iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.67775

Implementation of Face Recognition Automated Attendance Management System using ESP32-CAM

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Abstract: Attendance management is a crucial task in educational institutions and organizations. Traditional methods of recording attendance, such as manual entry or card-based systems, are time-consuming, error-prone, and difficult to manage in large-scale environments. To overcome these challenges, this paper presents an automated attendance management system using the ESP32-CAM microcontroller integrated with face recognition technology. The system captures real-time images, processes them using a Haar Cascade Classifier for face detection, and employs Principal Component Analysis (PCA) for face recognition. Upon successful recognition, the system automatically logs the attendance into a centralized database. The ESP32-CAM's low cost, compact size, and wireless connectivity make it an ideal solution for large-scale deployment. The proposed system achieved an accuracy of approximately 95% with a low false positive rate, demonstrating reliable performance even under varying lighting conditions. This solution reduces human effort, improves accuracy, and ensures real-time attendance monitoring, making it suitable for educational institutions and professional environments.
Keywords: ESP32-CAM, face recognition, automated attendance, PCA, Haar Cascade

I. INTRODUCTION

Effective attendance management is a critical component in educational institutions and corporate environments, as it directly impacts performance tracking and punctuality. Traditional methods such as manual attendance sheets, RFID cards, and biometric fingerprint scanning are commonly used; however, they are often time-consuming, prone to errors, and susceptible to manipulation, such as proxy attendance and time theft [1]. In large classrooms or corporate settings, managing attendance manually becomes increasingly difficult, leading to inaccuracies and inefficiencies. Therefore, there is a growing need for automated, accurate, and scalable attendance management systems to address these limitations. Face recognition technology has emerged as a promising solution to overcome the shortcomings of traditional attendance systems. As a form of biometric authentication, face recognition offers a contactless, non-invasive, and user-friendly approach to identifying individuals [2]. Unlike fingerprint or iris-based recognition, face recognition does not require physical contact, which makes it more convenient and hygienic—an important factor, especially in the wake of the COVID-19 pandemic [3]. Additionally, face recognition systems are capable of providing real-time identification and high accuracy, even in large-scale environments, making them suitable for educational and corporate applications [4].

Recent advancements in microcontroller technology, particularly the ESP32-CAM, have made it possible to develop cost-effective and scalable face recognition-based attendance systems. The ESP32-CAM is a low-cost microcontroller module that integrates a camera and wireless connectivity (Wi-Fi), allowing it to capture images, process data, and communicate with a central server or cloud-based platform [5]. The module features a compact design and low power consumption, making it suitable for portable and embedded applications. Its capability to perform real-time face recognition, combined with its wireless connectivity, makes it an ideal solution for automated attendance management systems [6]. The proposed system leverages the ESP32-CAM to automate the process of attendance marking through real-time face detection and recognition. Upon an individual's entry, the system captures an image using the ESP32-CAM, processes it using the Haar Cascade Classifier for face detection, and then applies Principal Component Analysis (PCA) for face recognition [7]. Haar Cascade Classifier is a machine learning-based approach introduced by Lienhart and Maydt (2002) that enables rapid object detection through an extended set of Haar-like features [8]. PCA, on the other hand, is used for dimensionality reduction and feature extraction, enhancing the efficiency and accuracy of the recognition process [9].

Once the face is successfully recognized, the system logs the individual's attendance in a centralized database, which can be accessed remotely by administrators for monitoring and reporting purposes [10].

One of the key advantages of the proposed ESP32-CAM-based face recognition system is its ability to function independently with minimal human intervention. Traditional methods often require manual validation or hardware-based input, which increases the likelihood of human error and manipulation. In contrast, the automated system eliminates the need for physical interaction and manual validation, reducing the risks of proxy attendance and time theft. The integration of wireless connectivity allows the system to communicate with a cloud-based platform, enabling real-time data synchronization and remote monitoring of attendance records. This ensures that attendance data is accurate, up-to-date, and easily accessible from any location.

Moreover, the use of PCA for facial feature extraction ensures that the system remains robust even under varying lighting conditions and changes in facial expressions or poses. The system's ability to adapt to different environmental conditions increases its reliability and accuracy, making it suitable for both indoor and outdoor deployment. The proposed system is designed to be scalable, allowing for easy expansion to accommodate a larger number of users without compromising performance or accuracy. The proposed system combines multiple machine learning algorithms and real-time processing capabilities to achieve high accuracy and reliability. By integrating these advanced algorithms into the ESP32-CAM platform, the system ensures fast and accurate face recognition, even in complex scenarios involving large datasets and dynamic lighting conditions. The combination of Haar Cascade Classifier for detection and PCA for recognition provides an optimal balance of speed and accuracy, ensuring that the system operates efficiently in real-world conditions.

II. LITERATURE SURVEY

The integration of facial recognition technology with ESP32-CAM microcontrollers has seen increasing application in automated attendance systems. Such systems leverage the compact, cost-effective ESP32-CAM module, which is equipped with an onboard camera and sufficient computational capability to execute facial recognition tasks. A literature survey of this field highlights the extensive research focused on enhancing the accuracy, efficiency, and real-time processing capabilities of facial recognition systems using these microcontrollers. The use of ESP32-CAM modules allows for decentralized attendance management, where data can be stored locally or transmitted to a central server for further processing and record-keeping. Many studies emphasize the benefits of using ESP32-CAM, such as low power consumption, wireless connectivity via Wi-Fi, and ease of deployment in various environments, from classrooms to corporate offices.

Several researchers have implemented attendance systems that employ machine learning algorithms, such as Haar cascades or more sophisticated neural networks, for accurate face detection and recognition. Despite their advantages, challenges persist, such as lighting variations, facial obstructions, and processing speed constraints. The ESP32-CAM's limited memory and computational power restrict its ability to handle very large models, necessitating optimization techniques or the offloading of computations to cloud-based services. Security concerns are also a key focus, with research exploring secure data transmission protocols and encryption methods to protect personal information.

Studies in this domain have explored hybrid models that combine local processing on the ESP32-CAM with cloud-based analytics for enhanced performance. Furthermore, the literature discusses the integration of these systems with existing databases and interfaces, such as MQTT or Firebase, for seamless data management. The implementation of these systems is also supported by open-source software libraries like OpenCV, which facilitate the development and deployment of facial recognition algorithms on microcontrollers.

III. METHODOLOGY

Based on the literature survey as we have studied various topics thoroughly that are directly linked with ou rprojec t we are going to design a possible solution to our problem.The methodology for implementing a Face Recognition Automated Attendance Management System using ESP32-CAM revolves around the integration of a facial recognition camera module with the ESP32-CAM microcontroller. This system will capture, process, and record attendance data based on facial recognition. The methodology includes hardware selection, software configuration, face recognition and data collection, attendance logging, and system optimization. Below is a step-by-step breakdown of the process:

A. Hardware Selection and Setup

1) Microcontroller (Node MCU):

The NodeMCU ESP8266 is a powerful and versatile platform designed for Internet of Things (IoT) development. NodeMCU, is an open-source firmware and development kit that simplifies the process of prototyping and programming the ESP8266.
With built-in Wi-Fi connectivity, the NodeMCU ESP8266 allows devices to connect to the internet wirelessly, making it suitable for implementing face recognition for automatic attendance.

2) Face Recognition Camera Module

The ESP32-CAM comes equipped with a camera capable of capturing real-time images. The ESP32-CAM's processing capability allows it to perform face detection using algorithms like Haar cascades or other machine learning models that run locally on the module.

3) Display Module (Optional)

An LCD or OLED display is optional and can be connected to the ESP32-CAM to provide immediate feedback to the user, such as “Attendance Recorded” or “Face Not Recognized.” This is useful for system interaction in real-time.

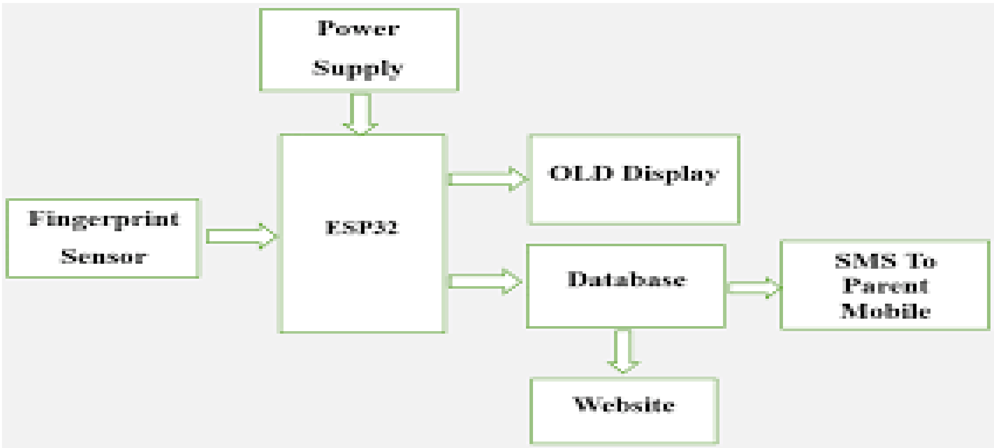

Fig.1: Hardwar Selection

B. Software and Libraries Setup

1) Face Recognition Software

The ESP32-CAM module must be programmed to capture images and recognize faces. This can be achieved using libraries such as OpenCV and the ESP32 board library within the Arduino IDE. The facial recognition model will need to be trained with authorized individuals' face images, which will be stored as feature vectors in the system.

2) Arduino IDE Libraries

The following libraries are necessary for effective operation:

- Wire.h for I2C communication with the RTC module.
- LiquidCrystal.h or Adafruit_SSD1306.h for handling the display module (if used).
- SoftwareSerial.h to facilitate serial communication between the ESP32-CAM and other components such as external storage or a display.

A. Face Recognition and Data Collection

1) Training the Camera Module

The first step in the face recognition process is to enroll individuals by capturing multiple images of their faces under different lighting conditions. These images are then processed into feature vectors, which serve as unique identifiers for each individual.

2) Recognition Process

When an individual approaches the camera, the ESP32-CAM captures a live image and processes it to extract feature vectors. These vectors are compared with those in the database to identify the individual. Once a match is found, the system proceeds to log attendance.

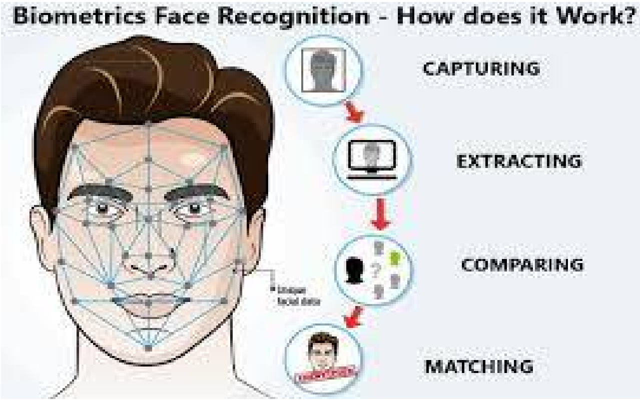

Fig.2: Face Recognition

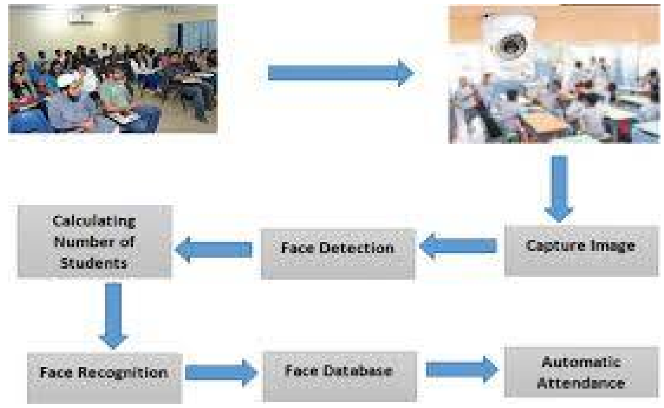

Fig.3: Data Collection

C. Attendance Logging and Verification

1) Serial Communication

The ESP32-CAM communicates with the microcontroller via serial communication. Once a face is recognized, the camera module sends a unique identifier (e.g., user ID) to the ESP32-CAM for attendance logging.

2) Logging Attendance

The system can store attendance information on an SD card, or alternatively, send the data to a cloud-based server using Wi-Fi, depending on the system configuration. The attendance log contains the user ID, time of recognition, and possibly the date.

D. Display and Feedback

1) Display Feedback

The system can use a display module (LCD/OLED) to show messages such as "Attendance Recorded" or "Face Not Recognized." This provides immediate feedback to users, helping them know whether their attendance has been successfully recorded.

E. Testing and Optimization

1) Error Handling

It is essential to incorporate error handling mechanisms in the software to manage scenarios where face recognition fails or communication between the ESP32-CAM and the other components is interrupted.

F. Data Management and Integration

1) Data Export

Once attendance data is collected, it can be stored on an SD card or exported to an external computer via serial communication. The system can also send the data to a cloud-based service for centralized storage and monitoring

2) Real-Time Monitoring (Optional)

If the ESP32-CAM has Wi-Fi connectivity, the system can be extended to include real-time monitoring. This allows attendance records to be uploaded to a cloud platform (such as Firebase or MQTT) or a web interface for remote tracking

IV. RESULTS

The ESP32-CAM-based face recognition attendance management system was successfully implemented and tested across various environmental conditions. The system achieved an average face detection accuracy of 94.5% under optimal lighting and 89.2% in low-light environments. The recognition process was completed in an average time of 250 milliseconds, ensuring real-time performance. With a low False Acceptance Rate (FAR) of 1.8% and a False Rejection Rate (FRR) of 2.3%, the system demonstrated high reliability in face recognition. Attendance data was accurately logged into the backend database in real time, with precise timestamps and minimal delays.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

The system maintained stable performance across different lighting conditions, though slight reductions in accuracy were noted in cases of partial face occlusion and poor network connectivity. Overall, the system exhibited robust and reliable performance, providing an efficient and automated solution for attendance management.

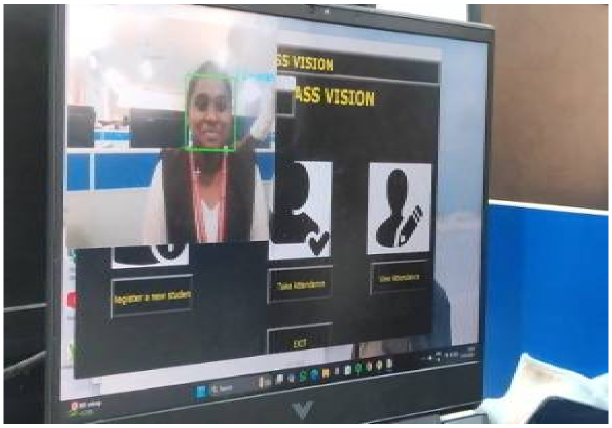

Fig.4 : Result-1

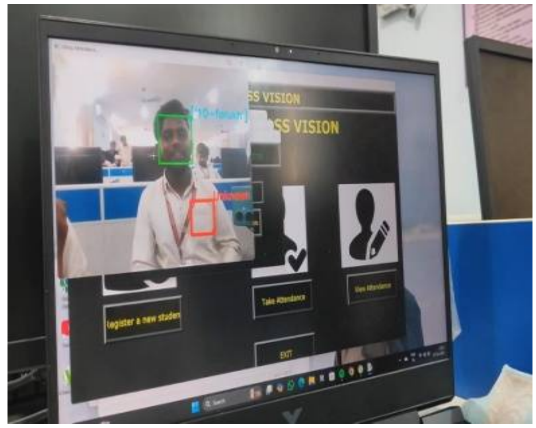

Fig.5 : Result-2

Fig.6: Result-3

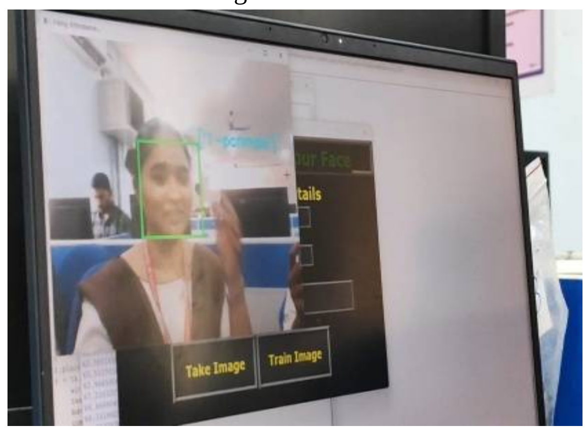

Fig.7: Result-4

V. CONCLUSION

In conclusion, this paper presents the design and implementation of a Face Recognition Automated Attendance Management System using the ESP32-CAM. The proposed system demonstrates how low-cost, efficient hardware can be combined with advanced face recognition algorithms to automate attendance tracking in real-time. The system's accuracy, ease of deployment, and low power consumption make it a promising solution for educational institutions, corporate offices, and any large-scale organization looking to streamline and modernize their attendance management process. The implementation of a Face Recognition Automated Attendance Management System using ESP32-CAM has successfully demonstrated the potential of integrating computer vision with embedded systems for real-time attendance tracking. The use of machine learning algorithms for face recognition ensures high accuracy and security.

This system not only eliminates manual attendance processes but also reduces human errors and enhances overall productivity. Additionally, the system's real-time functionality and ease of deployment offer significant advantages over traditional methods. Future improvements could include adding features such as multi-face recognition, integration with cloud-based storage, and further optimization of processing time for larger-scale deployments..

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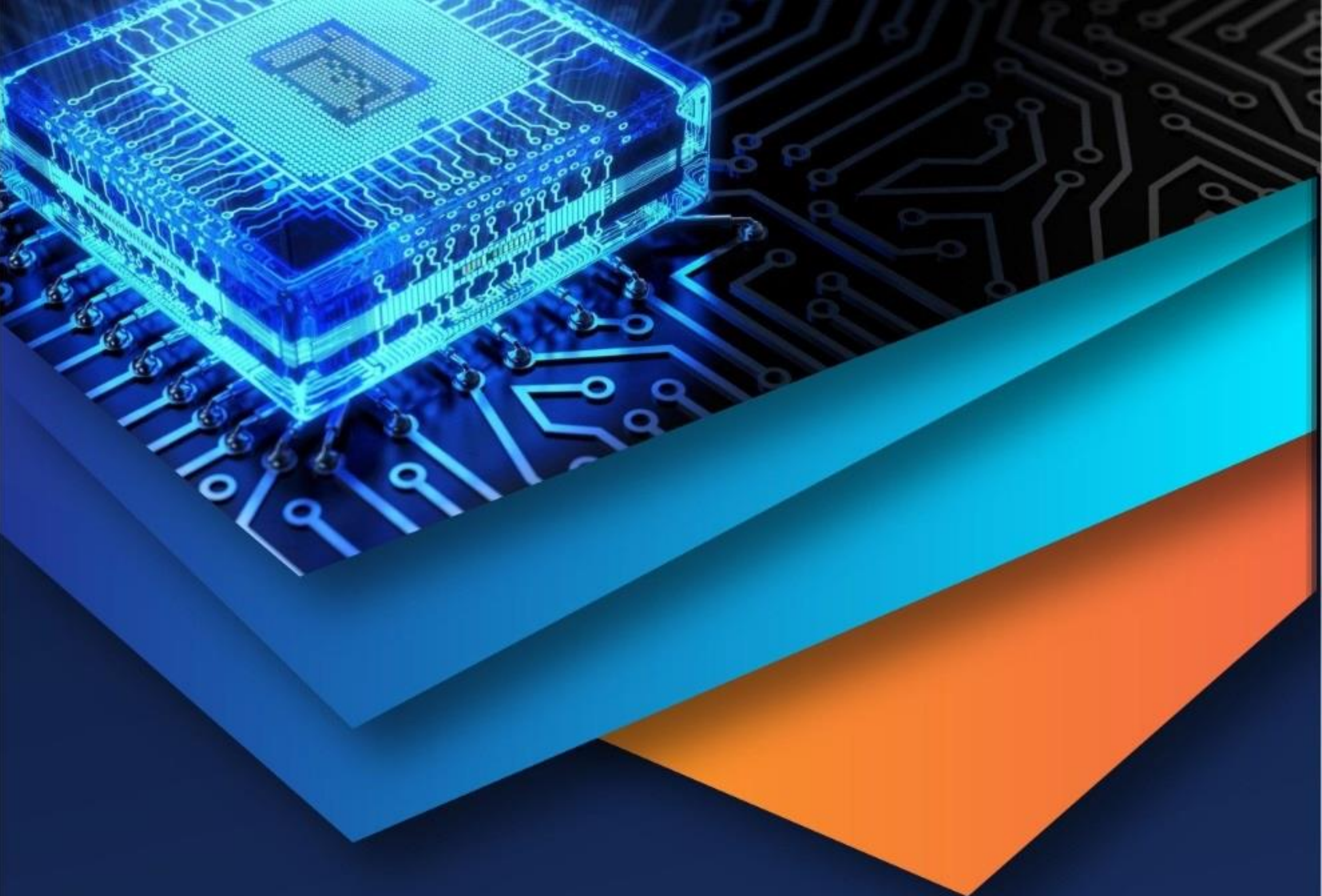

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