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Real Time Crowd Flow Management By Predicting Overcrowding Situation

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Abstract:
People's safety has become a major problem in many areas like malls, railway stations and streets where people gather in crowds. Managing this crowd is a huge task. Crowd evaluation has these days received a good deal interest for its wide variety of packages usage, such as video surveillance. It has been an active research topic in machine learning (ML) and computer vision using continuous videos. Crowded conditions may also originate from several scenarios, posing protection and safety concerns. The crowd size and dynamics of crowds affect the safety of the people.
This paper presents an automated system for real-time crowd monitoring and security management using ESP32 Microcontroller. The proposed system uses the laptop's built-in camera to continuously monitor the crowd. The system employs YOLO to detect and track individuals, analyze crowd density, and predict overcrowding situations, enabling timely alerts to organizers via SMS notification. It will generate a voice alert through a laptop. There will be three lanes: Lane-1, Lane-2, and Lane-3. Whenever excessive crowding is detected in any lane, the system will display a notification on the LCD to shift from the crowded lane to a less occupied one. For example, if Lane-1 is overcrowded and Lane-2 is empty, the LCD will display a message to move from Lane-1 to Lane-2.
Keywords: *ESP32--Microcontroller, LCD 16*2, Python Software IDE, Machine Learning, YOLO.*

I. Introduction

Crowd management is a complex and critical task, especially in high-density environments where sudden surges can lead to dangerous situations such as stampedes. Traditional approaches, which rely on manual monitoring through security personnel or CCTV systems, often fall short in providing timely detection and response. This highlights the need for intelligent, automated systems capable of analyzing crowd behavior in real time. Such systems can track density, movement patterns, and issue immediate alerts to prevent hazards.

The challenge intensifies in crowded spaces like malls, railway stations, and public streets, particularly during pandemic conditions where gatherings pose additional risks. Detecting individuals in dense crowds is difficult due to occlusion, making conventional tracking algorithms less effective. Recent research has focused on developing more efficient tracking methods to overcome these limitations.

Leveraging advanced computer vision technologies such as YOLO, integrated with lightweight platforms like the ESP32 microcontroller, offers a scalable and effective solution for real-time crowd detection and management. This approach enhances safety by combining accuracy, speed, and adaptability in monitoring dynamic crowd scenarios.

In recent years, crowd monitoring and management have attracted significant attention due to the need for improved safety and efficient handling of large gatherings. Researchers have explored various approaches by integrating artificial intelligence, machine learning, and computer vision techniques.

Several studies focus on deep learning-based frameworks for crowd analysis. One approach utilizes advanced neural network models to detect individuals in a scene, track their movement, and analyze their behavior. This multi-stage process typically involves detecting humans in video frames, estimating crowd density, and identifying unusual activities through pose-based analysis. Such systems are effective in understanding crowd dynamics and detecting abnormal situations.

Another line of research emphasizes the development of real-time intelligent surveillance systems. These systems combine object detection, tracking algorithms, and facial recognition to enhance security and crowd control. Additional features such as weapon detection and mobile-based alert systems further improve responsiveness and enable quick action during emergencies.

Some researchers have highlighted the use of AI-enabled CCTV networks for continuous monitoring. These systems process live video feeds to identify patterns, detect anomalies, and provide timely alerts. Although highly efficient, they require substantial infrastructure and raise important concerns regarding data privacy and ethical usage.

Practical implementations have also been proposed for public spaces such as malls, temples, and stadiums. Certain studies introduce applications that inform users about crowd levels in advance, allowing them to make better decisions before visiting a location. Other works adopt a multidisciplinary approach by incorporating social and behavioural analysis to better understand crowd behaviour.

Comparative studies between traditional image processing and deep learning methods reveal that conventional techniques, such as head detection using grayscale images, are less effective in complex environments. In contrast, convolutional neural network-based methods provide more accurate and reliable crowd density estimation.

For large-scale events, frameworks have been designed to model crowd movement and support emergency evacuation planning. These systems are particularly useful in managing high-density gatherings and ensuring safe exit strategies during critical situations.

In addition, low-cost hardware-based solutions have been developed using embedded systems. These systems can detect the number of people in a given area and monitor social distancing by triggering alerts when individuals are too close to each other. Such solutions proved especially useful during pandemic situations.

II. Methodology

The proposed system is designed to provide an intelligent and real-time solution for crowd monitoring and management using technologies such as the ESP32 microcontroller and computer vision techniques. In the system, a laptop's built-in camera continuously captures live video of the monitored area. This video feed is processed using a YOLO (You Only Look Once) based deep learning algorithm, which is highly efficient for real-time object detection. The algorithm identifies and counts the number of people present in each frame, enabling accurate estimation of crowd density in different zones, the system can detect unusual congestion or sudden increases in density, which may indicate a potential risk of overcrowding or even a crowd stampede situation. An ESP32 module is integrated with 16*2 LCD and to the laptop, to display the warnings.

By combining IoT (ESP32) and CV (YOLO), the system provides a smart, cost-effective, and scalable solution for enhancing safety in crowded environments such as events, public gatherings, temples, railway stations, and stadiums.

Block Diagram

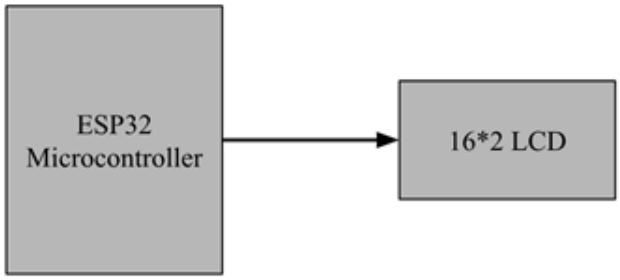

Fig. 1 Shows the Block Diagram of the System.

Description

ESP32 Microcontroller:

A powerful, low-cost **System-on-Chip (SoC)** microcontroller developed by **Espressif Systems**, designed for IoT, embedded systems, and connected device applications.

16*2 LCD:

A Liquid Crystal Display (LCD) can be of the character type or graphics type. Graphic LCD displays have a matrix of pixels that can be used to display text and graphics.

Working

The proposed system is designed to intelligently monitor and manage crowd movement using real-time video analysis and automated decision-making. It begins by capturing continuous live video feed through the laptop's in-built camera. This raw video data is then processed using computer vision techniques to extract meaningful visual features such as human presence, movement patterns, and spatial distribution within the frame.

Once the video is preprocessed, the system applies the YOLO (You Only Look Once) object detection algorithm, which is a fast and efficient deep learning model widely used for real-time applications. YOLO detects individuals present in each frame and accurately counts them. This count is then used to calculate the density of people in specific areas or lanes.

Based on the calculated crowd density, the system evaluates whether the number of people in a particular lane exceeds a predefined safe threshold. If the density approaches or surpasses this limit, the system identifies it as a potential overcrowding situation, which could lead to unsafe conditions such as congestion or even a stampede.

In such cases, the system immediately initiates multiple alert mechanisms. Firstly, it sends a real-time notification to the administrator or control authority, enabling quick human intervention if required. Secondly, it activates an automated voice alert system that audibly warns people about the overcrowded lane, helping in immediate awareness and response.

At the same time, the system continuously monitors all available lanes to determine their occupancy levels. It identifies which lanes are less crowded or completely free and considers them as safer alternatives for crowd movement.

Finally, the system communicates this information directly to the public through an LCD display. The display provides clear and concise instructions, guiding individuals to move from overcrowded lanes to less congested ones. This dynamic redirection helps in distributing the crowd evenly, reducing pressure on any single lane, and ensuring a smooth, safe, and well-controlled flow of people.

Overall, the system integrates real-time video processing, deep learning-based detection, automated alerts, and smart guidance mechanisms to effectively prevent overcrowding and enhance crowd safety management.

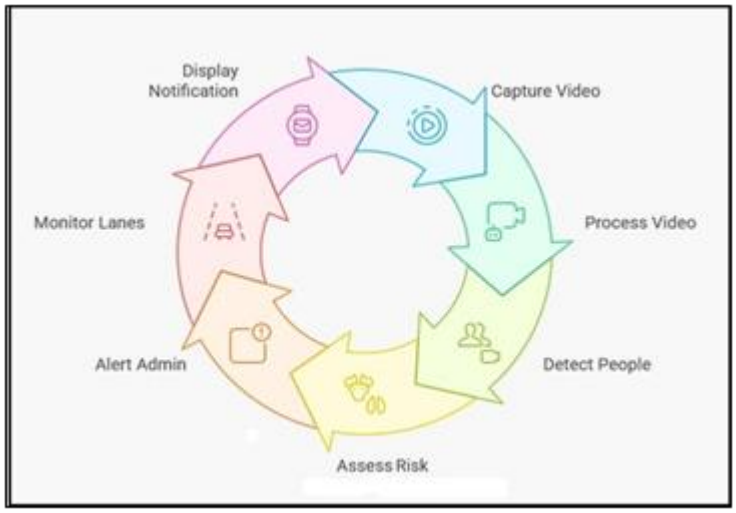

Fig. 3 Shows the Flowchart of the System.

Overall, the whole system ensures:

- Continuous real-time monitoring.
- Early detection of risky situations.
- Automated alerts and notifications.
- Efficient crowd flow management.

III. Experimental Setup & Result

Experimental Setup

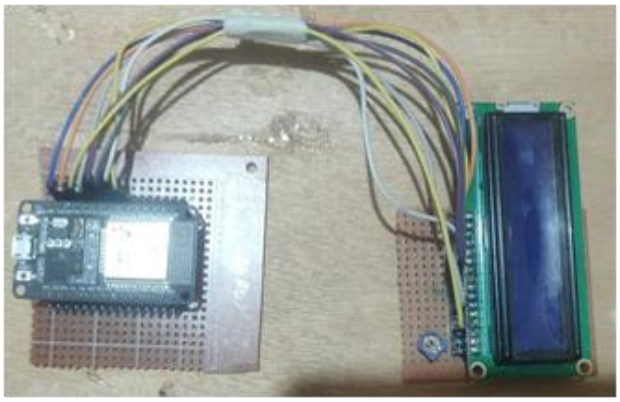

Fig. 3 Shows the experimental setup of the system.

Result

The implemented system successfully monitors crowd movement in real time using a ESP32 Microcontroller and laptop's camera. The YOLO-based algorithm accurately detects individuals, measures crowd density, and analyzes movement patterns across all three lanes. The system was able to predict potential overcrowding, mismanagement and stampede situations promptly. When excessive crowding occurred in any lane, the LCD display provided clear guidance for people to shift to less occupied lanes, effectively managing crowd flow. Additionally, SMS notifications were sent immediately to the administrator, and voice alerts were generated through the laptop, ensuring timely intervention. Overall, the system demonstrated reliable performance in enhancing security, preventing stampedes, and facilitating efficient real-time crowd management, validating the effectiveness of combining computer vision, IoT, and automated alert mechanisms.

Fig. 4 Shows crowd detected message on LCD

The system includes three lanes i.e. Lane 1, Lane 2, Lane 3. Whenever it detects that the lane is too crowded, it automatically suggests a better alternative through an LCD display. In this figure it is showing that "CROWD DETECTED, CHANGE LEFT".

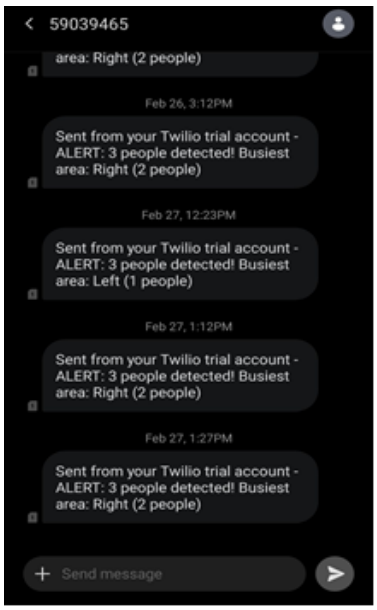

Fig. 5 Shows the alert messages generated via SMS

If the system predicts a potential overcrowding situation, it quickly alerts the administrator by sending a detailed SMS with number of people detected in a particular lane, along with voice alerts and displays to avoid any overcrowding.

IV. Conclusion

The developed system successfully provides a smart and reliable approach for managing crowd flow in real time. The proposed system successfully integrates real-time crowd monitoring to enhance safety and security in public gatherings. By utilizing YOLO for crowd detection and density analysis, it effectively predicts potential stampede situations and provides timely alerts to prevent accidents. With the ESP32 microcontroller as a cost-effective and portable platform, the system enables continuous surveillance, quick response, and efficient crowd flow management, thereby reducing risks and improving overall event safety.

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