Real-Time Video Anomaly Detection : Survey

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Abstract

This project aims to develop a real-time anomaly detection system using RTOS on a personal computer with a camera. It will monitor the scenes continuously and analyze the video frames to spot strange events, for example, unauthorized access, unexpected movements, and any other oddities, using computer vision techniques that may utilize lightweight AI models. Using RTOS will aid in organizing video capture, processing, and alert development task management more efficiently because they will all be able to execute their functions with exact timing and priority. This is very important for real-time events such as home security systems and automated monitoring systems. Real-time use is necessary for much longer to detect and respond rather than waiting for the anomaly to cause damage before taking remedial measures. The project is to show how RTOS can very well be put to use to make sure the system works responsively and reliably in real-time video processing tasks.

1 Introduction

Surveillance cameras are increasingly being used in public places, e.g., streets, intersections, banks, shopping malls, etc., to increase public safety. However, the monitoring capability of law enforcement agencies has not kept pace. The result is that there is a glaring deficiency in the utilization of surveillance cameras and an unworkable ratio of cameras to human monitors. One critical task in video surveillance is detecting anomalous events such as traffic accidents, crimes, or illegal activities. Generally, anomalous events rarely occur as compared to normal activities. Therefore, to alleviate the waste of labor and time, developing intelligent computer vision algorithms for automatic video anomaly detection is a pressing need. The goal of a practical anomaly detection system is to timely signal an activity that deviates from normal patterns and identify the time window of the occurring anomaly. Therefore, anomaly detection can be considered as coarse-level video understanding, which filters out anomalies from normal patterns. Once an anomaly is detected, it can further be categorized into one of the specific activities using classification techniques.

2 Motivation

Modern systems have become increasingly complex and integrated into every critical domain, such as security and surveillance. These modern systems require responses that are immediate yet reliable in maintaining safety, mitigating risks, and handling any critical scenarios that may arise. Unfortunately, these tasks have strict timing requirements that traditional operating systems are incapable of providing. This can lead to system delays in processing, missing significant events, or even leading to security vulnerabilities, which are attributes that are unacceptable in high-precision and reliable environments.

An RTOS is specifically designed to overcome these challenges by providing real-time, deterministic task scheduling, ensuring that strict deadlines are met consistently. This ability makes RTOS a very encouraging solution for time-sensitive applications, including video surveillance systems where any anomalies need to be detected rapidly. The ability to process video streams in real-time and identify anomalies quickly is important in helping to contain security threats, protect assets, and ensure the safety of people.

The present survey is based on the detection of real-time video anomalies through RTOS. More focus is being given to managing time-critical tasks effectively by this method. We have evaluated the timeliness of processing each video frame enabled by RTOS to allow for fast detection and response against any irregular activity in surveillance footage. The study intends to define and illustrate the importance of real-time operating systems (RTOS) in the enhancement of system performance and reliability in such areas as video surveillance system integration.

The research results will not only portray real applications of RTOS in the real-time video analysis domain but also show how it could create wide possibilities for improving the responsiveness and efficiency of new surveillance systems. In addition, the discussion opens the gates for exploration on RTOS as a technology for transformation to meet the increasing security and surveillance demands in an increasingly digital world.

3 Background and Terminology

3.1 Background

Technological advancement has ushered society into an era in which video surveillance systems have become a common tool in public safety, monitoring the industry, and protecting crucial infrastructures. These systems generate a high amount of video data, which must then be processed in real-time conditions for threat identification and response or aberration detection. Traditional anomaly detection systems mainly rely on post-event analysis, which hampers their potential to prevent such incidents or manage them in time.

In such environments, such as airports, hospitals, or power plants, it stands to reason that any delay in identifying these anomalies could be a source of abnormal access, impairment of equipment, or suspicious activity, leading to grave consequences. Current systems should facilitate such processing in a large volume of video but also account for time and reliability for detecting those irregularities. This is where Real-Time Operating Systems take into their realm since RTOS is designed to perform tasks with deterministic timing, guaranteeing responses within fixed time bounds. Therefore, real-time operation at this level is a natural evolution of integrating RTOS into video surveillance systems towards real-time anomaly detection.

The availability of advanced systems using machine learning and computer vision enhanced the accuracy of the anomaly detection systems. Still, these algorithms need high computational power and should be nimble for real-time performance. RTOS would then form the bedding ground over which these advanced analysis algorithms would be integrated into systems capable of processing, analyzing, and responding to anomalies in live video feeds with very low latency. This is particularly applicable in cases where the delays would lead to security breaches or operational threats.

3.2 Terminology

Having set the stage for real-time anomaly detection and RTOS, it is imperative to summarize key definitions and concepts.

Real-Time Systems. A real-time system is a computing environment that serves events between clearly specified deadlines. As in, the real-time systems are classified into the following two categories :

— **Hard Real-Time Systems** : Missing the deadline has catastrophic failures. For example, the airbag systems in cars, or, again, where a much better example would be that of an industrial control system.

— **Soft Real-Time Systems** : The deadline missed would impair the system's performance, simply not in an ultimate sense. Examples are video streaming and gaming applications.

Real-Time Operating System (RTOS). An RTOS is a special-purpose operating system that helps manage the hardware resources and ensures that tasks run under deterministic timing. Key features of an RTOS include :

— **Predictable Scheduling** : To schedule a task to finish at a given time, RMS (Rate-Monotonic Scheduling) or EDF (Earliest Deadline First) is used.

— **Interrupt Handling** : To handle and respond to hardware or software interrupts for real-time performance.

— **Low Latency** : Minimizes task execution latencies to accommodate time-critical operations.

Anomaly detection in surveillance is the identification of certain patterns or behaviors on video that are different from the usual and may specify alarm or trigger some other unusual events.

Video Surveillance Systems : Systems designed to monitor activities through video feeds using cameras, sensors, and analytics tools. New age systems leverage functions of AI and machine learning to automate anomaly detection and minimize manual monitoring.

Significant Contribution in Video Surveillance. RTOS has many advantages in different kinds of challenges regarding real-time video anomaly detection. Some of them are :

— **Timeliness** : It comprises assurance, which restricts the deadlines for analyzing video frames, which can cause immediate reactions.

— **Reliability** : It performs consistently, notwithstanding high system workloads or a resource-lean environment.

— **Scalability** : It supports multiple sensors, cameras, algorithms, and timing.

Combining the deterministic attributes of RTOS with state-of-the-art anomaly detection algorithms, unprecedented effectiveness in finding and facing security threats is possible in surveillance systems. This background and terminology provide ground information for the exploration of the possible achievement of RTOS for improving real-time anomaly detection in video surveillance systems.

4 Methodologies

Real-time anomaly detection with Real-Time Operating Systems (RTOS) requires a systematic methodology encompassing real-time systems abidance, high-end video processing, and anomaly detection algorithms.

4.1 Video Data Acquisition & Preprocessing

The objective is to capture and make the video for use for real-time analysis.

— **Frame Rate Optimization** : Choose a frame rate that balances the view threshold for real-time and processing capability, e.g., running at 30 fps.

— **Resolution Control** : Change the video resolution to fit the computational limits without losing any critical details ; for example, lower the resolution for less critical areas, while the resolution will be kept just as high for areas of interest.

— **Preprocessing Technologies** :

1. Filtering : Filter noise from video frames using Gaussian or median filters.
2. Background-subtraction : Using (for example) MOG to segment moving objects from the scene.
3. Edge Detection : Canny or Sobel, for example, can be used to mark the object boundary in the video stream.

4.2 Real-Time Video Processing Pipelines :

Some components are defined to standardize the processing of video frames for anomaly detection :

— **Capture Module** : Interface for video streams having cameras with sensors.

— **Prepossessing Module** : Describe the form of frames to be analyzed by use of resizing, cropping or normalization.

— **Detection module** : Applies either prescribed rules or machine-learning models to do anomaly detection.

— **Decision Module** : Makes decisions based on detection results, which could lead to alerts/ responses based on the findings.

— **Response Module** : Takes action such as notification of security personnel, event logging, or activating emergency protocols.

5 Challenges and Open Issues

Several challenges and open issues have been introduced in existing studies.

5.1 Scheduling & Deadline-Management

Successfully managing the scheduling of tasks and detection of anomalies- Another possible activity is setting deadlines without incurring delays.

— **Priority inversion** : Blocking by a lower-priority task of execution by a higher-priority task that then leads to a delay in the critical operation, such as anomaly detection or video frame acquisition. All of which eventually lead to missed deadlines or degraded system performance.

— **Dynamic Task Loads** : The system could have different loads like varying frame rates or sudden increases in processing requirements during difficult anomaly scenarios. Adapting in real time to external changes becomes incredibly difficult.

— **Real-time Scheduling Algorithms** : Difficulties arise when selecting and implementing effective scheduling algorithms like Rate-Monotonic Scheduling (RMS) or Earliest Deadline First (EDF) in case tasks have a high variation in their execution times.

5.2 High problems in Processing Huge Volumes of Video

— **Challenge** : Processing large volumes of video data under tight time conditions is a high-end task since this form of the system must, among others, allocate computation resources in a highly efficient way to materialize real-time end-product.

— **With High Throughput Requirements** : The surveillance systems of today include many high-definition video feeds, which necessitate high processing capacity during real-time processing of the frames.

— **Latency Minimization** : Any delay in processing a few frames can cause an anomaly detection too late for effective action, particularly in hardcore security situations.

— **Memory Constraints and Bandwidth** : Limited memory and downrates on embedded systems can bottleneck the processing pipeline, often when preprocessing and detection algorithms are resource-intensive.

5.3 Artificial Intelligence-Based Anomaly Detection

This could really be a big challenge because it covers the enhancement concern on yet-undelivered timing constraints of the RTOS for the operation of AI-based anomaly detection algorithms. This critical stitching touches upon the accuracy of detection to meet the timing requirements.

— **Complexity in Computation** : Advanced AI models, for example, a deep neural network, would indulge in heavy computational capabilities that do not naturally fit within the low latency requirements of an RTOS environment.

— **Optimization of the Model** : Challenges exist on how to size and complexity reduction in AI models increasingly optimal in operating on RTOS-available relatively high accuracies under models like quantization, pruning, or knowledge distillation.

— **Real-Time Training and Adaptation** : Online learning or adaptive algorithms built to update in real-time without displacing operations make things even more complex.

That is to say, by tackling such challenges using state-of-the-art and optimized designs along with rigorous testing, advanced real-time anomaly detection systems will be ready to face today's demands using RTOS's capabilities.
For instance, an effective application of real-time analysis could be a real-time detection anomaly, developed to perform and meet demand with what modern surveillance and security systems are using today, ranging from RTOS.
Real-time anomaly detection systems would thus meet the increasingly high requirements of modern surveillance and security systems by venturing into the innovative design,

optimization, and rigorous quality testing approach to these challenges.

6 Use Cases

We have gathered the major use cases for real-time anomaly detection from existing studies, which are as follows.

6.1 Public Safety in Smart Cities

Real-time anomaly detection constitutes a key pillar of the safety framework in smart cities. Authorities may use such systems, integrated with RTOS video surveillance, to rapidly and accurately identify and respond to separate and hazardous events.

— **Use Cases Description**

1. Traffic Management : Dysfunctional traffic culminates at an unexpected point, erratic driving, or illegal entry of unauthorized vehicles into restricted areas. Streams from traffic cameras are processed quickly in RTOS to detect anomalies and call for action to reroute traffic or dispatch law enforcement.
2. Crime Prevention and Detection : Monitor public spaces for any suspicious activities like loitering, breaking, or stealing. Running on RTOS, abnormal behavior can be detected and trigger an alert for the concerned personnel with minimum response delay.
3. Emergency Response : Monitor the public space for signs of emergency : fire, accident, stampede, etc. Analysis of critical video frames is prioritized in RTOS to detect emergencies and raises evocation procedures and services at high speed.

— **Advantages**

1. Enhancing security for proactive monitoring.
2. Improved response times of law enforcement and emergency services.
3. Prioritization of not routine behaviors for effective allocation of resources.

6.2 Healthcare & Patient Monitoring

Transformative impact such as real-time anomaly detection in health, primarily in patient monitoring systems. Such systems with RTOS capabilities would catch anomalies in patient behaviors or vital signs in a timely and would detect potential medical emergencies.

— **Monitoring Vital Signs** : In reality, as far as vital signs of a patient, such as heart rate, oxygen saturation, or blood pressure, are concerned, these have shields monitoring patients using sensors with video feeds inwards or in ICU units. Monitoring mortality trends through measurements of vital parameters in real-time and communicating up-to-date reports to healthcare personnel for prompt and timely intervention

— **Fall Detection in Elderly People** : Video capture footage from cameras mounted within assisted living or homecare could be used to detect falls or abnormal and unwanted movements in old individuals. This way, the RTOS will enable this system to immediately alert whenever it detects the occurrence of falls without having to delay medical assistance.

— **Behavioral Anomalies** : Detect prolonged immobility in a patient, agitation, or attempts to exit a monitored area.Anomaly detection algorithms run on RTOS assess behavior and can raise alerts if there is something fishy going on in the behavior marked as concerning to keep the patient safer.

Early emergency detection in healthcare systems leads to improved patient outcomes by addressing critical issues promptly and effectively. Automating the monitoring process not only enhances efficiency but also saves valuable time for healthcare personnel, allowing them to focus on more complex tasks. Additionally, these advancements significantly enhance patient safety, particularly in high-risk or critical scenarios, by providing consistent and accurate oversight that reduces the likelihood of errors or delays in care.

6.3 Use Cases Supported by RTOS

— **Deterministic Performance** : Ensures a high number of operations are performed within strict time constraints, which is especially critical in domains such as public safety and healthcare.

— **Task Prioritization** : Focuses exclusively on essential real-time tasks, such as monitoring vital signs or detecting potential safety threats, to ensure the most critical operations are addressed promptly.

— **Scalability** : Provides the flexibility to scale operations, from monitoring a single patient to managing a comprehensive city-wide surveillance network.

— **Integration with AI** : Enhances anomaly detection capabilities by incorporating machine learning techniques for continuous improvement and adaptability.

This demonstrates that RTOS effectively enables real-time anomaly detection, significantly enhancing safety and operational efficiency in crucial fields like public safety and healthcare.

7 Prototype Implementation

7.1 Introduction

This section describes a prototype demonstrating a real-time human detection system that incorporates adaptive mechanisms to handle deadline violations in real-time systems. The implementation leverages Python and ROS 2 with state-of-the-art object detection frameworks and libraries.

7.2 Technology Stack

The prototype is built with the following components :

- **Programming Language** : Python
- **Framework** : ROS 2 (Robot Operating System 2)
- **Libraries** :
  - **YOLOv8** : Ultralytics YOLOv8 for real-time object detection.
  - **OpenCV** : For image processing and visual display of live video feeds.
  - **rclpy** : ROS 2 Python client library for managing nodes, topics, and messages.

7.3 System Overview

The prototype demonstrates a real-time anomaly detection system that simulates adaptive behavior under variable conditions. It processes live video streams for human detection, ensuring compliance with real-time deadlines. The system dynamically adapts to network-induced latency or computational delays.

Scenario Walkthrough.

1. **Initial Operation (0-10 seconds)** :
   - The system operates at a frame rate of **30 FPS** with a processing deadline of **100ms**.
2. **Simulated Deadline Miss (10-20 seconds)** :
   - Simulated network latency or processing delay causes deadline violations.
   - The system detects missed deadlines and reduces the frame rate to **15 FPS** to recover.
3. **Recovery Phase (After 20 seconds)** :
   - The system monitors performance and restores the frame rate to **30 FPS** once deadlines are consistently met.

7.4 Implementation Details

The prototype implementation consists of two key ROS 2 nodes : `CameraNode` and `DemonstrationNode`.

CameraNode. This node captures frames from a webcam, converts them into ROS 2 image messages using `cv_bridge`, and publishes them to a topic. It operates at a target frame rate of 30 FPS.

Features

- Uses OpenCV to capture images.
- Converts OpenCV images to ROS-compatible messages.
- Publishes images to downstream nodes.

```python
class CameraNode(Node):
    ...
    def publish_frame(self):
        ...
        self.publisher_.publish(ros_image)
```

Listing 1 – `camera_node.py`

DemonstrationNode. This node subscribes to the `camera_frames` topic, performs real-time object detection using YOLOv8, and dynamically adjusts system parameters (frame rate and deadlines) based on detected anomalies.

Features

- Utilizes YOLOv8 for detecting objects, focusing on human identification.
- Publishes visualization markers for detected objects.
- Implements adaptive frame rate and deadline adjustment mechanisms.
- Logs detections and warnings for analysis.

Key Logic

- **Object Detection** : Processes incoming frames, runs object detection, and overlays bounding boxes and labels.
- **Deadline Monitoring** : Tracks processing times and compares them against deadlines.
- **Adaptive Behavior** : Adjusts frame rate and deadlines based on system performance.

```python
class DemonstrationNode(Node):
    ...
    def process_frame(self, msg):
        ...
        if elapsed_time_ms > self.deadline_ms:
            self.adjust_frame_rate_and_deadline()
```

Listing 2 – `demonstration_node.py`

Adaptive Mechanisms. The node simulates and responds to system anomalies by dynamically adjusting operational parameters :

- **Deadline Miss Handling** : Reduces the frame rate to meet deadlines.
- **Recovery Strategy** : Gradually restores normal operations once conditions stabilize.

7.5 Demonstration and Resources

- **Demonstration Video** : `https://drive.google.com/file/d/1vuJ7HEpXFULmdWSzAygJwXPG-kVcWIYq/view?usp=sharing`
- **Code Repository** : `https://github.com/aesashi/RT_AnomalyDetection_with_RTOS2-`

This prototype effectively demonstrates the integration of real-time object detection with adaptive control mechanisms in a ROS 2 environment. The system's ability to handle anomalies and maintain real-time deadlines positions it as a valuable reference for anomaly detection research in real-time operating systems.

8 Future Directions

A very promising development avenue is concerning the provision of advanced technology and innovation to the existing real-time anomaly detection arena. Following are some of the future research and development areas :

8.1 Advanced Scheduling Techniques :

- **Dynamic Task Scheduling :** The future generation of RTOS will surely provide richer scheduling algorithms capable of dynamically changing priorities as affected by conditions.
- **Multi-Core Optimization :** Better utilization of multi-core processors will facilitate enhanced multitasking of video streams or tasks, thereby improving system performance.
- **Examples :** in healthcare, prioritizing tasks based on the severity of patient anomalies, such as a cardiac event over routine monitoring.

9 Conclusion

Real-time anomaly detection in Real-Time Operating Systems (RTOSs) brings the paradigm shift in safety and surveillance applications such as healthcare and smart cities. With increasing demands for accuracy and immediacy in detection, today's digital systems require RTOS technology to facilitate the reliable execution of time-triggered tasks, making it the best-included model for time-critical applications. This survey presents the compelling role of the RTOS in addressing the key issues of task scheduling, resource optimization, concurrent data processing, and a few others, with the stability and performance of the entire system intact. RTOS can now prioritize important tasks, minimize latency, and enable more efficiency and responsiveness with rapid detection and mitigation of possible threats or abnormalities in real-time in anomaly detection systems. AI-driven anomaly detection applications in the RTOS address what is set as common ground for advanced computing techniques with real-time systems, but they also promote higher detection accuracy and eventually yield a more intelligent, automated decision-making process in high-criticality environments. Many advances have been made in anomaly detection systems; however, broad research areas remain on big data stream handling, scalability, and optimizing AI processing solutions under constrained time. Continuous improvement in RTOS technology, together with advances in AI and machine learning, would enhance the capabilities of real-time anomaly detection systems to handle emerging new challenges across every industry. In general, therefore, RTOS is the basic RT technology for constructing adaptive, powerful, and efficient real-time anomaly detection systems for end-user applications in ever more secure and automated environments.

Références

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