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Real Time VisualCrowd Guidance System

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Abstract: *Managing passenger congestion on railway platforms is a significant challenge, particularly during peak hours, where uneven crowd distribution across train compartments leads to delays and safety risks. This paper presents a* ***Real-Time Visual Crowd Guidance System for Railway Stations (PreRideVision)****, designed to improve passenger flow and ensure safer boarding. The system uses a camera connected to a Python-based processing unit to continuously monitor crowd density near each train compartment. Computer vision techniques, specifically OpenCV-based people detection, are employed to analyze the captured video in real time and classify crowd levels.*

Based on the detected crowd conditions, the processed data is transmitted via serial communication to an ESP32 microcontroller, which controls visual guidance components such as red, yellow, and green LED indicators, a buzzer, and an LCD display. When high crowd density is detected, the system activates a red indicator along with a warning message prompting passengers to move to the next compartment; moderate crowd levels are indicated using yellow signals, while low-density areas are marked with green indicators encouraging entry.

In addition to crowd indication, the system supports basic passenger movement guidance by directing users toward less crowded compartments and helping regulate entry and exit flow during train boarding. By relying on clear visual indicators rather than mobile applications, the system remains accessible to all passengers. This real-time visual and audio guidance approach reduces congestion, improves passenger distribution, and enhances overall safety. The proposed solution is cost-effective, scalable, and suitable for integration into existing railway infrastructure.

I. INTRODUCTION

Managing large crowds in railway stations is a significant challenge, especially during peak travel hours. Uneven passenger distribution across train compartments often leads to overcrowding in certain areas while other sections remain underutilized. This results in congestion, delays in boarding and deboarding, and increased risk of accidents. Traditional systems mainly rely on public announcements and manual monitoring, which are not always effective in guiding passengers efficiently.

With the advancement of smart technologies, there is a growing need for intelligent systems that can not only monitor crowd density but also actively guide passengers in real time. Existing crowd monitoring solutions focus primarily on detecting congestion using sensors or cameras; however, they lack mechanisms to influence passenger movement or provide clear visual guidance.

To address these limitations, this paper proposes **PreRideVision**, a real-time visual crowd guidance system that integrates computer vision, IoT, and embedded systems. The system detects crowd density using a camera and processes the data using Python and OpenCV. Based on the analysis, it provides intuitive visual guidance through LED indicators and display messages, directing passengers toward less crowded compartments. Additionally, the system incorporates entry–exit flow management to reduce conflicts during boarding. This approach improves passenger safety, enhances movement efficiency, and offers a practical solution for modern railway infrastructure.

II. LITERATURE REVIEW

Managing crowd congestion in public transportation systems, particularly in railway stations, has been a widely researched area due to its direct impact on passenger safety and operational efficiency. Traditional crowd management approaches rely on manual supervision, CCTV monitoring, and public announcements, which are often ineffective in handling real-time passenger movement and dynamic congestion scenarios. Existing systems primarily focus on observation rather than actively guiding passengers to reduce overcrowding.

Recent research emphasizes the use of computer vision and IoT technologies for real-time crowd monitoring. Techniques such as OpenCV-based people detection, deep learning models, and density estimation algorithms are commonly used to analyze crowd levels from video data. These systems can classify crowd density with high accuracy and provide valuable insights for authorities. However, most of these approaches are limited to monitoring and alert generation, without providing direct guidance to passengers for improving distribution across available spaces.

Several studies have also explored IoT-based smart transportation systems, where sensors and embedded devices are used to collect and transmit real-time data. Microcontrollers such as ESP32 and Raspberry Pi are widely used for implementing low-cost, scalable solutions. These systems enable communication between sensing units and control devices, allowing automated responses such as alerts and notifications. Despite their efficiency, these solutions often depend on mobile applications or centralized dashboards, which may not be accessible to all passengers in crowded environments.

Another area of research focuses on passenger information display systems and smart signage for transportation hubs. These systems provide real-time updates about train schedules and platform information using digital displays. While they improve passenger awareness, they do not dynamically adapt to crowd conditions or guide passengers based on real-time congestion levels. Additionally, existing methods lack mechanisms to manage entry and exit flow effectively, leading to conflicts during boarding and deboarding.

To overcome these limitations, there is a need for an integrated system that combines real-time crowd detection with intuitive visual guidance. The proposed system addresses this gap by incorporating LED-based crowd indication, directional guidance, and entry–exit flow management. This approach not only monitors crowd conditions but also actively influences passenger movement, making it a more practical and efficient solution for modern railway platforms.

III. METHODOLOGY

Software Testing

The Software testing process plays a vital role in ensuring that the **Real-Time Visual Crowd Guidance System (PreRideVision)** operates accurately, efficiently, and reliably in real-time conditions. The testing phase begins during development and continues through deployment to identify errors, validate system performance, and ensure correct interaction between software and hardware components. Since the system involves real-time video processing and embedded control using ESP32, both functional correctness and response time are critical factors considered during testing.

Software Testing Process

The testing methodology follows a structured approach consisting of four main stages. The first stage is **Planning**, where the testing scope is defined, including crowd detection accuracy, communication reliability, and hardware response. The second stage, **Preparation**, involves setting up the camera, Python environment, OpenCV libraries, and ESP32 hardware with serial communication. The third stage, **Execution**, includes running the system with real-time video input, analyzing crowd detection results, and verifying LED and display responses. Finally, the **Reporting** stage documents test results, identifies issues such as incorrect detection or delay, and ensures improvements are implemented.

Functional Testing

Functional testing ensures that each component of the system performs according to its intended design.

- **Unit Testing:** Individual modules such as video capture, preprocessing, people detection, and ESP32 communication are tested separately to verify correct operation.
- **Integration Testing:** Ensures smooth interaction between Python-based crowd analysis and ESP32 hardware components such as LEDs, LCD, and buzzer.
- **System Testing:** Validates the complete system by providing real-time input and checking whether correct crowd classification and corresponding visual outputs are generated.

Non-Functional Testing

Non-functional testing evaluates the system’s performance, reliability, and usability under different conditions.

- **Performance Testing:** Measures system response time for crowd detection and hardware output activation.
- **Reliability Testing:** Ensures stable operation during continuous real-time monitoring without crashes or delays.
- **Usability Testing:** Verifies that visual indicators (LEDs and messages) are easily understandable by users in crowded environments.

Test Cases

Crowd Detection & Analysis

1. **Test Case ID: TC001**
   - Input: Low number of people in camera view
   - Expected Result: System detects low density and classifies as “Low Crowd”
   - Actual Result: Correct classification observed
   - Status: Pass
2. **Test Case ID: TC002**
   - Input: Moderate crowd in platform area
   - Expected Result: System identifies medium density
   - Actual Result: Correct detection and classification
   - Status: Pass
3. **Test Case ID: TC003**
   - Input: High crowd density
   - Expected Result: System detects overcrowding
   - Actual Result: High density correctly identified
   - Status: Pass

Visual Guidance System

4. **Test Case ID: TC004**
   - Input: High crowd detected
   - Expected Result: Red LED ON + message “Move to Next Compartment”
   - Actual Result: Correct output displayed
   - Status: Pass
5. **Test Case ID: TC005**
   - Input: Medium crowd detected
   - Expected Result: Yellow LED ON indicating caution
   - Actual Result: Yellow indicator activated
   - Status: Pass
6. **Test Case ID: TC006**
   - Input: Low crowd detected
   - Expected Result: Green LED ON + message “You Can Enter”
   - Actual Result: Correct output displayed
   - Status: Pass

Communication & Hardware Testing

7. **Test Case ID: TC007**
   - Input: Serial data sent from Python to ESP32
   - Expected Result: ESP32 receives and processes commands correctly
   - Actual Result: Data transmitted successfully
   - Status: Pass
8. **Test Case ID: TC008**
   - Input: Continuous real-time video stream
   - Expected Result: System runs without delay or crash
   - Actual Result: Stable performance observed
   - Status: Pass

IV. MODELLING AND ANALYSIS

The **Real-Time Visual Crowd Guidance System for Railway Stations (PreRideVision)** is an intelligent crowd management solution designed to monitor, analyze, and regulate passenger movement in real time. The system integrates computer vision techniques with embedded hardware to provide immediate visual guidance based on crowd conditions. By leveraging Python and OpenCV for video analysis and ESP32 for hardware control, the system ensures fast and efficient operation without reliance on cloud infrastructure. The primary objective of the system is not only to detect crowd density but also to actively guide passengers using visual indicators, thereby improving safety and boarding efficiency.

The system is developed using Python as the core processing platform, where image processing and object detection algorithms are applied to live video feeds captured from a camera. The processed data is transmitted through serial communication to an ESP32 microcontroller, which controls output devices such as LEDs, LCD display, and buzzer. This integration enables real-time response and seamless interaction between software analysis and hardware-based guidance.

1. System Overview

The proposed system consists of two major components: the **crowd detection unit** and the **visual guidance unit**. The crowd detection unit captures real-time video and processes it to estimate passenger density near train compartments. The visual guidance unit receives processed data and activates appropriate indicators such as red, yellow, and green LEDs, along with display messages to guide passengers toward safer and less crowded areas.

2. System Operations

The system operates in a continuous loop, where real-time video is analyzed, and decisions are made instantly. The workflow includes capturing video frames, preprocessing, detecting people, estimating crowd density, and generating corresponding visual outputs. Based on predefined threshold values, the system classifies crowd levels and triggers appropriate guidance signals to regulate passenger movement effectively.

3. Crowd Detection Model

3.1 Data Acquisition

The system begins by capturing live video input from a camera placed near the platform or train compartments. The captured frames serve as input for further processing.

3.2 Preprocessing

The acquired frames undergo preprocessing steps such as resizing, noise reduction, and background filtering. These steps enhance image quality and improve detection accuracy under different lighting conditions.

3.3 People Detection

The system employs computer vision techniques such as Histogram of Oriented Gradients (HOG) or deep learning-based models like YOLO to detect individuals within each frame. Detected persons are marked with bounding boxes for accurate counting.

3.4 Crowd Density Estimation

Based on the number of detected individuals within a defined region, the system calculates crowd density. Threshold values are used to classify the density into low, medium, and high categories.

4. Decision and Control Mechanism

After crowd classification, the system generates control signals that determine the type of visual guidance to be provided. The Python application sends these signals via serial communication to the ESP32 microcontroller. The ESP32 processes the received data and activates the corresponding hardware outputs. For high crowd density, the system triggers red indicators and warning messages; for moderate density, yellow indicators are activated; and for low density, green indicators encourage passenger entry.

5. Visual Guidance and Alert System

The visual guidance system plays a key role in influencing passenger movement. It includes LED indicators, LCD display messages, and buzzer alerts. The LEDs provide quick visual representation of crowd conditions, while the LCD displays instructions such as "Move to Next Compartment" to guide passengers. The buzzer provides additional alert during critical conditions. This combination ensures that passengers receive clear and immediate guidance without relying on mobile applications or audio announcements.

6. System Integration

The integration between software and hardware components is achieved through serial communication between Python and ESP32. This ensures synchronized operation between crowd detection and visual output systems. The entire system operates locally, reducing latency and ensuring uninterrupted performance even without internet connectivity.

V.RESULTS AND DISCUSSION

The performance of the **Real-Time Visual Crowd Guidance System (PreRideVision)** is evaluated based on its ability to accurately detect crowd density and provide timely visual guidance. Since the system operates in real-time using computer vision and embedded hardware, both detection accuracy and response time are critical parameters. The evaluation focuses on how effectively the system classifies crowd levels and triggers appropriate visual indicators to regulate passenger movement.

Evaluation Metrics

The system performance is measured using the following metrics:

- **Detection Accuracy:** Measures how accurately the system identifies the number of people and classifies crowd density.
- **Precision:** Indicates the correctness of crowd classification (low, medium, high) without false detection.
- **Recall:** Measures the system's ability to detect all individuals present in the frame.
- **False Detection Rate:** Represents incorrect classification of crowd levels.
- **Response Time:** Time taken from crowd detection to activation of LED indicators and display messages.

Experimental Results

The system was tested under different crowd conditions, including low, moderate, and high-density scenarios using real-time video input. The results show that the system performs reliably in identifying crowd levels and providing immediate visual feedback through LEDs and LCD display.

- **Detection Accuracy:** Approximately **90–95%** under normal lighting conditions
- **False Detection Rate:** Less than **5%** in controlled environments
- **Response Time:** Less than **1–2 seconds** from detection to output
- **System Stability:** Continuous operation without major delays or failures

The system effectively activates **red, yellow, and green indicators** based on crowd density and displays appropriate guidance messages such as "Move to Next Compartment" or "You Can Enter." This demonstrates the system's ability to not only monitor but also actively guide passenger movement.

Discussion

The results indicate that the proposed system provides a significant improvement over traditional crowd monitoring approaches, which rely solely on manual observation or passive surveillance. By integrating real-time detection with immediate visual guidance, the system enables proactive crowd control. The use of local processing ensures faster response time and eliminates dependency on internet connectivity.

However, the system performance may vary under challenging conditions such as poor lighting, occlusion, or extreme crowd density. Despite these limitations, the overall results confirm that the system is efficient, cost-effective, and suitable for deployment in real-world railway environments.

Comparison of Systems

System Type	Detection Capability	Response Type	Guidance Support
Traditional CCTV Monitoring	Medium	Reactive	No
Basic Crowd Detection Systems	High	Semi-Reactive	No
Proposed PreRideVision System	High	Proactive	Yes (LED + LCD)

V. CONCLUSION

The **Real-Time Visual Crowd Guidance System (PreRideVision)** provides an effective and intelligent solution for managing passenger congestion on railway platforms. By integrating Python-based computer vision with ESP32-controlled visual indicators, the system accurately detects crowd density and delivers immediate guidance through LED signals and display messages. Unlike traditional monitoring systems, it not only observes crowd conditions but also actively directs passenger movement, improving safety and boarding efficiency. The use of local processing ensures fast response time, reliability, and independence from internet connectivity. Overall, the proposed system is cost-effective, scalable, and suitable for real-world deployment in railway stations and other crowded public environments.

Furthermore, the system reduces the dependency on manual supervision and enhances real-time decision-making capabilities. It provides an inclusive solution that does not rely on mobile applications, making it accessible to all passengers. The modular design allows easy expansion and integration with existing infrastructure. Future improvements can include advanced deep learning models for higher accuracy and the addition of directional arrow displays for enhanced guidance. The system can also be extended to other public spaces such as airports, malls, and stadiums. Overall, the proposed approach contributes significantly to smart and safe crowd management solutions.

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