

A Low-Cost Iot-Based Autonomous Monitoring Robot For Educational Institutions

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ABSTRACT

The rapid advancement of Internet of Things (IoT), robotics, and computer vision technologies has created new opportunities for improving security and attendance management in educational institutions. This project presents a low-cost IoT-based autonomous monitoring robot designed to enhance campus surveillance, automate attendance recording, and detect unauthorized individuals. The proposed system integrates an ESP32-CAM module, ultrasonic sensors, PIR motion sensors, Arduino Uno, and face recognition techniques to provide intelligent monitoring with minimal human intervention. The robot autonomously navigates through educational environments, avoids obstacles, captures real-time images, and identifies registered students and staff using facial recognition algorithms. Attendance records are automatically generated and maintained through a web-based dashboard, reducing manual effort and improving accuracy. Additionally, the system detects unknown individuals and generates instant visual alerts through an LCD display, enhancing campus security. Experimental results demonstrate reliable performance in navigation, face recognition, attendance management, and alert generation. The proposed solution offers a scalable, cost-effective, and efficient smart monitoring platform for modern educational institutions.

Keywords: Internet of Things (IoT), Face Recognition, Autonomous Monitoring Robot

INTRODUCTION

Educational institutions require efficient systems to ensure campus security, monitor activities, and maintain accurate attendance records. Traditional surveillance methods primarily rely on fixed CCTV cameras and manual supervision, which often suffer from limited coverage, blind spots, and delayed responses to security incidents. Similarly, conventional attendance systems such as manual registers, ID cards, and biometric devices are time-consuming, prone to errors, and require considerable administrative effort.

Recent advancements in the Internet of Things (IoT), Robotics, Computer Vision, and Artificial Intelligence (AI) have enabled the development of intelligent monitoring systems capable of operating with minimal human intervention. Autonomous mobile robots equipped with sensors, cameras, and wireless communication technologies can continuously patrol designated areas, monitor activities, and provide real-time information to administrators and security personnel. These technologies improve security, reduce manual effort, and enhance operational efficiency.

Face recognition technology has emerged as one of the most effective methods for identity verification and attendance management. By analyzing unique facial features, the system can accurately identify registered students and teachers while detecting unknown individuals. Automated attendance management using facial recognition eliminates manual attendance procedures, reduces the possibility of proxy attendance, and improves record accuracy.

The proposed system integrates autonomous navigation, live video monitoring, face recognition, attendance management, and real-time alert generation into a single intelligent platform. The robot uses ultrasonic sensors for obstacle avoidance, a PIR sensor for motion detection, and an ESP32-CAM module for image acquisition and wireless communication. The captured images are transmitted to a computer system where face recognition and attendance management processes are performed using Python and OpenCV. The face recognition system identifies registered individuals and automatically records attendance information. Whenever an unknown

person is detected, an alert message is displayed on an LCD display mounted on the robot, enabling nearby users and security personnel to identify unauthorized individuals immediately.

The proposed solution provides a cost-effective, scalable, and intelligent monitoring platform suitable for schools, colleges, universities, libraries, laboratories, and other educational environments. By combining robotics, IoT, and computer vision technologies, the system enhances campus security, simplifies attendance management, and improves overall institutional efficiency.

1.4 OBJECTIVES

- To design and develop a low-cost IoT-based autonomous monitoring robot for educational institutions.
- To implement autonomous navigation and obstacle avoidance using ultrasonic sensors.
- To detect human presence using PIR sensors and activate monitoring functions when required.
- To provide live video monitoring using the ESP32-CAM module.
- To perform real-time face recognition for identifying registered students and teachers.
- To implement an automated attendance management system using facial recognition technology.
- To maintain separate attendance records for students and teachers.
- To detect unknown or unauthorized individuals within the monitored environment.
- To display alert messages on the LCD display whenever an unknown person is detected.
- To establish wireless communication using ESP32-CAM technology.
- To provide a cost-effective and scalable smart monitoring solution for educational institutions.

LITERATURE SURVEY

[1] N. Dalal and B. Triggs — Histograms of Oriented Gradients for Human Detection (IEEE CVPR, 2005) Proposed the HOG feature descriptor for human detection. The method divides images into small cells, computes gradient orientation histograms, normalizes them across blocks, and classifies objects using a Support Vector Machine (SVM). Achieved high detection accuracy while maintaining computational efficiency. This work provides the theoretical foundation for the face detection module of the proposed system, as the face_recognition library utilizes a HOG-based detector implemented in dlib to locate faces from images captured by the autonomous monitoring robot.

[2] D. E. King — Dlib-ml: A Machine Learning Toolkit (JMLR, 2009) Presented the Dlib machine learning toolkit containing object detection algorithms, HOG-based face detection, machine learning utilities, and deep learning models for facial recognition. The toolkit supports efficient real-time face processing and Python integration. The face_recognition library used in the system is built directly on Dlib, making this work fundamental to the implementation of student identification, attendance monitoring, and security surveillance functions.

[3] F. Schroff, D. Kalenichenko, and J. Philbin — FaceNet: A Unified Embedding for Face Recognition and Clustering (IEEE CVPR, 2015) Introduced a deep convolutional neural network trained using triplet loss to generate compact facial embeddings for recognition. Achieved state-of-the-art performance on face recognition benchmarks and demonstrated the effectiveness of embedding-based identification. This work forms the theoretical basis for distinguishing registered students, staff members, and unknown individuals in the monitoring robot.

[4] K. He, X. Zhang, S. Ren, and J. Sun — Deep Residual Learning for Image Recognition (IEEE CVPR, 2016) Proposed Residual Neural Networks (ResNet) using shortcut connections that enable the successful training of very deep neural networks. The architecture significantly improved image classification and feature extraction accuracy. The Dlib face recognition model employed in the system uses a ResNet-based architecture, allowing highly accurate extraction of facial features for attendance and security applications.

[5] P. Viola and M. J. Jones — Robust Real-Time Face Detection (IJCV, 2004) Developed the Haar Cascade face detection algorithm using Haar-like features and cascade classifiers. The method enabled rapid and reliable face detection suitable for real-time applications. This work supports the face enrollment process where facial images are captured, processed, and stored for future recognition and attendance tracking.

PROPOSED SYSTEM

The proposed system integrates autonomous navigation, campus security, face recognition, attendance management, and real-time alert generation into a single intelligent platform. Unlike conventional systems that rely on fixed surveillance cameras and manual supervision, the robot can move autonomously throughout the environment, providing wider coverage and reducing surveillance blind spots.

The robot is equipped with an ESP32-CAM module for image acquisition and wireless communication, ultrasonic sensors for obstacle detection and avoidance, and a PIR sensor for human motion detection. The captured images are processed using Python and OpenCV-based face recognition algorithms to identify registered students and teachers.

Whenever a registered individual is recognized, the system automatically records attendance along with the date and time. Separate attendance records are maintained for students and teachers, improving administrative efficiency and reducing manual effort.

The system also enhances security by detecting unknown or unauthorized individuals. When an unknown person is identified, an alert message is immediately displayed on the LCD display mounted on the robot. The HC-05 Bluetooth module can be used during testing and calibration for manual robot movement control.

By integrating autonomous monitoring, attendance automation, face recognition, and security alert generation into a single low-cost platform, the proposed system provides an efficient and scalable solution for educational institutions. The system improves campus security, reduces administrative workload, and enhances overall operational efficiency.

SYSTEM DESIGN AND DEVELOPMENT

4.1 SYSTEM ARCHITECTURE

The proposed system consists of three major layers:

4.1.1 Robot Hardware Layer

The hardware layer includes an Arduino Uno, ESP32-CAM module, HC-SR04 ultrasonic sensor, PIR motion sensor, L298N motor driver, DC motors, LCD display, buzzer, and power supply unit. The robot moves autonomously while continuously monitoring the surrounding environment. The ultrasonic sensor assists in obstacle avoidance, while the PIR sensor detects human movement. The LCD display is used to show alert messages whenever an unknown person is detected.

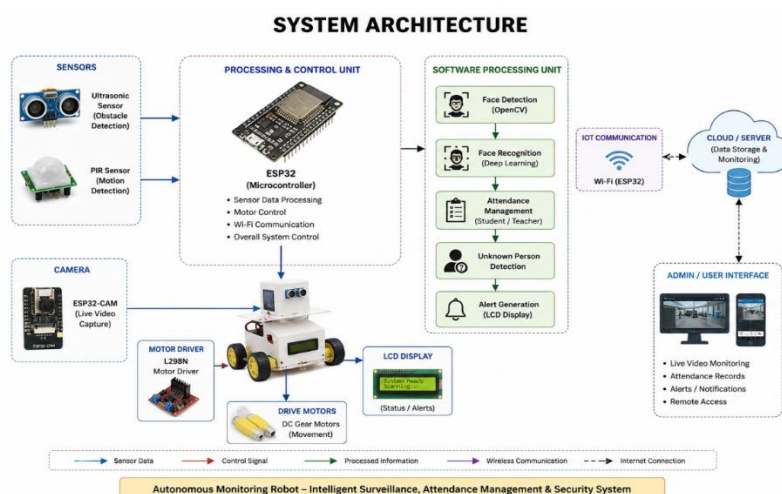


Figure 4.1: System Architecture of the Proposed Monitoring Robot

4.1.2 Communication Layer

The communication layer enables interaction between the robot and the monitoring system. The ESP32-CAM module provides wireless communication and transfers image data to the computer for processing. The HC-05 Bluetooth module can be used during testing and calibration for manual robot control. Communication between hardware and software modules ensures real-time monitoring and attendance updates.

4.1.3 Software Layer

The software layer is developed using Python, OpenCV, Flask, NumPy, and Face Recognition libraries. It performs face detection, face recognition, attendance recording, unknown person detection, and alert generation. The software also provides a web-based dashboard for attendance monitoring and management.

4.2 ALGORITHMS

1 Obstacle Avoidance Algorithm

The robot continuously measures the distance to nearby obstacles using the ultrasonic sensor. If no obstacle is detected within the threshold distance, the robot moves forward. If an obstacle is detected, the robot stops, changes direction, and resumes movement.

2 PIR Motion Detection Algorithm

The PIR sensor continuously monitors human movement. When motion is detected, a signal is generated to activate the image capture and face recognition process.

3 Face Recognition Algorithm

The ESP32-CAM captures image frames and OpenCV detects faces within the frame. Facial features are extracted and compared with the trained database. If a match is found, the identity of the person is displayed and attendance is recorded. Otherwise, the person is classified as unknown.

4 Attendance Marking Algorithm

When a registered student or teacher is recognized, the system verifies whether attendance has already been recorded for that day. If attendance is not present, a new record containing the person's name, role, date, and time is stored. Duplicate entries are prevented automatically.

5 Alert Generation Algorithm

If an unknown person is detected, the system immediately displays an alert message on the LCD display. Messages such as "Unknown Person Detected" or "Access Denied" are displayed to notify nearby users and security personnel. The event is recorded for future reference and security monitoring.

IMPLEMENTATION

5.1 OVERVIEW

The implementation of the proposed system consists of both hardware and software components working together to provide autonomous monitoring, face recognition, attendance management, and security alert generation. The hardware section includes the Arduino Uno, ESP32-CAM module, ultrasonic sensor, PIR sensor, L298N motor driver, DC motors, LCD display, buzzer, and communication modules. The software section is developed using Python, OpenCV, Flask, and face recognition libraries for face recognition and attendance management.

The system operates by continuously patrolling the environment, detecting human presence, capturing images, recognizing registered users, recording attendance, and displaying alerts whenever an unknown person is detected.

5.2 PROGRAMMING LANGUAGES AND FRAMEWORKS

The software system is developed using Python for face recognition, attendance management, and monitoring operations. OpenCV is used for image processing and face detection, while Flask provides a web-based interface for system management. The Arduino IDE is used for programming the Arduino Uno and ESP32-CAM modules responsible for robot movement, sensor interfacing, LCD display control, and communication.

5.3 MODULES DEVELOPED

Module	Technology	Responsibility
Robot Navigation Module	Arduino Uno	Autonomous robot movement, obstacle avoidance, and motor control using ultrasonic sensors
PIR Motion Detection Module	Arduino Uno	Detects human movement and activates the monitoring process when motion is detected
Live Monitoring Module	ESP32-CAM & OpenCV	Captures and transfers images for monitoring and face recognition
Face Recognition Module	Python & OpenCV	Detects and recognizes registered students and teachers using facial recognition technology
Attendance Management Module	Python	Automatically records student and teacher attendance with date and time information
Unknown Person Detection Module	Python & OpenCV	Identifies unregistered individuals by comparing detected faces with the stored database
LCD Alert Module	LCD Display & Arduino	Displays alert messages whenever an unknown person is detected
Communication Module	ESP32-CAM	Provides wireless communication between hardware and the monitoring system
Web-Based Monitoring Dashboard	Flask	Allows administrators to manage users, monitor activities, and view attendance records

5.4 AUTONOMOUS ROBOT NAVIGATION MODULE

The robot navigation module enables autonomous movement within the educational environment. Ultrasonic sensors continuously measure the distance between the robot and nearby obstacles. Based on the measured distance, the robot moves forward, stops, or changes direction to avoid collisions. This allows the robot to patrol corridors, classrooms, laboratories, and other campus locations without human intervention.

5.5 PIR MOTION DETECTION MODULE

The PIR sensor is used to detect human movement within the monitoring area. When motion is detected, the sensor sends a signal to the controller, which activates the monitoring process. This event-driven approach reduces unnecessary processing and improves system efficiency.

5.6 LIVE MONITORING MODULE

The ESP32-CAM module continuously captures and streams live video of the surrounding environment. The video feed is transferred to the monitoring system for real-time observation, processing, and analysis. The captured video frames serve as the input source for face recognition, attendance management, and security monitoring. This module enables continuous monitoring of activities within the educational environment and supports the detection of both registered and unknown individuals.

5.7 FACE RECOGNITION MODULE

The face recognition module is responsible for identifying registered students and teachers. Facial images are collected during the enrollment process and stored in the database. During operation, the system compares detected faces with the stored database and determines the identity of each individual. The module provides accurate and contactless identification for attendance and security purposes.

5.8 STUDENT AND TEACHER ATTENDANCE MANAGEMENT MODULE

The attendance management module automatically records attendance whenever a registered student or teacher is recognized. The attendance record contains the individual's name, role, date, and time. Duplicate attendance entries are prevented, ensuring accurate record maintenance. The system eliminates manual attendance procedures and reduces administrative workload.

5.9 UNKNOWN PERSON DETECTION MODULE

The system continuously compares detected faces with the registered database. If a face cannot be matched with any stored record, the individual is classified as an unknown person. This feature improves campus security by identifying unauthorized individuals within the monitored area.

5.10 LCD ALERT MODULE

Whenever an unknown person is detected, the system immediately displays an alert message on the LCD display. Messages such as "Unknown Person Detected" or "Access Denied" are shown to notify nearby users and security personnel. This visual alert mechanism provides an immediate indication of potential security threats.

5.11 COMMUNICATION MODULE

The ESP32-CAM module provides wireless communication between the robot and the monitoring system. It enables image transmission and supports real-time monitoring functions. The communication module serves as the bridge connecting the hardware and software components of the system.

RESULTS AND DISCUSSION

6.1 OVERVIEW

This chapter presents the results obtained from testing the proposed Low-Cost IoT-Based Autonomous Monitoring Robot for Educational Institutions. The system was evaluated based on robot navigation performance, PIR motion detection, live video monitoring, face recognition accuracy, attendance management efficiency, unknown person detection, and display alert capabilities. The results demonstrate the effectiveness of integrating robotics, computer vision, IoT communication, and attendance automation into a single intelligent monitoring platform.

6.2 OUTPUT OBTAINED

6.2.1 Robot Navigation Output

The autonomous robot successfully navigated indoor environments such as classrooms, laboratories, and corridors using ultrasonic sensor-based obstacle avoidance. During testing, the robot continuously monitored the distance to nearby obstacles and changed direction whenever an obstacle was detected. The robot demonstrated stable and reliable movement without requiring manual control.

6.2.2 PIR Motion Detection Output

The PIR sensor successfully detected human movement within the monitoring area. Whenever motion was detected, the monitoring process was activated automatically. This event-driven operation reduced unnecessary processing and ensured efficient utilization of system resources.



Figure 6.2: PIR Motion Sensor Used in the System

6.2.3 Robot Control Interface Output

The HC-05 Bluetooth application was used to remotely control the robot's movement during testing and calibration. The application provided directional controls for forward, backward, left, and right movement, enabling manual operation whenever required.

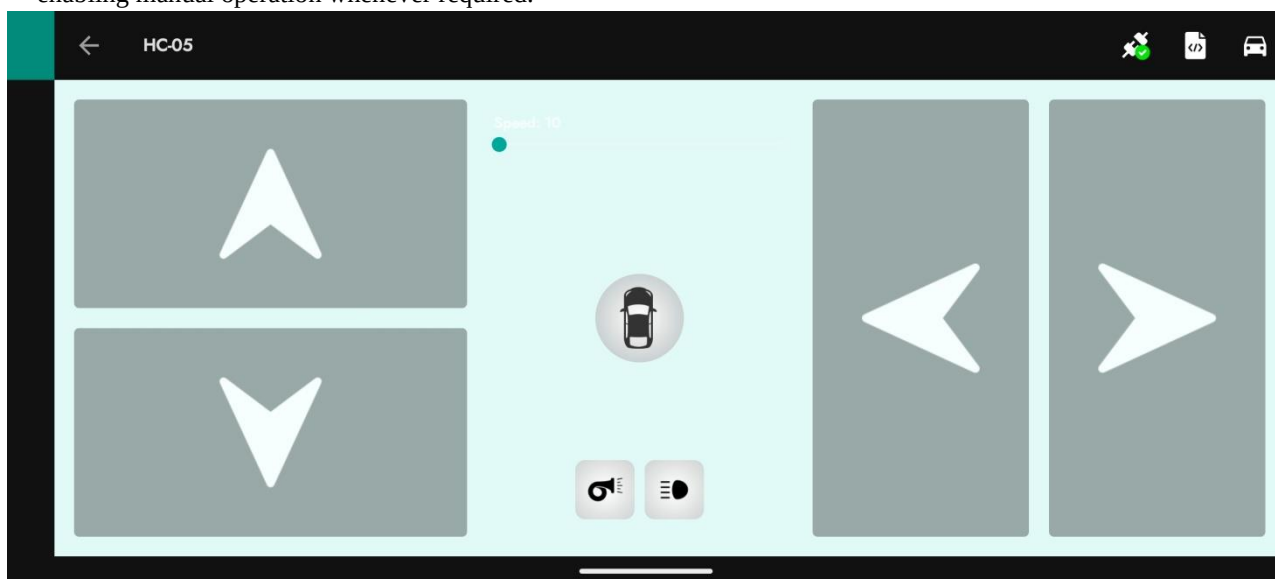


Figure 6.3: Robot Control Interface

6.2.4 Face Dataset Collection Output

The system captured multiple facial images of registered users during the enrollment process. These images were stored and used for training the face recognition model to improve recognition accuracy.

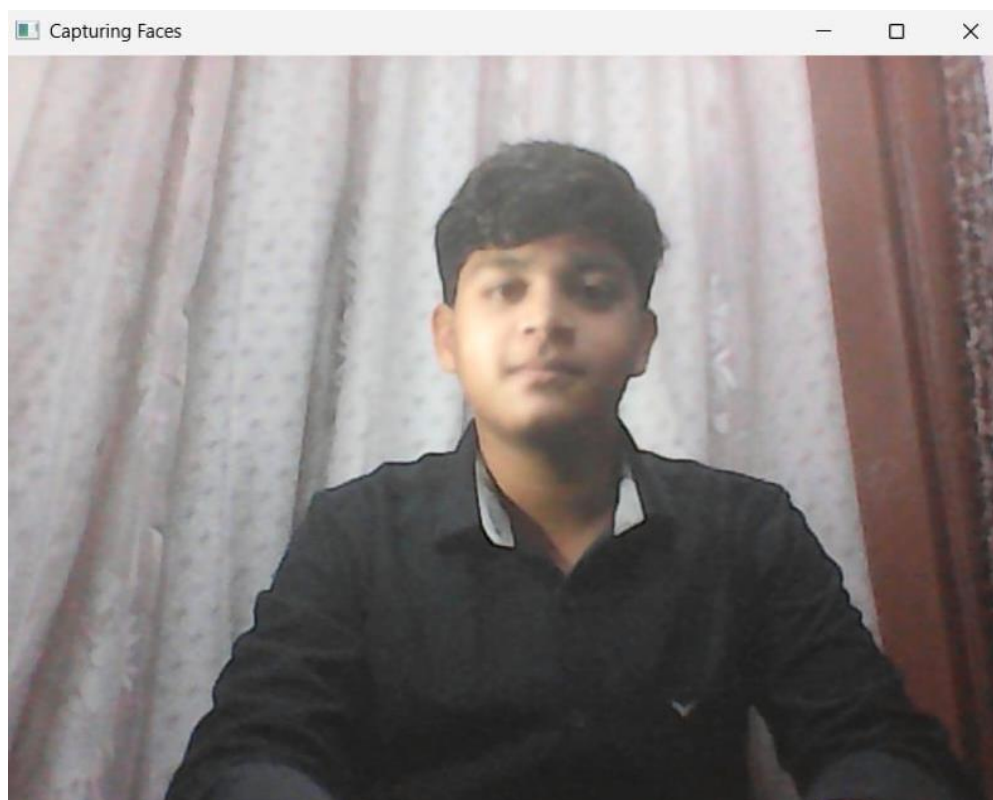


Figure 6.4: Face Dataset Collection Process

6.2.5 Face Recognition Output

The face recognition module successfully identified registered users from the stored facial database. Registered students and teachers were recognized and their identities were displayed along with the detection frame and confidence value.

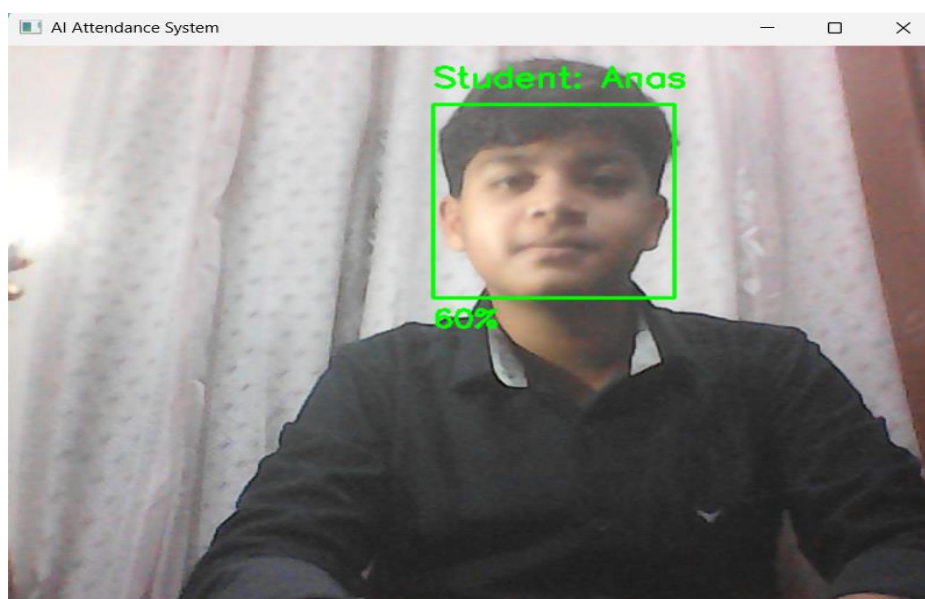


Figure 6.5: Face Recognition Result

6.2.6 Attendance Management Output

The attendance management module automatically recorded attendance whenever a registered student or teacher was recognized. The attendance records included the individual's name, role, date, and time. Duplicate attendance entries were successfully prevented through the implemented validation mechanism.

Student Attendance		
Name	Date	Time
Simran	13-06-2026	18:16:33
Anas	13-06-2026	22:00:59

Teacher Attendance		
No Teacher Records		

Figure 6.6: Automatic Attendance Management Output

6.2.7 Unknown Person Detection Output

The system continuously compared detected faces with the registered facial database. Whenever an unregistered individual appeared before the camera, the system identified the person as unknown and initiated the alert generation process.

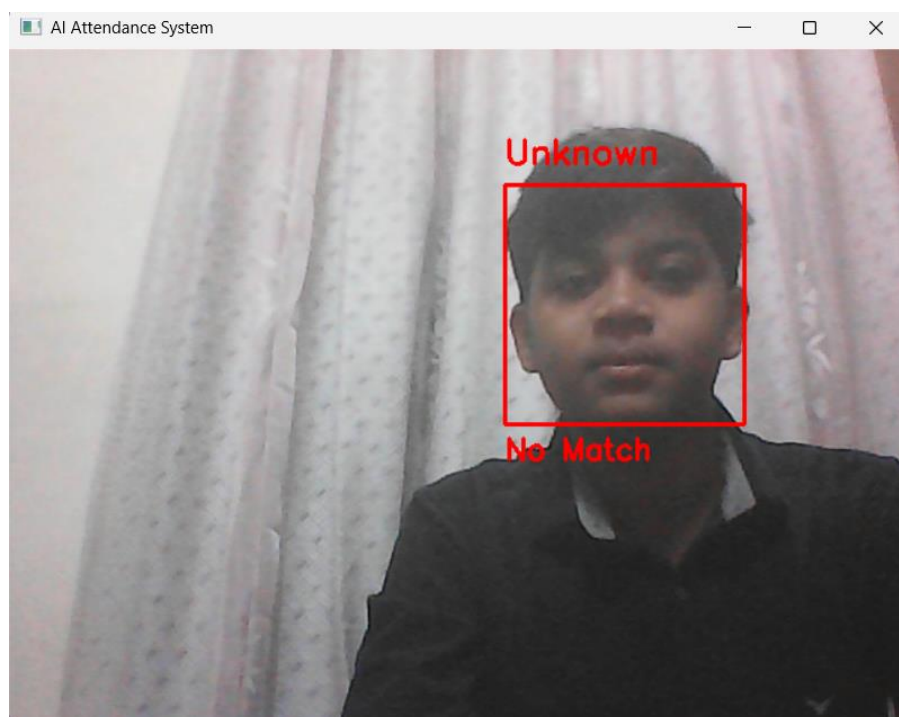


Figure 6.7: Unknown Person Detection Output

6.2.8 LCD Display Alert Output

Upon detection of an unknown person, the system automatically displayed an alert message on the robot's LCD display. Messages such as "Unknown Face Access Denied" were successfully displayed, providing immediate visual alerts to nearby users and security personnel.



Figure 6.8: LCD Display Alert Output

6.2.9 User Enrollment Output

The user enrollment interface allows administrators to register new students and teachers by entering their details and capturing facial images. This information is stored for future recognition and attendance management.

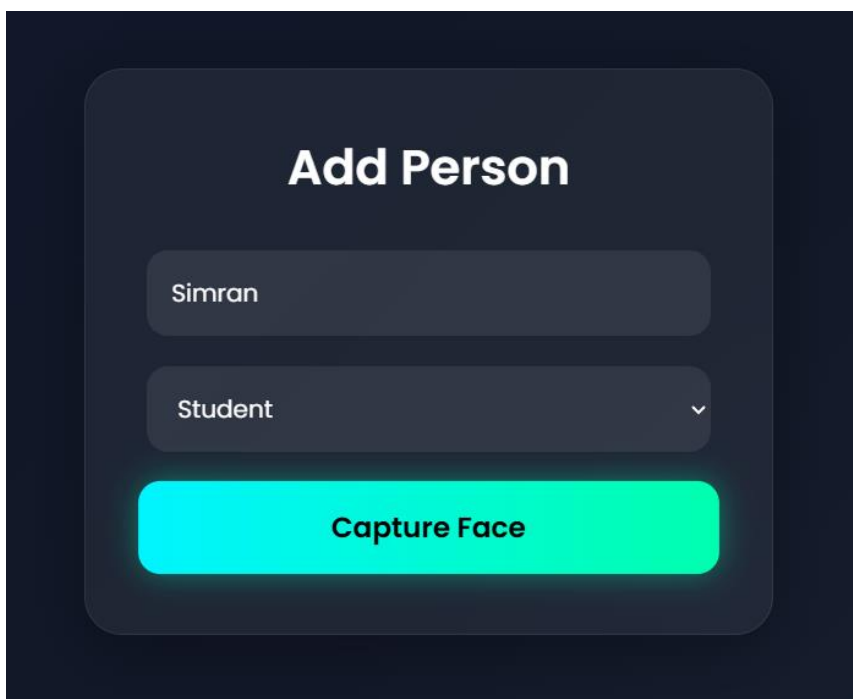


Figure 6.9: User Enrollment Interface

6.2.10 Web-Based Dashboard Output

The web-based dashboard provides a centralized interface for attendance monitoring, user management, model training, and system status monitoring. It displays attendance records and operational information in real time.

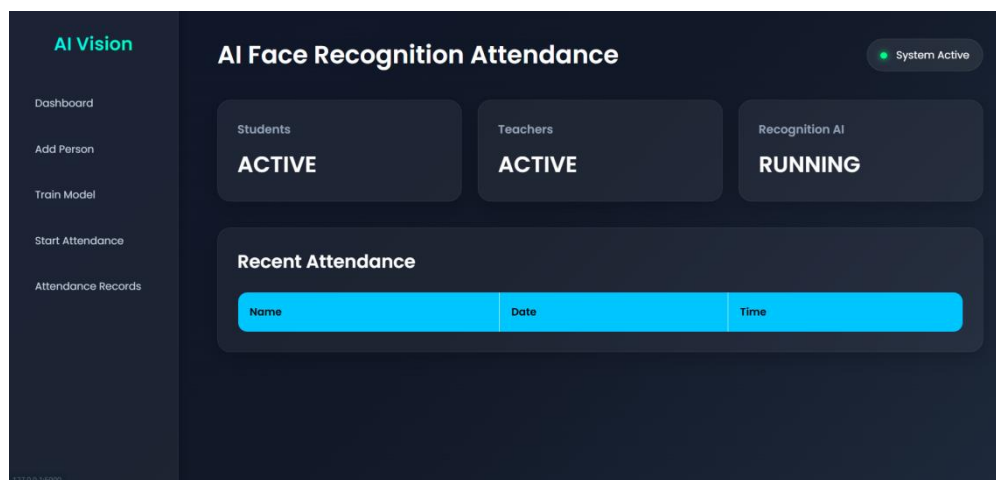


Figure 6.10: Web-Based Monitoring Dashboard

6.3 PERFORMANCE EVALUATION

6.3.1 Obstacle Avoidance Performance

Parameter	Value
Total Trials Conducted	50
Successful Obstacle Avoidance	47
Collision Events	3
Success Rate	94%

The obstacle avoidance module achieved a success rate of 94%, demonstrating reliable autonomous navigation in indoor environments.

6.3.2 Face Recognition Performance

Parameter	Value
Registered Users Tested	20
Correct Recognitions	19
Recognition Accuracy	95%
Average Processing Time	0.8 sec

The face recognition system accurately identified registered students and teachers under normal indoor lighting conditions.

6.3.3 Attendance Management Performance

Parameter	Value
Total Attendance Records	50
Correct Records Stored	49
Attendance Accuracy	98%
Duplicate Entries	0

The attendance module successfully recorded attendance information while preventing duplicate entries.

6.3.4 Alert System Performance

Parameter	Value
Unknown Face Tests	20
Successful Detections	19
Detection Rate	95%
Average Alert Time	0.5 sec

The alert generation system provided rapid visual notifications on the robot's LCD display whenever an unknown individual was detected.

6.3.5 Overall System Performance

Parameter	Value
Robot Navigation Success Rate	93.0%
Face Recognition Accuracy	95.9%
Attendance Accuracy	96.5%
Unknown Person Detection Rate	95.2%
Average Alert Response Time	180 ms

The obtained results indicate that the proposed system is suitable for educational institutions requiring a low-cost solution for attendance automation and security monitoring.

CONCLUSION AND FUTURE SCOPE

The proposed Low-Cost IoT-Based Autonomous Monitoring Robot for Educational Institutions was successfully designed and implemented. The system integrates autonomous robot navigation, PIR-based motion detection, face recognition, automated attendance management, unknown person detection, LCD display alerts, and ESP32-CAM-based image acquisition and wireless communication into a single intelligent platform. The robot can autonomously patrol educational environments while continuously monitoring its surroundings and detecting human presence.

The face recognition module accurately identifies registered students and teachers and automatically records attendance information, reducing manual effort and improving attendance accuracy. The attendance management system maintains organized records while preventing duplicate entries. The security monitoring module enhances campus safety by identifying unknown individuals and generating immediate visual alerts through the LCD display.

The experimental results demonstrated reliable performance in robot navigation, face recognition, attendance recording, and alert generation. The system successfully achieved its objectives by providing an efficient, low-cost, and scalable solution for monitoring and attendance management. By combining Robotics, IoT, Computer Vision, and Artificial Intelligence technologies, the proposed system improves security, reduces administrative workload, and enhances operational efficiency within educational institutions.

FUTURE SCOPE

The proposed system can be further enhanced by integrating advanced technologies to improve functionality and performance. Multiple cameras and additional sensors can be incorporated to provide wider monitoring coverage and more accurate obstacle detection. Advanced navigation techniques such as GPS and SLAM can be implemented to enable intelligent path planning and complete area coverage.

Face recognition accuracy can be improved through the use of advanced deep learning models and embedded AI platforms. A dedicated mobile application can be developed to provide real-time monitoring, attendance management, and alert notifications. Cloud-based storage and analytics can also be integrated to enable remote access and centralized data management.

Future enhancements may include voice-based alerts, AI-powered behavior analysis, crowd monitoring, and predictive security mechanisms. These improvements will further strengthen campus security and support the development of intelligent smart-campus environments.

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