International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Anomaly Detection System in Surveillance Videos Using Unmanned Aerial Vehicle Systems

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Submitted: 26/01/2024 **Revised**: 04/03/2024 **Accepted**: 12/03/2024

Abstract: This paper introduces a One-Class Support Vector Machine (OC-SVM) anomaly detector tailored for aerial video surveillance using small-scale Unmanned Aerial Vehicles (UAVs) operating at low altitudes. Anomaly detection is crucial in various UAV-based surveillance applications, including vehicle tracking, border control, and dangerous object detection. It enables the identification of areas or objects of interest without prior knowledge, enhancing the surveillance capabilities of UAVs. OC-SVM, known for its lightweight and fast classification, enables the implementation of real-time systems, even on low-computational small-scale UAVs. Textural features are employed to detect both micro and macro structures in the analyzed surface. This capability allows the system to identify small and large anomalies critical in low-altitude aerial surveillance scenarios. Experiments conducted on the UAV Mosaicking and Change Detection (UMCD) dataset demonstrate the effectiveness of the proposed system. Evaluation metrics include accuracy, precision, recall, and F1-score. The model achieves 100% precision, indicating it never misses an anomaly, with a recall trade-off reaching up to 71.23%. The proposed model outperforms classical Hara lick textural features by approximately 20% across all evaluation metrics, further validating its effectiveness. The proposed system is compared against existing methods to assess its efficiency and effectiveness in anomaly recognition. Based on the evaluation results, the paper concludes that the proposed model outperforms prevailing methodologies regarding accuracy and performance.

Keywords: *Anomaly detection; small-scale unmanned aerial vehicles; feature extraction; real-time applications; support vector machines*

1. Introduction

The increasing utilization of Unmanned Aerial Vehicles (UAVs), or drones, in a wide range of applications, emphasizing their mobility and versatility. Recent advancements have led to the development of models that enable UAVs to process real-time intelligence, either independently. This capability allows for open-ended reasoning in lightweight systems, enhancing the UAVs' ability to adapt to dynamic environments and tasks [1-3]. Moreover, the integration of real-time intelligence enables UAVs to track events and provide descriptions in real time.

This functionality is precious when human operators face potential hazards. By suggesting estimated optimal commands for action, UAVs can serve as companions to human operators, enhancing situational awareness and aiding decision-making processes. Overall, the emergence of UAVs equipped with real-time intelligence capabilities represents a significant advancement in robotics technology, with potential applications across various industries, including surveillance, search and rescue, environmental monitoring, and infrastructure inspection [4-5].

The passage underscores the increasing prevalence of visual surveillance, mainly through the use of Closed-Circuit Television (CCTV), in addressing security concerns globally. As crime rates escalate, the adoption of CCTV technology has become commonplace in modern life, especially in locations requiring heightened security measures [6]. However, effectively identifying anomalies or objects of interest from the extensive volume of surveillance videos poses a significant challenge. Recent advancements in research have led to the development of a diverse array of modern approaches for Anomaly Detection (AD) in surveillance footage [7]. These approaches are crucial for enhancing security measures and detecting and predicting accidents, congestion, and

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other irregularities. Additionally, AD techniques can provide valuable statistical insights into road traffic status and other monitored environments. As a result, various computer vision-centric studies and challenges have been conducted to address these needs, including traffic monitoring, activity recognition, emergency management, human behaviour analysis, event detection, and more. These endeavours aim to leverage computer vision technologies to improve the efficiency and accuracy of anomaly detection systems, thereby bolstering overall security and situational awareness across various domains [9].

The paragraph provides an insightful overview of anomaly detection (AD) within the broader domain of behaviour understanding. It defines anomalies as unexpected, unusual, irregular, or unpredictable events or items that deviate from standard patterns or datasets. These anomalies are context-dependent and differ from prevailing patterns within the phenomenon of interest [10]. In various domains, such as public security, safety, sports analysis, group activity monitoring, and visual surveillance, automated AD plays a critical role. Mechanical surveillance systems are precious in congested environments as they can predict uncommon and complex situations, aiding in making suitable safety and emergency control decisions. The passage highlights the importance of surveillance techniques in challenging and crowded environments like political rallies, busy streets, airports, shopping malls, public celebrations, and train stations. By detecting and managing crowds, these surveillance techniques contribute to public security and safety and achieve statistical objectives. Integrating automated AD within surveillance systems enhances situational awareness and supports proactive decision-making in various real-world scenarios [11-12].

The methodology and challenges associated with anomaly detection (AD) models are outlined and grounded in behaviour representation. AD models extract essential features from surveillance data, such as optical flow, spatiotemporal volume, shape, and trajectory. These features serve as inputs for the detection process. Various approaches, including Principal Component Analysis (PCA), Support Vector Machine (SVM), k-nearest Neighbour (k-NN) algorithm, and correlation analysis, are employed to utilize the extracted behavioural features for anomaly detection. The primary objective of these frameworks is to detect anomalies using static and time-variant systems. Additional techniques like sliding windows (SWs) are integrated with the approaches above to address dynamic and time-variant anomalies. Despite these efforts, existing systems need help to sufficiently capture time-variant model dynamics, resulting in difficulty characterizing anomalous contexts [13-14]. Additionally, occlusion issues are not adequately addressed, leading to suboptimal detection results. Recent research has explored machine learning (ML) techniques, including Long Short-Term Memory (LSTM), Recurrent Neural Networks (RNN), Convolutional Neural Networks (CNN), etc., to overcome these challenges. These approaches leverage the characteristics of time series data, both univariate and multivariate, to improve anomaly detection accuracy [15].

2. Literature Survey

The author [16] presents a real-time crowd anomaly detection (AD) system utilizing Conv-LSTM network. The approach leverages deep learning (DL) techniques to predict violent activities and promptly alert stakeholders to such occurrences in real time. The Conv-LSTM network is specifically employed to capture video frames and detect violent actions within the crowd. The system proposed in the study demonstrates improved accuracy and speed compared to previous methods. However, despite these advancements, the system's accuracy still needs to be enhanced by the complexity of classifying individual or group activities accurately. This suggests that while Conv-LSTM networks offer promising capabilities for real-time AD in crowded scenes, further refinement and optimization may be necessary to address the challenges associated with accurately identifying and classifying various activities within the crowd. Overall, the study contributes to the growing body of research on utilizing deep learning techniques for real-time crowd anomaly detection, highlighting both the progress made and the ongoing challenges in achieving high accuracy in complex real-world scenarios [17].

The study by the author [18] introduces a supervised Local Distinguish Ability Enhancing Network (LDA-Net), which consists of a human detection module and an anomaly detection (AD) module. The primary aim of this network is to improve the ability to distinguish anomalies within surveillance data. The authors propose using an inhibition loss function and embedding techniques to address the misclassification challenge in highly imbalanced datasets. Simulation results demonstrate that the supervised LDA-Net achieves state-of-the-art performance in anomaly detection tasks. However, the authors note that creating a new axis in the developed model increases computational complexity. This suggests that while the network exhibits superior performance, there are trade-offs regarding computational resources required for its implementation. Overall, the study contributes to advancements in anomaly detection methodologies by proposing a novel network architecture and addressing challenges associated with imbalanced datasets. However, further research may be needed to optimize the computational efficiency of the proposed approach for practical deployment in real-world surveillance systems.

The study introduces an online anomaly detection (AD) technique specifically designed for surveillance videos. This technique leverages transfer learning and continual learning approaches to adapt and improve over time [19]. The algorithm combines the feature extraction capabilities of neural network-based methodologies with statistical detection methods to enhance anomaly detection performance. Simulation results demonstrate that the developed algorithm achieves notably high accuracy for detecting anomalies in surveillance videos. However, the authors note that despite the success of their approach, there are still challenges in quickly learning to detect abnormalities. This suggests that while the algorithm shows promise in detecting anomalies, further improvements may be necessary to enhance its ability to promptly identify and respond to abnormal events in real-time surveillance scenarios. Overall, the study contributes to online anomaly detection in surveillance videos by proposing a technique integrating transfer learning, continual learning, neural network-based feature extraction, and statistical detection methods. Despite the challenges identified, the algorithm demonstrates significant potential for improving anomaly detection performance in surveillance systems.

The author [20] proposed an approach centered on bidirectional prediction for anomaly detection (AD) in surveillance videos. The authors build a loss function based on the actual target frame and its bidirectional prediction frame to improve the prediction accuracy. Additionally, they develop an anomaly score estimation approach focused on the foreground regions of the prediction error map, using a Sliding Window (SW) scheme. Experimental results demonstrate that the proposed approach achieves improved anomaly detection performance, as higher anomaly scores indicate. However, the authors note that the method's effectiveness relies heavily on assumption-centric data generation. As a result, the approach may need a higher false alarm rate, where everyday activities are incorrectly flagged as anomalies. Overall, while the approach shows promise in enhancing anomaly detection in surveillance videos, the reliance on assumption-centric data generation and the associated high false alarm rate are significant limitations to consider. Further research may be needed to mitigate these limitations and improve the robustness of the proposed approach for real-world applications [21].

The study by author [22] presents a lightweight anomaly detection (AD) approach centered around a Convolutional Neural Network (CNN). In this approach, spatial features extracted by the CNN are inputted into a residual attention-based Long Short-Term Memory (LSTM) network for sequence learning. This architecture is found to be efficient for both anomaly detection and recognition tasks. The effectiveness of the developed model is validated through extensive experiments. However, the authors highlight a challenge related to modeling normal activity. Since "normal" encompasses a broad range of activities, it is difficult to develop a comprehensive model specifically for normal behavior. Categorizing every possible normal behavior can be challenging and may not capture the full spectrum of normal activities accurately. Overall, the study contributes to the field of anomaly detection by proposing a lightweight CNN-LSTM-based approach that demonstrates effectiveness in detecting anomalies in surveillance videos. However, the challenge of modeling normal behavior remains a limitation, highlighting the complexity of capturing the diversity of normal activities in surveillance scenarios.

A data-driven adaptive anomaly detection (AD) technique specifically designed for human activity recognition. This technique utilizes an ensemble of novelty detection systems called the Consensus Novelty Detection Ensemble, which includes a One-Class Support Vector Machine (SVM) to model human behavior patterns [23]. The simulation results demonstrate that the developed system performs well in detecting anomalies in human activity. However, the authors note a limitation associated with deep learning systems, which require significant computational resources and large amounts of data for training. This observation underscores a common challenge in deploying deep learning-based approaches, particularly in resource-constrained environments. While deep learning models often achieve impressive results, they require substantial computational power and extensive datasets to train effectively. Overall, the study contributes to anomaly detection by proposing a data-driven adaptive approach for human activity recognition. While the developed system shows promising performance, the limitations associated with deep learning models highlight the importance of considering practical constraints when designing and deploying anomaly detection systems.

The author proposed a new framework for motion extraction called BQM (Background Modeling and Motion Extraction) [24]. This framework extracts regions of interest from the motion data and filters to eliminate non-significant regions. To detect abnormal activity effectively, the authors propose using a deep learning strategy, specifically a Sparse Autoencoder. Experimental results indicate that the developed system outperforms existing systems regarding abnormal activity detection. However, the authors identify a limitation related to trajectory-centric features, particularly in crowded or complex scenarios with numerous shadows and occlusions. This limitation suggests that while the proposed framework shows promise, it may need help accurately capture and analyze trajectory-based features in challenging environments. Addressing this limitation could involve exploring alternative feature extraction techniques or refining the model architecture to improve its robustness in crowded or complex scenes. Overall, the study contributes to abnormal activity detection by introducing a novel framework and leveraging deep learning techniques. While the system demonstrates improved performance, ongoing research may be needed to address specific challenges associated with complex surveillance scenarios.

The author's [25] study introduces an effective anomaly detection (AD) technique centered around deep features. The approach involves extracting spatiotemporal features from surveillance data, which are then passed through a multilayer Bi-Directional Long Short-Term Memory (BD-LSTM) system. This BD-LSTM system can accurately classify ongoing incidents in complex surveillance scenes typical of intelligent cities. Simulation results demonstrate that the developed system performs better than existing anomaly detection methods. However, the authors highlight a challenge associated with learning to predict abnormalities promptly. This challenge suggests that while the proposed technique shows promise in detecting anomalies, there may be limitations in its ability to predict these abnormalities sufficiently early to allow for timely intervention or response. Addressing this challenge could involve exploring methods to improve the predictive capabilities of the BD-LSTM system or incorporating additional features or contextual information to enhance anomaly detection and prediction accuracy. Overall, the study contributes to advancing intelligent anomaly detection techniques for surveillance applications, particularly in the context of smart cities. However, addressing the challenge of timely anomaly prediction remains important for future research and development.

The author [26] presents a technique for abnormal event detection using weakly labeled training videos. The authors utilize a Deep Residual Learning framework, specifically the I3D-Residual Network (ResNet)-50, for feature extraction (FE). This framework enables significant improvements in accuracy and recall for video anomaly detection (AD). The introduction of the I3D-ResNet-50 architecture contributes to enhanced performance in detecting anomalous events in videos. However, the authors note that the presence of additional kernel dimensions in the 3D network increases the complexity of the training model due to the higher number of parameters involved. This observation highlights a common trade-off in deep learning models, where increased model complexity can lead to improved performance. Still, it may also require more computational resources and longer training times. Addressing this challenge may involve optimizing model architecture or exploring techniques for reducing model complexity without sacrificing performance.

The study introduces a practical, lightweight anomaly recognition approach centered around the author's proposed Convolutional Neural Network (CNN) [27]. The strategy involves extracting spatial CNN features from video frames and inputting them into a residual attention-based Long Short-Term Memory (LSTM) network. This architecture enables accurate recognition of abnormal activity in surveillance videos. Experimental results validate the higher accuracy of the developed system compared to existing methods. However, the authors note a challenge related to hyperparameters, which can influence the performance of these approaches. They include parameters such as learning rate, batch size, and network architecture. Proper tuning of hyperparameters is crucial for achieving optimal performance in machine learning models, including CNNs and LSTMs. The observation regarding the influence of hyperparameters underscores the importance of thorough experimentation and parameter tuning to achieve the best possible performance from the developed anomaly recognition approach. Overall, while the developed lightweight CNN-centric approach shows promise in anomaly recognition, careful consideration and optimization of hyperparameters are necessary to maximize its effectiveness in real-world surveillance applications.

Unmanned Aerial Vehicle Systems for Surveillance Videos:

Unmanned Aerial Vehicle (UAV) systems have revolutionized surveillance operations across various domains, offering unprecedented flexibility, efficiency, and coverage. The integration of UAVs equipped with high-definition cameras enables the capture of surveillance videos from vantage points that were previously inaccessible or cost-prohibitive. These videos provide rich visual data that can be leveraged for enhanced situational awareness, threat detection, and decision-making processes.

Design and Analysis of UAVs:

Computer-Aided Design (CAD) software like SolidWorks, Autodesk Inventor, or CATIA allows engineers to design the mechanical components of UAVs in a virtual environment. Computational Fluid Dynamics (CFD) plays a critical role in the design, analysis, and optimization of Unmanned Aerial Vehicles (UAVs), offering valuable insights into aerodynamic performance, flight characteristics, and system integration. These tools facilitate 3D modeling, assembly design, and simulation of mechanical systems, ensuring proper fit and function before fabrication [28].

UAVs often encounter challenges related to thermal management, especially in high-performance applications or adverse environmental conditions. Nanofluids, with their enhanced thermal conductivity properties, offer a promising solution for improving heat dissipation and thermal regulation within UAV systems [29].

Benefits of UAV Surveillance Videos:

Wide-Area Coverage: UAVs can cover expansive areas swiftly and efficiently, providing comprehensive surveillance footage of both urban and remote locations.

Real-Time Monitoring: The agility and maneuverability of UAVs allow for real-time monitoring, enabling prompt responses to unfolding events or emergencies.

Anomaly Detection: Surveillance videos captured by UAVs facilitate the detection of anomalies or suspicious activities, aiding in the identification of potential threats.

Cost-Effective: Compared to traditional manned surveillance methods, UAV systems offer a cost-effective solution for continuous monitoring and reconnaissance.

Versatility: UAVs can be deployed in various environments and conditions, including disaster zones, border security, and infrastructure inspections, enhancing their versatility for surveillance applications.

Challenges and Solutions:

Data Overload: The sheer volume of surveillance videos generated by UAV systems can overwhelm analysts. Implementing advanced video analytics and machine learning algorithms can automate the process of video analysis, enabling efficient extraction of actionable insights.

Data Security and Privacy Concerns: UAV surveillance raises concerns regarding data privacy and security. Establishing robust protocols for data encryption, access control, and compliance with regulatory frameworks is essential to address these concerns and maintain public trust.

Environmental Factors: Adverse weather conditions, such as strong winds or fog, can affect UAV operations and degrade video quality. Investing in robust UAV platforms with weather-resistant capabilities and sensor technologies can mitigate these challenges.

Future Directions:

Integration of AI and Machine Learning: Continued advancements in AI and machine learning will enhance the capabilities of UAV surveillance systems, enabling automated detection of complex activities and behaviors.

Multimodal Data Fusion: Integrating data from multiple sensors, including visual, thermal, and LiDAR, will enrich the analysis of surveillance videos, providing multidimensional insights for enhanced situational understanding.

Collaborative UAV Networks: Developing collaborative UAV networks that can seamlessly share information and coordinate surveillance tasks will further optimize resource allocation and response capabilities.

UAV surveillance videos represent a powerful tool for enhancing situational awareness, threat detection, and decision-making in diverse operational contexts. Addressing challenges such as data overload, privacy concerns, and environmental factors requires interdisciplinary efforts and technological innovations. By harnessing the full potential of UAV systems and leveraging emerging technologies, we can unlock new opportunities for effective surveillance and security operations.

3. Proposed Methodology of Human Anomaly Detection System Videos Using unmanned Aerial Vehicle System Results Analysis:

The proposed method for detecting human anomalies in video surveillance utilizes a novel NFMF-DBiLSTM model. Here's an overview of the critical steps outlined in the paper. Figure 1 serves as a visual representation of the proposed scheme for human anomaly detection in video surveillance. Block diagrams like these are valuable tools for understanding the flow of information and processing steps within a complex system. They provide a clear and concise overview of how different components interact and contribute to the overall functionality of the method. Figure 1 depicts the sequence of operations from video input to anomaly classification. Each block in the diagram likely represents a specific processing step or component, such as video preprocessing, feature extraction, feature selection, and classification.

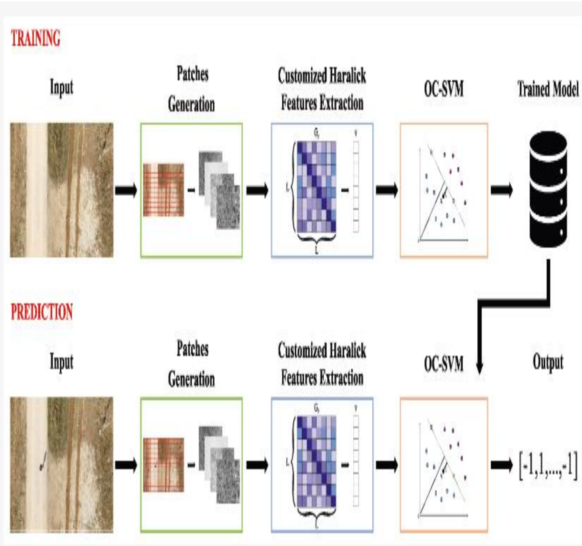

Fig 1: Block diagram of the proposed methodology

3.1 Video to Frames Conversion: The process begins by converting videos into individual frames to facilitate analysis.

3.2 Preprocessing Steps: Several preprocessing steps are performed on the frames, including contrast enhancement, background subtraction, and clustering. These steps help enhance the frames' quality and isolate relevant information.

3.3 Feature Extraction and Selection: After preprocessing, features are extracted from the frames. These features capture essential characteristics relevant to anomaly detection. A feature selection process is employed to choose the most discriminative features for the classification task.

3.4 Classification: The selected features are then fed into the NFMF-DBiLSTM model for classification. This model leverages bidirectional long short-term memory (BiLSTM) networks, enhanced with the novel Newton Form and Monotonic Function elements, to classify frames as standard or anomalous.

4. Results and Description

Here, the performance of the proposed technique is evaluated and analogized with that of the prevailing methods. The proposed human AD system is employed in PYTHON's working platform.

4.1. Performance analysis of enhancement

The work presents a novel lightweight method for anomaly detection in low-altitude aerial images, focusing on textural features and One-Class SVM for real-time capabilities. Input frames are converted to grayscale and divided into patches in the Grayscale conversion and patch splitting. GLCMs (Gray-Level Co-occurrence Matrices) are extracted from these patches to derive textural statistics. One-Class SVM is employed to detect anomalies in the input using these statistics. A discretized circumference is introduced to capture displacements along all directions simultaneously and is achieved intrinsically via the chosen pattern in the discretized circumference.

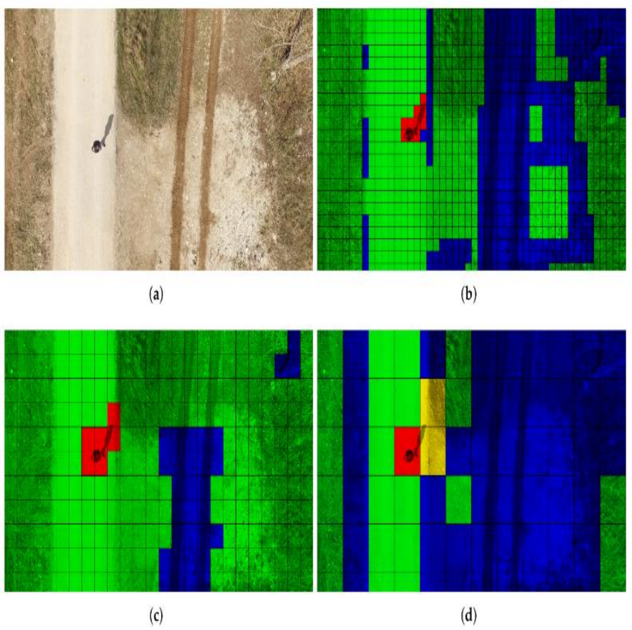

Fig 2: Output generated using different patch sizes. The red and green patches indicate anomalous and normal patches correctly classified. Blue patches correspond to regular patches classified as anomalies. Yellow patches represent abnormal patches classified as usual.

It is also developed to correctly handle the proposed spatial relationship and extract meaningful patch characteristics. Experiments were conducted on the UMCD dataset to assess the system's performance. These parameters were found to be crucial for achieving satisfactory performance. The system can achieve 100% precision with a reasonable recall trade-off, reaching a 71.23% recall score. Overall, the presented approach demonstrates effectiveness in anomaly detection via textures, particularly in low-altitude aerial images, with real-time capabilities and lightweight implementation. A new spatial relationship is introduced, represented by a discretized circumference. This circumference considers displacements along all directions, improving patch representation and ensuring rotation invariance. Generalized equations are developed to accurately compute Haralick's textural features within the proposed spatial relationship. Experiments are conducted on the UMCD dataset, a public dataset, to assess the system's performance. Different patch sizes and circumferences with varying radii are evaluated. Overall, this method offers a promising approach to anomaly detection in low-altitude aerial images by leveraging textural features and machine learning techniques, with specific enhancements to traditional methods to improve performance.

Figure 2 illustrates the performance of different patch sizes in anomaly detection. These patches do not miss anomalies in the input but exhibit more false positives. False positives are particularly evident on vehicle tracks and grass due to substantial contrast with the terrain texture and illumination variation, causing darker areas. Employing a wider patch leads to classification errors for both standard and abnormal patches. Uninformative statistics are extracted from the GLCM, resulting in more false positives and negatives. Smaller patches are preferred for surveillance scenarios where detecting anomalies is crucial. This size maximizes system precision while maintaining a minor recall trade-off that is more than that of other sizes. In summary, the medium-sized patch balances detecting anomalies and minimizing false positives and negatives, making it the most suitable choice for the UMCD dataset and similar surveillance applications.

5. Conclusion

This work introduces a novel, lightweight approach capable of real-time anomaly detection in low-altitude aerial images. Input frames are converted to grayscale. The images are then divided into patches to facilitate analysis. GLCMs (Gray-Level Co-occurrence Matrices) are extracted from the patches. Textural statistics are derived from the GLCMs, providing representations of the patches. An OC-SVM (One-Class Support Vector Machine) is utilized to detect anomalies in the input based on the extracted textural statistics. Traditional Haralick textural features, which are based on single offset displacements, are enhanced. The experiments conducted on the UMCD dataset provide valuable insights into the effectiveness of the proposed approach under various conditions. The absence of existing methods addressing anomaly detection via textures on the UMCD dataset underscores the novelty of this work. To evaluate its effectiveness, a comparison was made with baseline Haralick textural features using single displacements. Patch size and circumference radius were identified as crucial components for achieving satisfactory performance, particularly in security applications where detecting anomalies is paramount.

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