which uses an automated face recognition system (Rohit et al., 2021).

AIM AND OBJECTIVES
i. To design and fabricate a prototype security door that admits entry using a facial recognition system.
ii. To create a model with datasets for the entry authorization.
iii. To test and evaluate the system.

The development of door security systems all started in ancient Egypt, where a simple wooden pin lock was built. During the Roman era, a modification was made replacing the wooden pin lock with metal pins such as copper, gold, and silver. This increased the cost and could only be afforded by the rich, making gold key be seen as a display of one's status and wealth. In recent times, pin locks have been displaced by durable tumbler mechanisms made with non-corrosive stainless steel and titanium (Security Systems Limited, 2024). The initial significant effort to enhance lock security occurred in 1778 when Robert Barron secured a patent for a double-acting tumbler lock. This significant development in lock engineering still forms the fundamental principle of all lever locks. Later, in 1818, Jeremiah Chubb refined the tumbler lock by integrating a detector, a retaining spring that captured and held any tumbler raised excessively during picking attempts. This feature alone prevented the bolt from retracting and also indicated any attempted tampering with the lock (Security Systems Limited, 2024). Various types of locks have been developed, including deadbolts, door reinforcements, door chains, and internal locks (Ashish et al., 2017). Additionally, advancements in authentication methods have been made, from lock-and-key systems to password authentication, RFID cards, and fingerprint recognition (Burak et al., 2015).
Table 2: Comparison of the security door systems

<table>
<thead>
<tr>
<th>Factors</th>
<th>Key and lock system</th>
<th>Authentication by user password</th>
<th>Authentication by RFID</th>
<th>Smart security door lock systems</th>
<th>Authentication by Fingerprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Security</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Very high</td>
<td>High</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Source: Vivek et al. (2021).

Fingerprint recognition has emerged as a dependable biometric authentication technique, thanks to its widespread availability, unique characteristics, and precision (Osineke et al., 2012). In contrast, facial recognition, while non-intrusive and widely accepted, may have lower accuracy and security levels compared to fingerprint recognition (Ifeoma et al., 2019).

The proposed system in this review aims to introduce a new solution to address security issues in intelligent door systems. It utilizes real-time smart door technology based on video technology and Raspberry Pi embedded systems for robust and reliable performance (Anjali et al., 2017). Comparative analysis with other systems demonstrates the superior security, cost-effectiveness, and user-friendliness of the proposed system (Lwin et al., 2015).
MATERIALS AND METHOD

The methodology utilized draws from Dennis and Wixom’s prototype methodology (Dennis and Wixom, 2003), encompassing three phases: analysis, design, and implementation. This approach was chosen for its ability to assess project feasibility effectively and mitigate costs.

**Raspberry Pi**

The Raspberry Pi shown in Figure 1, operates on an open-source, Linux-based platform, it's versatile and accessible.

![Figure 1: Raspberry Pi. (2024).](image)

**Source:** Raspberry Pi. (2024).

Connectable to a TV or monitor and keyboard, it handles tasks like web browsing and video playback. Ideal for diverse projects and IoT applications, newer models include built-in Wireless LAN and Bluetooth Low Energy. Setting up requires a monitor, keyboard, mouse, power supply, and SD card with NOOBS. Raspberry Pi 3 Model B+ has GPIO pins that enable device connections via Python (Dushyant et al., 2010).

**Power Supply circuit**

A power supply circuit generates a +5V output for digital electronics experimentation, addressing poor voltage regulation issues in cheap wall transformers. It provides around 150mA of current, expandable to 1A with proper cooling. Components include a 7805 regulator IC, capacitors, and potentially a heatsink for higher currents.
**Pi camera module**

The Raspberry Pi supports standard USB webcams. An adjustable camera support bracket is available for secure mounting, featuring multiple positions and a 1/4” hole for tripod attachment, provided with plastic pieces, screws, and hex nuts.

![Image of Pi camera module](image)

**Figure 2: Pi camera module.**

**Tact switch**

A tact switch facilitates electrical flow when pressed manually, serving to activate devices. Designed for PCB mounting, it enables circuit formation and operates with momentary action. Specifications include power rating, resistance, and operating force. Tactile feedback ensures users feel a click when activated. It allows power or connections when pressed, finding use in calculators, telephones, appliances, locks, and various devices (Cudevices, 2024).

![Image of Tact switch](image)

**Figure 3: Tact Switch.**

**Ultrasonic sensor**

The Ultrasonic Sensor operates by the principle of reflection of sound waves. By calculating the time taken for a reflected wave to come back to its source, the distance between it and an object can be calculated.
Figure 4: Ultrasonic sensor.

LCD Display

The display is configured to be 20 characters wide and arranged in 4 rows, on a blue background. It incorporates a single LED backlight with an included resistor, enabling a direct power supply from 5V.
Buzzer

A buzzer is a sound-producing device used for signaling. The buzzer consists of a unified assembly incorporating electronic components to achieve sound. It is extensively utilized across a diverse array of electronic devices to produce electronic products that produce sound.

Motor Driver

The Motor Driver is an assembly of electronic components to achieve both clockwise and anti-clockwise movements on the DC motor. It is designed using a similar design technique to L298 integrated circuit (Dual H-bridge).
The Heatshrink is a 1mm heat-shrinkable tube that shrinks in diameter when heated. When heat is applied to it, typically with a heat gun, it shrinks to 50% of its original diameter. This heat shrink sleeve features a thermoplastic-covered interior surface.

A potentiometer is a type of manually adjustable variable resistor that uses the principle of resistance to control the current in a circuit, thereby adjusting the performance of the LCD.
LED light

An LED is a semiconductor light-emitting device. It is used as a signaling device in this project. When the door opens/closes the LED lights up to indicate these operations. Its unique characteristics distinguish it from sources like incandescent or fluorescent lamps, making them part of solid-state lighting technology.

Jumper wires

Jumper wires are wires with connector pins at each end. While basic, they offer flexibility in circuit adjustments. Colors, though arbitrary, can aid in distinguishing connections like ground or power.

Source: Spark Fun Education. (2024)
Power Bank

Power Banks are offered in a range of sizes, spanning from slender, pocket-sized units to more substantial, high-capacity models. Their primary function is to recharge smartphones, tablets, and similar electronic devices.

Figure 12: Power bank.

DC Motor

These gear motors find application in a wide range of scenarios and are commonly encountered in both residential and commercial settings. The gearbox within the gear motor functions to decrease the revolutions per minute (RPM), thereby yielding varying levels of torque at the output.

Figure 13: DC motor.
Plastic gear rack and Steel door

This rack converts rotational motion into linear motion, which is used to achieve the opening and closing of the door. It consists of a steel door and a horizontal gear rack. The electric motor rotates to move the gear rack.

![Door Panel Diagram](image)

Figure 14: Plastic gear rack and Steel door.

Wooden Case

We have used a wooden case to enclose the components of this system. This will serve as the prototype of the room or place to be secured by this system.
RESULTS AND DISCUSSION

The diagram shown in Figure 15 illustrates the assembly process of the Prototype Security door. It involves utilizing tools such as a hand drill and saw to create openings for various components including the potentiometer, camera, ultrasonic sensor, drive motor, buzzer, guide rod, LCD, LED, tactile switch, and door panel.

Figure 15: WoodenCase
Design Calculations

The DC motor is required to produce Torque required to open the door as shown in Figure 16

![Mechanism for opening of the door](image)

*Figure 16:* Mechanism for opening of the door

*Source:* Engineering. (2024).

![Rotation of the DC motor](image)

*Figure 17:* Rotation of the DC motor

*Source:* Engineering. (2024).

Find the rating \( n \) (in rev/min) of the DC motor required to open a door of Mass 120g. The maximum current and voltage supplied by the circuit are 1.2A and 5V. The power supplied to the DC motor is 6 watts (\( P = IV \)). The distance travelled in opening the door is 0.1m. The work done in opening the steel door is equivalent to the Torque \( T \) required which is 0.12Nm (0.12kg * 10 * 0.1m).

\[
\text{Work required to open the door} = Fs \quad (1)
\]

\[
\text{Power } P = 2\pi n T \quad (2)
\]
Solving for rating n, rating n required is approximately 478rev/min. Therefore an electric motor that rotates with a speed of 478 rev/min (rpm) is required to open or close the door.

**Figure 18:** Circuit diagram of the security system

**Setting up of Raspberry Pi**

The initial phase involved burning the Raspbian operating system into the SD card to be used in the Raspberry PI 3 model B+ using Win32DiskImager. After connecting all cables and powering on, the system boots up. The subsequent step is installing OpenCV, which requires installing dependencies and prerequisites. Tasks include expanding the file system, updating existing packages, and installing developer tools like CMake to finish up the process (Raspberry Pi, 2024).

**Training the model for authorized users**

Teachable Machine is a powerful tool for creating machine learning models. It simplifies the process of capturing data to create training datasets and utilizes cutting-edge algorithms to train machine learning models directly in your web browser. Three users were trained as authorized users named Class 1, Class 2, Class 3.

Setting up the Teachable Machine project involves several steps:

1. Access Teachable Machine: Visit the Teachable Machine website and look for "Get Started.", click on it. Then select "Image Project" to open as shown below the training window.
2. Creating the Dataset: Choose a name for the classes. Ensure intuitive class names, and consider including a “Background” class to help the model distinguish between objects and the background.

3. Adding Image Samples: Capture images using your webcam or you can upload images from another source. Aim for a large quantity of high-quality data for each class to ensure an accurate model.

4. Training the Model: Click the “Train Model” button. Training can take some time, especially with a large dataset. Monitor for browser notifications about slowing down and acknowledge them to prevent interruption.
5. Previewing the Model: Once training is complete, test the model's accuracy by turning on the input in the Preview pane. Present different objects to the webcam and observe the model's predictions.

6. Exporting the Model: Click the "Export Model" button and download the model. The downloaded zip file will contain a "keras_model.h5 file and a "labels.txt" file, which you'll use in your Python environment.

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**Figure 21:** Teachable Machine interface with sample pictures being exported.

**Python Code implementations**

```python
from gpiozero import Button, import time
from picamera import PiCamera, from time import sleep
import RPi.MyRaspPins as MyRaspPins
import lcddriver
from gpiozero import DistanceSensor

MyRaspPins.setwarnings(False)

#Setting MyRaspPins mode
MyRaspPins.setmode(MyRaspPins.BCM)

#Set up myBuzzer
```
myBuzzer=23
MyRaspPins.setup(myBuzzer,MyRaspPins.OUT)

# Set up LCD display
myScreen = lcddriver.lcd()

# Set up Motor module
in1 = 21
in2 = 20
enablePin = 25
temp1 = 1
MyRaspPins.setmode(MyRaspPins.BCM)
MyRaspPins.setup(in1,MyRaspPins.OUT)
MyRaspPins.setup(in2,MyRaspPins.OUT)
MyRaspPins.setup(en,MyRaspPins.OUT)
MyRaspPins.output(in1,MyRaspPins.LOW)
MyRaspPins.output(in2,MyRaspPins.LOW)
startMotorPin=MyRaspPins.PWM(enablePin,1000)
startMotorPin.start(100)

# Set up Ultrasonic sensor
distanceSensor = DistanceSensor(17, 27)

# Set up Power button
btn = Button(16, hold_time=3) btn.when_held = systemTurnedOn
# Set up Reset button

```python
btn = Button(24, hold_time=3) btn.when_held = systemTurnedOn
```

def systemTurnedOn():
    print("Button pressed")

def showVideoAndCaptureFaceForTenSeconds():
    myProjectCamera = PiCamera()
    myProjectCamera.start_preview()
    sleep(10)
    myProjectCamera.capture('/home/pi/Desktop/image.jpg')
    myProjectCamera.stop_preview()
    print("Camera on")

def peepBuzzerForFiveSeconds():
    count = 0;
    while count < 5:
        MyRaspPins.output(myBuzzer, MyRaspPins.HIGH)
        print("You will hear sound")
        sleep(0.5)
        MyRaspPins.output(myBuzzer, MyRaspPins.LOW)
        print("You will not hear sound")
        sleep(0.5)

def lcdWelcomeDisplay():
myScreen.lcd_display_string("You're highly Welcome", 1)

def openDoor():
    if(temp1==1):
        MyRaspPins.output(in1,MyRaspPins.LOW)
        MyRaspPins.output(in2,MyRaspPins.HIGH)
        print("door opening")

def closeDoor():
    if(temp1==1):
        MyRaspPins.output(in1,MyRaspPins.HIGH)
        MyRaspPins.output(in2,MyRaspPins.LOW)
        print("door closing")

def stopDoor():
    if(temp1==1):
        MyRaspPins.output(in1,MyRaspPins.LOW)
        MyRaspPins.output(in2,MyRaspPins.LOW)
        print("door movement stopped")

def clearUpMyRaspPins():
    MyRaspPins.cleanup()
    print("MyRaspPins Clean up") break

def runPredictions():
model = load_model('keras_model.h5')

facePredictions = model.predict('image.jpg')

index = np.argmax(facePredictions)

class_name = class_names[index]

classification_score = facePredictions[index]

if classification_score < 80:
    myScreen.lcd_display_string("Face not recognised", 1)
    peepBuzzerForFiveSeconds()

elif classification_score > 80:
    myScreen.lcd_display_string("Face recognised", 1)
    openDoor()

    sleep(5)

    closeDoor()

    stopDoor()

    myScreen.lcd_display_string("Thank You", 4)


def detectIfFacePresent():

    c = int(distanceSensor.distance*100)

    if c < 40:
        myScreen.lcd_display_string("Ultrasonic sensor...", 1)
        myScreen.lcd_display_string("Reading distance...", 2)
        myScreen.lcd_display_string("Object Present < 40cm", 3)
        showVideoAndCaptureFaceForTenSeconds()
        runPredictions()

    elif c > 40:
        myScreen.lcd_display_string("Ultrasonic sensor...", 1)
myScreen.lcd_display_string("Reading distance...", 2)

myScreen.lcd_display_string("No Object detected > 40cm", 3)

clearUpMyRaspPinss

test1fFasePresent()

Testing

The testing involved ten images, with authorized persons labeled accordingly and unauthorized individuals labeled as unknown. Results were binary, with zero for unauthorized and one for authorized individuals.

![Image](image.png)

**Figure 22:** Picture snapped during the testing of the work.

The test procedure outlined system setup, booting the Raspberry Pi 3, following LCD instructions, and face recognition triggering door opening or buzzer alerts for unauthorized attempts. Real-world door positioning should be at 1.70m (WorldData, 2024), reflecting the average height in West Africa. Discussions address limitations in memory, camera quality, and project size, recommending enhancements such as higher-quality cameras, increased memory capacity, and upgrading to faster Raspberry Pi modules for improved operability in field applications requiring restricted access.
Table 3. Results of testing done with ten images

<table>
<thead>
<tr>
<th>S/N</th>
<th>USERS</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Authorized user</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
<tr>
<td>3.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
<tr>
<td>4.</td>
<td>Authorized user</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
<tr>
<td>6.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
<tr>
<td>7.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
<tr>
<td>8.</td>
<td>Authorized user</td>
<td>1</td>
</tr>
<tr>
<td>9.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
<tr>
<td>10.</td>
<td>Unauthorized user</td>
<td>0</td>
</tr>
</tbody>
</table>

CONCLUSION

The proposed system integrates OpenCV, Teachable Machine, and Python with a camera module to create a secure and accurate security system. Future enhancements include voice-based assistance for guests, integration with police databases for alerts, and cost reduction using WhatsApp for notifications. Cloud-based storage optimizes visitor records while upgrading to a faster processing module like Raspberry Pi 4 can enhance system efficiency. Automatic door control ensures swift access management with immediate opening/closing post-identification and a preset closing duration. Additionally, future work should focus on improving algorithms, integrating other security measures, and fostering local innovation using accessible materials and open-source software. Enhancing user experience and database management tools will further ensure the system's effectiveness and reliability in real-world applications.

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