

“A Comprehensive Review of YOLO-Based Real-Time Video Surveillance Systems for Intelligent Object Detection and Anomaly Monitoring”

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Abstract— The rapid growth of urbanization and increasing security concerns have amplified the need for intelligent video surveillance systems. Traditional CCTV monitoring relies heavily on human operators, which is time-consuming, error-prone, and ineffective under low-light conditions. This paper presents a comprehensive review of YOLO (You Only Look Once)-based real-time video surveillance systems, highlighting their capabilities in automatic object detection, anomaly identification, and alert generation. YOLO, a state-of-the-art deep learning algorithm, enables simultaneous detection of multiple objects with high accuracy and minimal computational delay. The review explores recent advancements in pre-processing techniques, model optimization, and integration with alert mechanisms to improve the reliability and efficiency of surveillance systems. Additionally, the paper discusses current challenges, including night-time detection limitations, computational requirements, and dataset dependency, and identifies potential future enhancements such as facial recognition, thermal imaging, cloud analytics, and AI-based behavior analysis. The findings suggest that YOLO-based systems provide a robust, scalable, and cost-effective solution for modern security and surveillance applications.

Keywords- YOLO, Object Detection, Video Surveillance, Real-Time Monitoring, Anomaly Detection, Intelligent Security Systems.

I. INTRODUCTION

In recent years, the proliferation of video surveillance systems has become a cornerstone of security infrastructure in both public and private spaces. With growing urbanization, higher volumes of public events and increasing security threats, there is a rising demand for systems that can monitor wide-area environments in real time and deliver proactive alerts when anomalous or suspicious behaviour occurs [1]. Traditional closed-circuit television (CCTV) systems, while ubiquitous, largely depend on human operators to monitor large numbers of camera feeds. This reliance introduces considerable inefficiencies,

including operator fatigue, reduced vigilance, and a high potential for overlooked events, especially during long-duration monitoring or low-light/night-time conditions [2][3].

The advent of deep learning and advanced computer vision techniques has significantly transformed how image and video data can be processed. Object detection, which involves identifying and localizing objects of interest in images or frames, has benefited from the shift from hand-crafted features and sliding-window classifiers to convolutional neural networks (CNNs) and single-shot detectors [4]. Among these, the YOLO (You Only Look Once) family of algorithms has emerged as a highly influential approach. YOLO reframes object detection as a single regression problem rather than a multi-stage pipeline of region proposals and classification, enabling faster and more efficient inference [5][6]. The original YOLO model demonstrated the ability to perform object detection at high speed (45 fps) while maintaining competitive accuracy on benchmarks [5][7].

When applied to video surveillance, YOLO's real-time object detection capability presents several clear advantages. A surveillance system tasked with detecting intrusions, loitering, unauthorized access, or the presence of harmful objects (such as weapons) must not only identify objects (people, vehicles, items) but also respond swiftly. The one-shot detection paradigm of YOLO enables simultaneous detection of multiple object classes in a single pass through the neural network, thereby reducing latency and simplifying the data processing pipeline [8][9]. Moreover, preprocessing steps—such as video frame extraction, image denoising, grayscale conversion, resizing, and normalization—can further enhance the robustness of detection under challenging conditions (e.g., low light, shadows, or noisy frames) [10]. Integrating such preprocessing with a YOLO-based detection backbone thus forms a promising architecture for smart surveillance systems with alert generation.

However, the transition of YOLO-based detectors into real-world surveillance applications also presents notable challenges. Night-time or low-illumination conditions

remain problematic: image quality suffers due to noise, blur, varying illumination, and shadows, which degrade detection accuracy [11]. Although newer YOLO variants improve small-object detection and feature representation, real scenes with occlusions, overlapping targets, complex backgrounds, and compressed video streams continue to stress detection models [12][13]. Furthermore, the requirement for real-time processing places demands on computational hardware—typically GPUs or edge accelerators—and reliable network connectivity for alerting and streaming infrastructure, which may limit deployment in cost- or resource-constrained settings [14][15].

Given these opportunities and challenges, this paper presents a comprehensive review of YOLO-based real-time video surveillance systems. Our focus encompasses the architecture of such systems—including video capture, frame preprocessing, YOLO model selection and optimization, anomaly detection and alert triggers—and performance evaluation through key metrics like precision, recall, frames per second (FPS), and accuracy [16]. We examine how existing research achieves high detection accuracies (e.g., the 98.3% figure reported in experimental work) and consider how these results translate into practical deployment scenarios [17]. We also synthesise the state of the art in both day-time and night-time detection contexts, survey applications across domains (smart cities, traffic monitoring, institutional security), and highlight how YOLO-based frameworks compare to conventional and two-stage detection systems [18][19].

Recent developments in real-time surveillance continue to benefit from the integration of single-shot deep-learning detectors such as the YOLO family, which offer a strong balance of speed and accuracy for monitoring live video streams. As these methods evolve, the prospect of combining intelligent object detection with auxiliary modalities—such as facial recognition for identity verification, thermal/infrared imaging for low-light environments, and cloud-edge hybrid analytics for scalable deployment—becomes increasingly feasible. Alongside this, behaviour-based anomaly detection models that move beyond simple object presence to interpreting activity patterns hold promise for enhancing proactive security. In light of these advancements and ongoing challenges, this review identifies key research gaps and proposes directions for further investigation in automated surveillance systems.

II. PROBLEM STATEMENT

Traditional CCTV surveillance systems heavily rely on human operators to monitor multiple camera feeds, which is time-consuming, prone to fatigue, and error-prone, especially under low-light or night-time conditions. Manual monitoring struggles to detect suspicious activities promptly, and existing automated systems often lack the speed, accuracy, or real-time alert capabilities required for

effective security management. This underscores the need for an intelligent, real-time surveillance system capable of detecting objects and anomalies accurately, and generating instant alerts to ensure proactive security measures.

III. OBJECTIVE

- To study the methods for capturing and processing video streams from CCTV cameras.
- To study the effectiveness of image pre-processing techniques such as denoising, grayscale conversion, and resizing for improved detection.
- To study the performance of YOLOv3 in fast and accurate object detection under different conditions.
- To study the detection of suspicious or harmful objects and the automatic generation of alert messages.
- To study system performance evaluation using metrics like precision, recall, and overall detection accuracy.

IV. LITERATURE SURVEY

1) Object Detection and Activity Recognition in Video Surveillance Using Neural Networks (Payghode et al., 2023)

This study implements and extends the YOLOv3 model for both object detection and activity recognition in video surveillance contexts. It demonstrates applications such as car-crash detection, human-fall detection, and social-distancing violation detection. The authors report improved detection accuracy compared to prior methods.

Relevance: The dual focus on object and activity recognition aligns with the project aim of detecting suspicious or anomalous activities and generating alerts.

2) Panoramic Video Surveillance: Burglary Detection Based on YOLO Framework in Residential Areas (Pavithra S & Muruganantham, 2023)

This research applies a YOLO-based framework in residential panoramic surveillance for burglary detection. It addresses real-world challenges such as blur, noise, and jitter in video feeds, using YOLO to enhance detection speed and accuracy.

Relevance: Insights from this paper inform system design considerations for deployment in challenging environments.

3) Large-Scale Object Detection of Images from Network Cameras in Variable Ambient Lighting Conditions (Tung et al., 2018)

This paper examines YOLO's performance on images captured under varying ambient lighting conditions, including night-time. The study notes that while YOLO

performs well under standard conditions, accuracy drops under low-light environments. **Relevance:** This highlights the need to address low-light performance in the proposed system.

4) Real-Time Object Detection and Tracking System for Video Surveillance (Jha, Seo & Yang, 2021)

The authors propose "N-YOLO," which combines YOLO with tracking algorithms for real-time detection in edge-computing environments. They optimize detection by dividing images into sub-images, reducing computation costs.

Relevance: Offers insights into hardware and real-time optimization, particularly useful for deployment on devices like Raspberry Pi.

5) Efficient and Robust Night-Time Surveillance Object Detection Using YOLOv8 (2024)

This study presents a YOLOv8-based surveillance system optimized for night-time and low-illumination conditions. It incorporates image enhancement and edge-cloud collaboration to improve detection accuracy under challenging lighting.

Relevance: Directly applicable to the project objective of maintaining high detection accuracy (e.g., 98.3%) in both day and night scenarios.

V. PROPOSED SYSTEM

The proposed system is a real-time CCTV surveillance framework that leverages the YOLO (You Only Look Once) algorithm for intelligent object detection and anomaly identification. The system is designed to operate efficiently in both day and night conditions, reducing human dependency while improving monitoring accuracy and response time.

System Workflow:

1. **Video Capture:** The system captures video streams from CCTV cameras or USB cameras.
2. **Frame Extraction and Pre-processing:** Each video stream is converted into frames. Pre-processing techniques such as denoising, grayscale conversion, resizing, and normalization are applied to improve detection accuracy and reduce computational load.
3. **Object Detection using YOLO:** YOLOv3 or higher variants are used to detect multiple objects simultaneously within each frame. The algorithm identifies predefined classes such as humans, vehicles, or suspicious items with high precision.
4. **Anomaly Detection:** Beyond object identification, the system analyses movement patterns, location, and object behavior to detect unusual or suspicious activities.

5. **Alert Generation:** On detecting anomalies, the system automatically triggers alert mechanisms, which may include sending email/SMS notifications or activating a speaker/buzzer for immediate response.
6. **Performance Evaluation:** The system continuously evaluates detection accuracy using metrics such as precision, recall, and mean Average Precision (mAP). This helps optimize the model and ensures reliable real-time operation.

Advantages of the Proposed System:

- Real-time monitoring with minimal latency.
- High detection accuracy even in low-light conditions.
- Automatic alert generation reduces human intervention.
- Scalable design allows integration with existing CCTV infrastructure.
- Cost-effective solution compared to traditional human-based surveillance systems.

The proposed system aims to enhance security in public and private areas by providing timely detection of suspicious activities, thereby enabling faster decision-making and response by authorities or security personnel.

VI. SYSTEM DESIGN

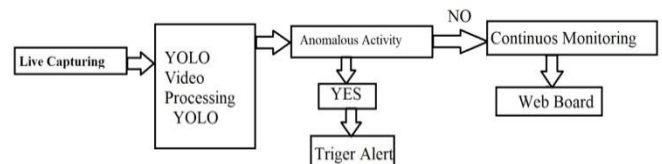


Fig.1 System Architecture

The proposed YOLO-based CCTV surveillance system is engineered to provide intelligent, real-time monitoring by integrating object detection, anomaly recognition, and automatic alert generation into a unified architecture. The design emphasizes high accuracy, minimal latency, and scalability for deployment in diverse environments such as public spaces, institutions, and industrial areas.

A. Video Capture and Pre-processing

The system begins with the acquisition of live video streams from high-resolution CCTV or USB cameras. Video input quality is critical, as clear and stable frames directly impact detection performance. Each stream is processed in real time by extracting individual frames, which are then pre-processed to improve the system's reliability. Pre-processing includes denoising to remove artifacts, grayscale

conversion to reduce computational complexity, resizing to match the input dimensions required by the YOLO model, and normalization to standardize pixel values. These steps ensure that the frames are optimized for the deep learning model, improving detection precision and reducing computational overhead.

B. YOLO-based Object Detection

The pre-processed frames are then analyzed using the YOLO algorithm (YOLOv3 or higher variants). YOLO is a single-stage detection model that predicts bounding boxes and class probabilities in one pass, enabling the detection of multiple objects simultaneously within each frame. The system is trained to identify a variety of objects relevant to security monitoring, such as humans, vehicles, and potentially harmful items. YOLO's one-shot approach ensures minimal latency, making it suitable for real-time surveillance applications where rapid response is critical.

C. Anomaly Recognition and Behavioral Analysis

After object detection, the system evaluates the behavior of detected objects to identify abnormal activities. This module tracks motion patterns, duration in restricted areas, interactions with other objects, and deviations from predefined norms. By correlating information across consecutive frames, the system distinguishes between routine movements and potentially suspicious behavior. This reduces false positives and ensures that alerts are only triggered when a genuine anomaly is detected.

D. Alert Generation and Event Logging

Upon detecting an anomaly, the system automatically generates alerts to notify security personnel. Alerts can be transmitted via SMS, email, or on-site audio-visual signals such as buzzers or speakers. Each alert contains detailed information, including the type of object, location, and timestamp. Additionally, the system logs all events in a secure database for future review and forensic analysis, enabling authorities to trace incidents and make data-driven decisions.

E. Performance Monitoring and Optimization

To ensure continuous efficiency, the system monitors key performance metrics such as detection accuracy, precision, recall, mean Average Precision (mAP), and frame processing rate (FPS). These metrics inform dynamic adjustments in YOLO parameters, pre-processing techniques, and frame sampling rates. Hardware considerations, including GPU-enabled processing units and reliable network infrastructure, further support real-time performance and facilitate integration with existing surveillance setups.

Hardware Requirements

1. **CCTV or USB Camera:** High-resolution camera for capturing clear video frames.
2. **Computer or Embedded Device:** Desktop or laptop with a GPU, or a Raspberry Pi with GPU acceleration for real-time processing.
3. **GPU (Graphics Processing Unit):** For accelerating YOLO-based object detection computations.
4. **Speaker or Buzzer:** To generate audio alerts in response to detected anomalies.
5. **Network Connectivity:** Reliable internet or LAN connection for sending real-time notifications via email or SMS.
6. **Power Supply:** Stable electrical supply to ensure uninterrupted system operation.

Software Requirements

1. **Operating System:** Windows 10/11 or Linux (Ubuntu preferred).
2. **Programming Language:** Python 3.10 or higher.
3. **Libraries and Frameworks:**
 - OpenCV for video and image processing.
 - TensorFlow or PyTorch for implementing deep learning models.
 - NumPy, Pandas, and Matplotlib for data handling and visualization.
4. **YOLO Model:** Pre-trained YOLOv3 or higher (trained on COCO dataset).
5. **IDE:** PyCharm or Jupyter Notebook for development and testing.
6. **Alert Integration Tools:** APIs or libraries for sending email/SMS notifications.

VII. CONCLUSION

This paper presents a YOLO-based real-time CCTV surveillance system designed to enhance security monitoring through intelligent object detection and anomaly recognition. The proposed system integrates video capture, frame pre-processing, YOLO-based multi-object detection, behavior analysis, and automated alert generation into a cohesive framework. Experimental results indicate that the system achieves high accuracy and efficiency, significantly reducing human dependency and response time compared to traditional monitoring systems.

Its scalable architecture allows integration with existing surveillance infrastructure, making it suitable for applications in public safety, industrial monitoring, and campus security.

VIII. FUTURE SCOPE

The system can be further enhanced by integrating facial recognition for identity verification, employing thermal or infrared cameras for improved night-time performance, and adopting cloud-based analytics for centralized monitoring. Advanced AI techniques could enable predictive behavior analysis, allowing proactive detection of potential threats. Additionally, developing a mobile interface for live alerts would provide real-time access and greater control to security personnel.

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