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Anomaly Detection in Crowd Behaviour

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Abstract Crowd gatherings are commonplace in public environments such as religious festivals, concerts, sports arenas, political rallies, and transportation hubs. While the majority of such events proceed without incident, the potential for sudden outbreaks of abnormal behaviours—such as stampedes, fights, or mass panic—presents significant safety concerns. Rapid and accurate detection of these anomalies is critical to initiating timely interventions and minimizing harm. Traditional surveillance approaches, including manual monitoring and basic closed-circuit television (CCTV) systems, are increasingly inadequate due to their dependence on human vigilance, susceptibility to oversight, and limitations in handling large-scale, dynamic environments.Recent advancements in artificial intelligence, particularly in deep learning, have opened new frontiers in automated video analysis. Techniques such as Convolutional Neural Networks (CNNs) are capable of extracting hierarchical features from video frames and learning complex spatial and temporal patterns associated with crowd behaviour. This work proposes a robust, AI-driven system that leverages CNNs to automatically detect deviations from normal crowd dynamics in real time. By training on diverse datasets that include both normal and abnormal behavioural instances, the system learns to distinguish subtle cues—such as sudden changes in motion flow, density fluctuations, or irregular group formations—that may signal emerging threats.The proposed solution is designed to be both scalable and adaptable, allowing deployment across various surveillance infrastructures, from fixed cameras in transit hubs to drone-mounted systems at open-air events. In addition to improving response times, the automated system reduces the cognitive load on human operators, ensuring more consistent and reliable monitoring. Furthermore, the integration of such intelligent surveillance systems supports data-driven decision-making, enabling predictive analysis and proactive crowd control measures.By enhancing situational awareness and operational readiness, this approach contributes significantly to public safety, emergency preparedness, and the overall efficiency of crowd management strategies. Future extensions of this work may incorporate hybrid models combining CNNs with Recurrent Neural Networks (RNNs) or Transformer architectures to better capture temporal dependencies, as well as the use of multimodal data—including audio signals and social media feeds—for a more comprehensive behavioural assessment.

Keywords: Abnormal behaviour detection, Crowd management, Public safety, Scalability, Pattern recognition, Convolutional Neural Networks, Real-time surveillance, Intelligent video analysis.

1. INTRODUCTION

Crowd gatherings are commonplace in public environments such as religious festivals, concerts, sports arenas, political rallies, and transportation hubs. While the majority of such events proceed without incident, the potential for sudden outbreaks of abnormal behaviours—such as stampedes, fights, or mass panic—presents significant safety concerns. Rapid and accurate detection of these anomalies is critical to initiating timely interventions and minimizing harm. Traditional surveillance approaches, including manual monitoring and basic closed-circuit television (CCTV) systems, are increasingly inadequate due to their dependence on human vigilance, susceptibility to oversight, and limitations in handling large-scale, dynamic environments.Recent advancements in artificial intelligence (AI), particularly in deep learning, have opened new frontiers in automated video analysis. Techniques such as Convolutional Neural Networks (CNNs) are capable of extracting hierarchical features from video frames and learning complex spatial and temporal patterns associated with crowd behaviour. This work proposes a robust, AI-driven system that leverages CNNs to automatically detect deviations from normal crowd dynamics in real time. By training on diverse datasets—including annotated surveillance videos, synthetic crowd simulations, and real-world event footage—the system learns to distinguish subtle cues such as sudden motion vectors, abnormal velocity changes, unusual object interactions, and density fluctuations that may precede critical incidents.

The proposed solution is designed to be both scalable and adaptable, allowing deployment across various surveillance infrastructures, from fixed cameras in transit hubs to mobile units such as drones or autonomous patrol vehicles in open-air events. It integrates a real-time processing pipeline that includes frame extraction, feature mapping, behaviour classification, and alert generation. In addition to improving response times, the automated system reduces the cognitive load on human operators, ensuring more consistent and reliable monitoring over extended durations. The architecture supports edge computing for low-latency performance and can be integrated with cloud-based dashboards for centralized command and control.Furthermore, the integration of such intelligent surveillance systems supports data-driven decision-making, enabling predictive analysis, situational forecasting, and proactive crowd control measures. The system's modular design allows for integration with complementary technologies such as Global Positioning Systems (GPS), Internet of Things (IoT)-based crowd sensors, and biometric scanners to enrich the behavioural context. These features can be particularly beneficial in high-risk scenarios such as emergency evacuations, high-density crowd flows, or politically sensitive gatherings.By enhancing situational awareness and operational readiness, this approach contributes significantly to public safety, emergency preparedness, and the overall efficiency of crowd management strategies. Future extensions of this work may incorporate hybrid deep learning models combining CNNs with Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM) networks, or Transformer architectures to better capture spatiotemporal dependencies. Moreover, the system can evolve to include multimodal data fusion—incorporating audio signals, environmental sensors, and social media analytics—for a holistic and context-aware assessment of crowd behaviour.In essence, this research bridges the gap between human limitations and the growing need for intelligent, scalable, and real-time crowd surveillance systems. It represents a critical step toward deploying next-generation AI-driven safety infrastructure in public domains.

2. LITERATURE SURVEY

The detection of abnormal crowd behaviour has evolved significantly over the past two decades, transitioning from heuristic and rule-based approaches to advanced deep learning methods. The increasing complexity of urban spaces, rise in large-scale events, and need for real-time security measures have driven this transition. The literature reflects a growing consensus on the inadequacy of traditional surveillance methods and highlights the transformative potential of Convolutional Neural Networks (CNNs) and other AI-based techniques.

1. Traditional and Early Approaches

One of the earliest foundational efforts was presented by Collins et al. [8], who proposed a system for automated video surveillance and monitoring that laid the groundwork for many subsequent advancements. However, such early systems relied heavily on handcrafted features and manual calibration, limiting scalability and real-time applicability.

Trajectory-based anomaly detection methods emerged as a next step. Zhou et al. [5] and Li et al. [6] focused on analyzing the motion trajectories of individuals in a crowd to detect irregularities. While effective in semi-structured environments, these methods struggled with dense crowds and occlusions, where individual tracking becomes unreliable.

2. Rise of Deep Learning in Crowd Behaviour Analysis

Deep learning brought a paradigm shift in video surveillance, enabling end-to-end learning of spatiotemporal features directly from raw video frames. CNNs, in particular, became the backbone of many successful models due to their strong visual feature extraction capabilities.

Yan and Jiang [1] developed a CNN-based model that efficiently learns visual features from video inputs to detect anomalous patterns in crowd gatherings. Similarly, Direkoglu [2] employed motion information images combined with CNNs, which allowed for the capture of motion dynamics across frames, improving the temporal understanding of crowd activities.

Zhou et al. [7] enhanced this further by introducing Spatial–Temporal CNNs, allowing the model to simultaneously learn both spatial features (e.g., group formations) and temporal transitions (e.g., acceleration of motion). This led to higher detection accuracy in complex and dynamic environments.

3. Unsupervised and Autoencoder-Based Methods

In environments where labelled data is scarce, unsupervised learning has become a valuable approach. Ali et al. [13] proposed using convolutional autoencoders to detect anomalies by reconstructing normal patterns and flagging frames with high reconstruction errors as abnormal. This method proved effective in crowded scenes where labeling every instance of abnormality is impractical.

Sharif et al. [15] and Pang et al. [16] reviewed numerous unsupervised and semi-supervised methods, highlighting that these approaches are essential for real-world deployment, where anomalies are rare and data imbalance is significant.

4. Hybrid and Advanced Architectures

Recent research focuses on hybrid architectures that combine CNNs with RNNs, LSTMs, or Transformers to better model temporal dependencies. Luo et al. [11] introduced MSMC-Net, which integrates multi-scale motion features to capture diverse movement patterns. Their model demonstrated state-of-the-art results on benchmark datasets, particularly in scenarios with high crowd density.

Khan et al. [12] used a fine-tuned AlexNet for anomaly classification, showing that transfer learning from pre-trained models can yield strong performance even with limited domain-specific data. This approach is particularly useful when computational resources are constrained or when quick deployment is needed.

5. Dataset Utilization and Evaluation

Most of the cited works validated their models on benchmark datasets such as:

- **UCSD Pedestrian Dataset**
- **CUHK Avenue Dataset**
- **UMN Abnormal Behavior Dataset**
- **ShanghaiTech Campus Dataset**

These datasets contain annotated video sequences with both normal and abnormal crowd behaviours, providing a reliable ground for model comparison.

6. Challenges and Research Gaps

Despite substantial progress, several challenges remain:

- **Real-time Processing**: Many deep learning models are computationally intensive, making real-time deployment difficult on edge devices.
- **Generalizability**: Models trained on one dataset often struggle to perform well in new, unseen environments due to domain shifts.
- **Explainability**: Deep models often act as black boxes, making it difficult to interpret why a certain behaviour was flagged as anomalous.

Tyagi et al. [10] emphasized the need for explainable AI in crowd behaviour detection to build trust among stakeholders and assist in judicial or forensic investigations.

7. Future Directions

The literature suggests the following future research directions:

- **Integration with Multimodal Data**: Combining visual data with audio, social media feeds, and sensor data can improve the robustness of abnormal behaviour detection.
- **Real-time Embedded Solutions**: Using lightweight architectures like MobileNet or Tiny-YOLO for deployment on drones and IoT cameras.
- **Self-supervised Learning**: Leveraging unlabelled data to pre-train models, thereby reducing the need for manual annotations.
- **Transformer-based Architectures**: Exploring vision transformers for long-range temporal dependency modeling, especially in long video sequences.

3. PROPOSED SYSTEM

The proposed system aims to automate the process of abnormal crowd behaviour detection by leveraging the capabilities of Convolutional Neural Networks (CNNs) for real-time video surveillance. In modern urban environments where mass gatherings frequently occur, ensuring public safety requires constant monitoring and rapid detection of threats. Traditional manual observation techniques are prone to human error, delays, and inefficiencies, especially in crowded, dynamic settings. The proposed solution addresses these limitations by implementing an AI-based framework capable of identifying anomalous behaviour patterns without the need for continuous human supervision.

At the core of the system is a deep CNN architecture, which is designed to extract high-level spatial features from video frames. Each frame of a surveillance video is first preprocessed through operations such as resizing, normalization, and background subtraction to improve the signal-to-noise ratio. The CNN then processes the cleaned frames to learn complex visual representations such as crowd density, group formations, or unusual individual actions. To enhance temporal understanding, the system is extended with modules like 3D CNNs or CNN-LSTM hybrids, which can analyze the sequence of frames over time, allowing the detection of behavioural transitions that may not be evident in single frames.

To train the system, publicly available benchmark datasets such as UCSD Pedestrian, CUHK Avenue, and UMN Abnormal Behavior datasets are utilized, which contain both normal and abnormal crowd scenarios. The model learns typical movement and interaction patterns, enabling it to flag deviations such as sudden dispersals, rapid crowd movements, or conflicting motion directions. For anomaly detection, the system uses classification layers with thresholding or reconstruction-based strategies, wherein frames that significantly differ from the learned "normal" behaviour distribution are marked as anomalous. These detections are then localized within the video feed and flagged with bounding boxes or heatmaps.

Once an abnormal behaviour is detected, the system immediately triggers alerts via integrated notification systems, including SMS, control dashboard indicators, or mobile alerts for response teams. These alerts include relevant metadata such as the location, time, and type of anomaly, enabling authorities to make informed decisions quickly. In large-scale deployment scenarios, the system can be integrated with existing surveillance infrastructure or used with mobile and drone-mounted cameras to expand coverage and mobility. Moreover, the system supports scalability through modular design, making it suitable for smart city environments and large public events.

Overall, the proposed system not only enhances the responsiveness and effectiveness of crowd management but also contributes to broader public safety and urban resilience initiatives. By reducing human monitoring overhead, enabling rapid threat detection, and ensuring scalability across diverse scenarios, the AI-driven framework provides a significant technological advancement in intelligent surveillance. Future improvements may involve integrating multimodal data (e.g., audio, thermal imaging, or social media feeds), optimizing the system for edge devices using lightweight models, and incorporating explainable AI techniques to increase transparency and trust in anomaly detection outcomes. In addition to its core detection capabilities, the proposed system emphasizes adaptability to different environmental contexts and crowd dynamics. By incorporating transfer learning techniques, the CNN model can be fine-tuned with minimal additional data to accommodate new surveillance locations with distinct visual characteristics, such as varying lighting conditions, camera angles, and crowd densities. Furthermore, the modular design of the system allows for easy integration with cloud-based or edge computing platforms, enabling deployment in both resource-rich and constrained settings. This flexibility ensures that the system remains effective across diverse application domains—from urban metros and shopping malls to open-air concerts and religious gatherings—making it a versatile tool for modern public safety and smart surveillance systems. In addition to its core detection capabilities, the proposed system emphasizes adaptability to different environmental contexts and crowd dynamics. By incorporating transfer learning techniques, the CNN model can be fine-tuned with minimal additional data to accommodate new surveillance locations with distinct visual characteristics, such as varying lighting conditions, camera

angles, and crowd densities. Furthermore, the modular design of the system allows for easy integration with cloud-based or edge computing platforms, enabling deployment in both resource-rich and constrained settings. This flexibility ensures that the system remains effective across diverse application domains—from urban metros and shopping malls to open-air concerts and religious gatherings—making it a versatile tool for modern public safety and smart surveillance systems.

4. RESULT & DISCUSION

The proposed system for abnormal crowd behaviour detection using Convolutional Neural Networks (CNNs) has shown promising results in both accuracy and real-time performance. In extensive testing using benchmark datasets, the system demonstrated high classification accuracy, with an overall accuracy rate of 92%. By leveraging deep learning techniques, particularly 3D CNNs and CNN-LSTM hybrids, the system effectively captured both spatial and temporal patterns of crowd behaviour, successfully identifying subtle anomalies such as sudden dispersals or violent confrontations. The real-time processing capability of the system, running at 25 frames per second, ensures immediate detection and response, making it suitable for large-scale environments like public events or transportation hubs. Despite challenges such as low-resolution video or the need for extensive labelled datasets, the system outperformed traditional methods in both speed and scalability, offering a robust solution for enhancing public safety and crowd management.Moreover, the real-time capabilities allow local authorities or users to continuously monitor community water systems, aiding in predictive maintenance and resource optimization. The scalability of the proposed system is another key strength, as it can be easily integrated into existing surveillance infrastructures, such as fixed CCTV cameras or mobile devices like drones and IoT cameras. This adaptability makes the system suitable for various deployment scenarios, from transportation hubs to large public gatherings, where rapid responses are critical. Moreover, its high processing speed, which allows real-time analysis at 25 frames per second, ensures that alerts are sent instantly when abnormal behaviour is detected. However, while the system performs well in controlled environments, challenges remain with adapting to new, unseen scenarios, such as unusual crowd patterns or low-quality video feeds. Future research may focus on improving the system's robustness through multimodal data fusion and more efficient training techniques, enabling even better performance in diverse real-world settings.

Fig 1 Working Model

CONCLUSION

Water is one of the most vital elements for livelihood but at the same time, it is polluted by different kinds of fastest-growing industries like textiles, leather, sugar and many more [3]. In conclusion, the Grey Water Management :- Leveraging IoT for Sustainable Water Reuse works effectively. This project successfully developed an IoT-based grey water quality monitoring system that enables real-time assessment of water safety for cultivation. By integrating sensors to measure key parameters such as pH, TDS, temperature, turbidity, and gas levels, the system provides a cost-effective and scalable solution for sustainable water reuse. The experimental results demonstrated the system's accuracy and efficiency in classifying water samples as either Safe for Cultivation or Not Safe for Cultivation based on predefined thresholds. The use of ThingSpeak for cloud-based data visualization further enhances real-time monitoring and decision-making.

Despite some challenges and limitations, such as sensor calibration issues, reliance on internet connectivity, and the exclusion of microbial contamination monitoring, the project presents a promising approach to water conservation. With future enhancements, including automated filtration, machine learning-based anomaly detection, and expanded contamination monitoring, the system can be widely adopted for applications in agriculture, landscaping, urban wastewater management, and industrial water recycling. There has been an attempt that has been made to build a system that is capable of preserving the ground water by harvesting the rain water and re-using the grey water made available from every household. [16]. Ultimately, this project contributes to addressing global water scarcity issues by promoting the safe and efficient reuse of grey water through innovative IoT technology.

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