Design and implementation of a Smart Doorbell based on facial detection and IoT

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Abstract

This paper presents a comprehensive study on the development and implementation of a smart doorbell system designed to enhance home security and convenience. The proposed system integrates advanced technologies such as video surveillance, facial detection, and wireless communication. It leverages IoT (Internet of Things) principles to enable real-time interaction, remote monitoring, and control through a smartphone application. Key features include facial detection for visitor identification, cloud storage for image recording, and notifications to alert homeowners of visitors or suspicious activity. The system aims to address challenges in energy efficiency, data security, and user-friendly design. Experimental results demonstrate the system's effectiveness in improving accessibility and security for modern smart homes.

Keywords—smart doorbell, facial detection, real-time interaction, image recording, notifications

I. Introduction

Burglary is a crime that can have a major impact both financially and psychologically on victims, whilst also influencing feelings of public safety within communities [1], [2]. In fact, numerous intrusions are not only linked to property theft but also to bullying. In 2022, many cases were recorded involving individuals entering people's homes with malicious intent, abusing family members, especially women and children [3], [4]. After one month of implementing a peak campaign to enhance public security, Ho Chi Minh City has recorded significant positive changes. According to statistics from the Ho Chi Minh City Police, 309 social order-related crimes were reported last month, marking a 33.55% decrease compared to the same period last year. This has left the population intrigued and, at the same time, has driven the urgent need for contemporary home security solutions.

(a)

(b)

Figure 1: Blurred image of people in (a) hall, (b) outdoor

Smart doorbells have rapidly gained popularity as a key component of modern smart home ecosystems [5]. Ring and Nest are leading brands offering high-end devices named smart doorbell with advanced features such as motion alerts, two-way communication, and integration with smart home platforms. Research efforts have explored integrating video doorbells with IoT platforms for enhanced functionality such as capturing images in front of the door automatically [6]. However, their products often come with several blurred image of unrecognized face, as shown in Fig. 1 [7].

This paper presents the design and development of an Smart Doorbell, aimed at providing homeowners with cost-effective security and convenience through real-time video monitoring, cloud integration, and facial detection. The device leverages a Raspberry Pi 5 microcontroller, a Raspberry Pi Camera V2, a ReSpeaker 2-Mics Pi HAT to enable features such as live video streaming, visitor detection, and two-way communication. The device integrates with cloud service platforms like Firebase and Cloudinary to store and analyze visitor data, enabling personalized notifications and enhanced security insights. The proposed smart doorbell addresses several limitations of existing solutions, such as high costs, limited customization, and dependency on proprietary ecosystems. By emphasizing affordability, modularity, and open IoT integration, this device serves not only individual homeowners but also property managers and small businesses. This study focuses on developing a cost-effective IoT-enabled smart doorbell, providing real-time video and motion detection and enabling cloud-based data storage and analysis for long-term visitor tracking and enhanced security insights.

The rest of this paper delves into the hardware and software design, implementation, testing, and potential applications of the smart doorbell. By combining real-time monitoring, secure communication, and IoT capabilities, this device aims to redefine home security and convenience for modern households.

II. METHODOLOGY AND MATERIALS

A. Methodology

Face detection using Haar Cascade is a popular and effective method in computer vision, particularly for real-time face recognition tasks [8]. This technique was first introduced by Paul Viola and Michael Jones in 2001 and is widely used due to its computational efficiency and ability to detect faces in images with a high degree of accuracy. The core idea behind Haar Cascade is to use a machine learning object detection framework to identify features within an image that are likely to correspond to human faces.

At the heart of Haar Cascade is the concept of Haar-like features, which are simple rectangular patterns that capture information about the relative intensity of pixel regions within a given image [9]. These features resemble the Haar basis functions used in signal processing and are essentially patterns such as edges, lines, and corners, which are common in facial structures.

B. System design

The smart doorbell is equipped with a high-definition camera as shown as Fig 2. When a visitor approaches and stands in front of the doorbell, the system automatically detects the presence of a face using Haar Cascade [10]. It then captures an image of the visitor. Upon detecting a face, the smart doorbell captures a clear picture of the individual. If the visitor's face is staying too long, the system can trigger an alarm for enhanced security. This feature can be configured to alert the homeowner of an unknown visitor. Once a picture is taken, the image and relevant data time are uploaded securely to cloud storage platforms Cloudinary and Firebase [11]. This enables homeowners to access the data remotely, even if they're not at home. Cloud storage also ensures that the captured images and records are stored safely for later review. When a visitor presses the doorbell button, the system initiates a real-time video call between the doorbell and the homeowner's mobile device or home system. The homeowner can see the visitor live through the video feed and communicate with them via two-way audio. This function allows homeowners to interact with the visitor without opening the door, ensuring both convenience and security. In addition to live interaction, the homeowner can also access a history of past visitors through their cloud storage system. This can include images, video recordings, and logs of previous doorbell presses, which provide a useful record for home security management. By integrating face detection, picture capturing, cloud-based storage, alarm notifications, and video calling, the smart doorbell serves as a comprehensive and efficient solution for home security and communication. It enhances the safety of the home by allowing homeowners to monitor and interact with visitors remotely, while also ensuring that all data is securely stored and easily accessible.

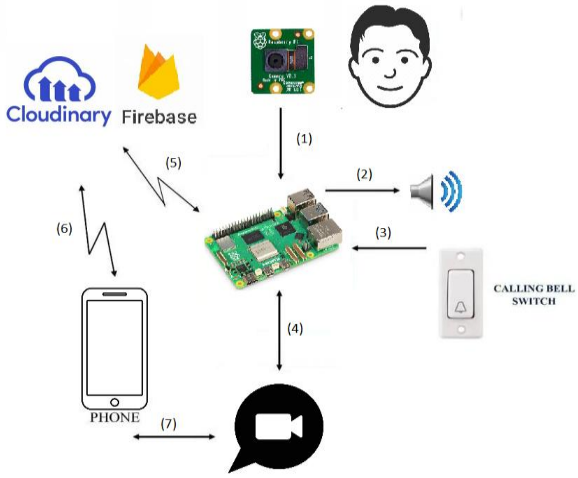

Figure 2: Smart doorbell system

C. Experiment Setup

The system comprises a controller of Raspberry Pi 5 board, connecting to peripherals including Raspberry Pi Camera V2 and ReSpeaker 2-Mics Pi HAT [12]. We have created a stereo speaker connect with the board and 27W USB-C Power Supply as power supply for Raspberry Pi 5. The device should be connected to Wi-Fi network so it can communicate with cloud services and send data [13].

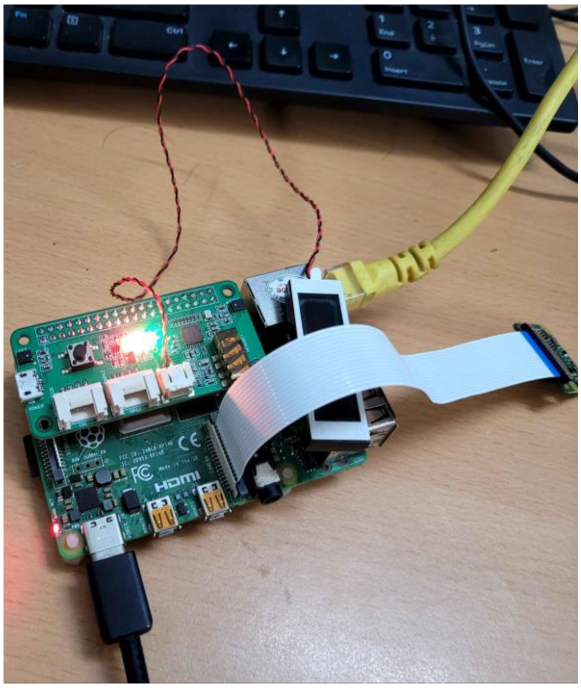

Figure 3: Smart doorbell setup

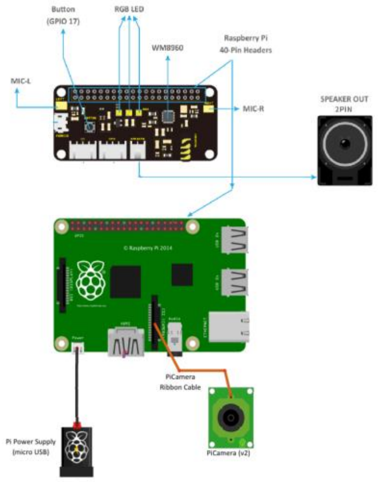

Figure 4: Smart doorbell wiring diagram

D. Mobile Application Design

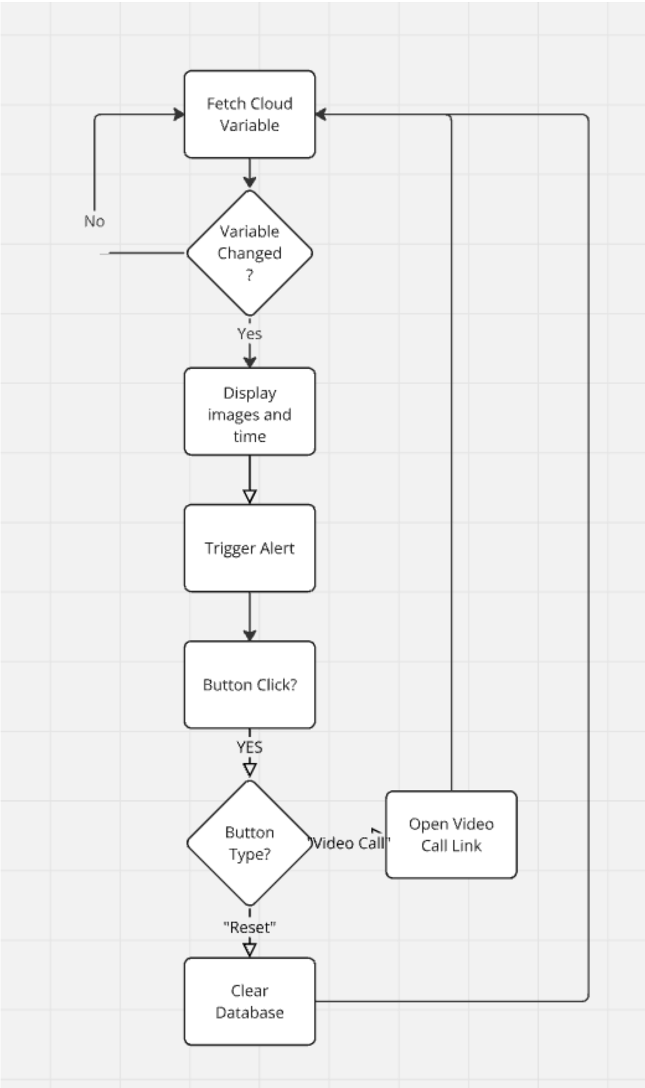

Figure 5: Flowchart of the Smart doorbell application's processing

With the target of building a mobile application that can connect with Firebase and Cloudinary, a mobile application has been designed for display all storage images, and set a video call with the system [14]. All the processing steps were conducted on a server following the flowchart in Fig 5. The application initializes variables for tracking system state and event occurrences. Upon screen opening, it continuously fetches and displays the variable from real-time database. When the variables changes, the application extracts image and time data, display them on screen, and triggers an alert. User confirmation of the alert opens a video call link. Button clicks initiate video calls or clear the database. The application also employs text-to-speech for audio notifications.

III. Results and Discussions

A. Face detection result

To evaluate and comment most intuitively, we conducted tests and detected faces in different cases. There are 50 images of human faces in various states such as: straight or profile angle, adequate or low light, and day or night [15]. Fig 6, 7 and Table 1, 2 summarize the data collected during testing and provide a visual representation of the system's performance. The smart doorbell system employs facial detection to identify visitors. The system was tested with a range of users, including family members, friends, and strangers. The results show that the accuracy is quite high under different conditions. However, in the case of lack of light, the accuracy is lower [16].

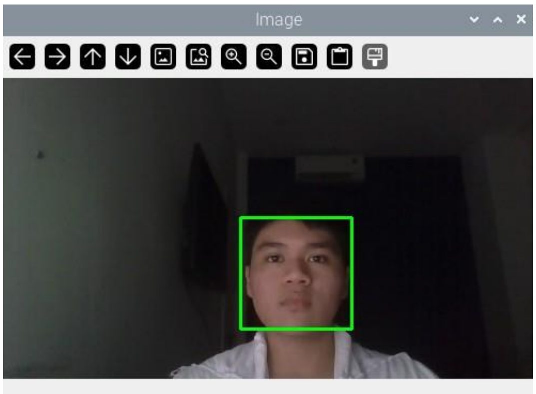

Figure 6: Face Detection in case of lack of light

In order to determine speed of the novel automatic facial detection system, comparison of changes over 50 images of the 2 sets of daytime and night time were presented in Fig. 9. In general, it shows that the system took approximately from 1 to 2 seconds to detect and recognize a face, which is fast enough to provide real-time notifications to the user [17].

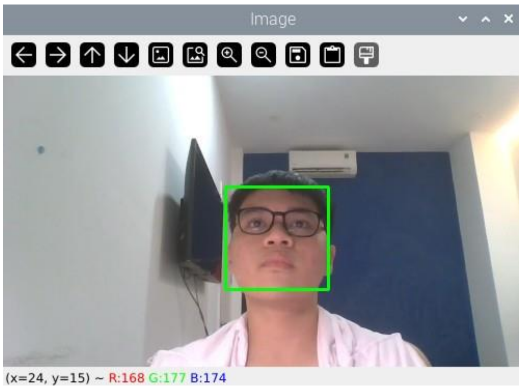

Figure 7: Face Detection in Good Lighting

	Straightedge			
	Bright enough		Lack of light	
	There are glasses	No glass	There are glasses	No glass
Aim	40/50 = 80%	43/50 = 86%	31/50 = 62%	33/50 = 66%
Open	42/40 = 84%	44/50 = 88%	34/50 = 68%	37/50 = 74%
	Tilt angle			
	Bright enough		Lack of light	
	There are glasses	No glass	There are glasses	No glass
Aim	38/50 = 78%	41/50 = 82%	33/50 = 66%	34/50 = 68%
Open	40/50 = 80%	43/50 = 86%	35/50 = 70%	38/50 = 78%

Table 1: Results of Face Detection with Straight and Tilted Angles (Daytime)

	Straightedge			
	Bright enough		Lack of light	
	There are glasses	No glass	There are glasses	No glass
Aim	39/50 = 78%	40/50 = 80%	30/50 = 60%	31/50 = 63%
Open	40/50 = 80%	42/50 = 84%	35/50 = 70%	37/50 = 74%
	Tilt angle			
	Bright enough		Lack of light	
	There are glasses	No glass	There are glasses	No glass
Aim	37/50 = 74%	40/50 = 80%	30/50 = 60%	31/50 = 63%
Open	39/50 = 78%	42/50 = 84%	31/50 = 63%	33/50 = 66%

Table 2: Results of Face Detection with Straight and Tilted Angles (Night time)

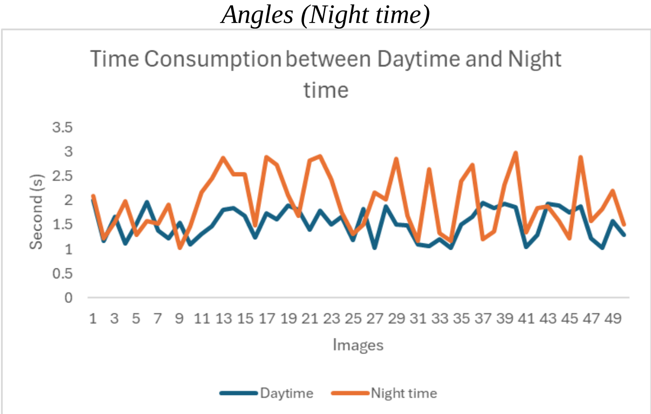

Figure 9: Time Consumption between Daytime and Night time

B. The designed product

To complete the Smart Doorbell, the process begins with final assembly and testing. All hardware components, such as the camera, sensors, speaker, microphone, and buttons, are thoroughly checked to ensure proper functionality. Calibration is performed to adjust the camera angle, sensor sensitivity, and speaker, microphone volume [18]. Quality assurance tests are then conducted under various conditions, such as low light, extreme temperatures, and weak network connections, to validate performance. After confirming reliability, the device is placed into its protective casing, with all external features aligned correctly, and the internal parts securely fixed with screws or adhesive. We have designed a 3D-printed case for the product, as shown as Fig. 8 [19].

Figure 8: Smart doorbell

C. The designed mobile application

The application with a user-friendly interface for mobile users was developed using the Thunkable platform, as illustrated in Fig. 10 [20]. This application enables users to manage stored images captured by the smart doorbell from Cloudinary efficiently. To access the video call room, users can simply press the “Call Video” button [21].

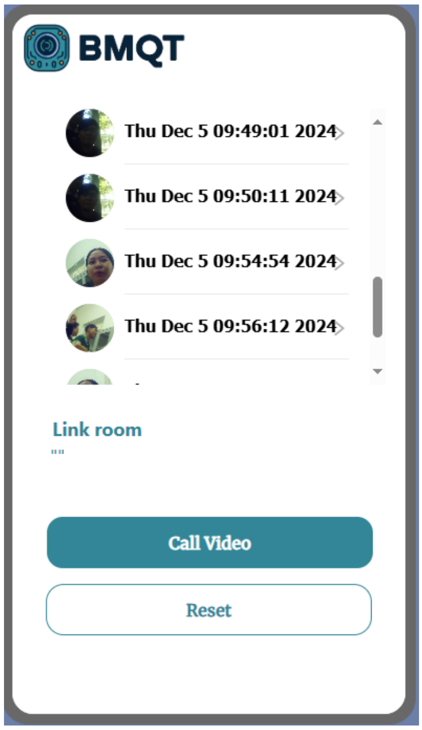

Figure 10: Screen of Mobile App Doorbell.

IV. CONCLUSION AND FUTURE WORKS

Our study demonstrated that the smart doorbell system achieved high accuracy and efficiency in detecting faces and integrating with mobile applications. The face detection functionality was initially tested in controlled environments with ideal lighting conditions, resulting in reliable and consistent performance. However, to enhance its robustness for real-world scenarios, the system was tested under varying lighting conditions, diverse face angles, and different distances.

The integration with the mobile application proved seamless, allowing users to manage stored images and initiate video calls directly through the application. The "Call Video" feature successfully connected users to a live communication channel, demonstrating low latency and high reliability in operation.

From the dataset of images captured by the smart doorbell, facial recognition performance was evaluated, and key metrics such as detection accuracy, processing time, and false-positive rates were recorded. The results indicate that the system can handle real-time recognition tasks effectively, even with medium-quality image inputs. To further enhance the system's utility, a database management system using Google Sheets was implemented on the server side. This system logged captured images along with their corresponding date and time, providing an organized approach to data storage and retrieval.

Furthermore, we have been extending expanding the database to include a wider variety of facial profiles and environmental conditions. Additionally, features such as multi-user recognition and enhanced integration with AI-based assistants will be explored to improve usability and accuracy. By incorporating new physiological and environmental parameters, the smart doorbell system aims to become an even more effective and versatile solution for home security and communication.

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