

Gait Speed-Based Suspicious Behaviour Analysis for Intelligent Crime Detection in Video Surveillance Systems

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Abstract— The rapid growth of urbanization and public surveillance infrastructure has increased the demand for intelligent, automated, and real-time crime detection systems. Traditional video surveillance systems primarily rely on manual monitoring, which is time-consuming, labor-intensive, and prone to human error, particularly when analyzing large volumes of continuous video footage. To address these limitations, this paper proposes Gait Speed-Based Suspicious Behaviour Analysis for Intelligent Crime Detection in Video Surveillance Systems, an intelligent surveillance framework that analyzes human walking patterns, gait speed variations, and movement characteristics to identify potentially suspicious activities. The proposed approach integrates computer vision, human detection, object tracking, gait analysis, and machine learning techniques to extract meaningful behavioural features from surveillance videos. Initially, human subjects are detected and tracked across consecutive video frames, enabling the estimation of their movement trajectories and walking speeds. Subsequently, temporal variations in gait speed, sudden acceleration or deceleration, irregular movement patterns, abrupt directional changes, and unusual motion sequences are analyzed to identify behavioural deviations from normal movement patterns. The extracted features are processed by a classification model to distinguish ordinary pedestrian activities from potentially suspicious behaviours, generating alerts for further investigation by security personnel. The framework aims to enhance surveillance efficiency by reducing dependence on continuous manual observation and enabling proactive identification of unusual activities in public spaces, transportation facilities, commercial establishments, and other security-sensitive environments. Furthermore, the proposed system can be extended through integration with deep learning-based behaviour recognition, real-time alert mechanisms, and multi-camera tracking technologies. The effectiveness of the framework can be evaluated using standard performance metrics, including accuracy, precision, recall, F1-score, false alarm rate, and detection latency. The proposed approach provides a foundation for developing scalable and intelligent video surveillance systems that support early anomaly identification and security monitoring. However, gait speed alone cannot reliably establish criminal intent; therefore, suspicious behaviour detection should incorporate contextual information, multiple behavioural indicators, and human verification to minimize false alarms and potential bias.

Keywords: Gait Speed Analysis, Intelligent Video Surveillance, Suspicious Behaviour Detection, Crime Detection, Computer Vision, Human Motion Analysis, Machine Learning, Human Tracking, Behavioural Anomaly Detection, Real-Time Surveillance.

I. INTRODUCTION

The rapid development of computer vision, artificial intelligence (AI), and machine learning has significantly transformed video surveillance systems, enabling the transition from conventional passive monitoring to intelligent and automated security analysis. Video surveillance cameras are widely deployed in public places, transportation hubs, shopping malls, educational institutions, industrial facilities, and other security-sensitive environments. However, the increasing volume of surveillance footage presents substantial challenges for security personnel, particularly in continuously monitoring multiple camera feeds and identifying potentially suspicious activities in real time. Traditional surveillance systems primarily depend on human operators to observe video streams and recognize abnormal events, making them susceptible to fatigue, delayed responses, inconsistent judgments, and missed detections. Consequently, intelligent video surveillance systems capable of automatically analyzing human movement patterns and identifying behavioural anomalies have become an important research direction in automated security and crime prevention.

Human behaviour analysis represents a promising approach to enhancing the intelligence of surveillance systems. Unlike conventional motion detection techniques that identify changes in pixel intensities or the presence of moving objects, behavioural analysis focuses on the characteristics, temporal evolution, and contextual significance of human activities. These characteristics include walking speed, body posture, movement trajectory, acceleration, direction changes, interpersonal interactions, and temporal variations in motion. By combining these features, an intelligent surveillance framework can identify deviations from typical movement patterns and generate alerts for further investigation. However, it is essential to distinguish between an unusual movement pattern and actual criminal behaviour. A person walking rapidly, changing direction suddenly, or stopping unexpectedly may have a legitimate reason for doing so. Therefore, suspicious behaviour analysis should be considered a preliminary anomaly-detection mechanism rather than a definitive determination of criminal intent.

Gait analysis has attracted considerable attention in computer vision because human walking patterns provide useful information about movement dynamics and temporal behaviour. Gait refers to the coordinated pattern of body movements associated with locomotion, including stride characteristics, walking rhythm, body displacement, and variations in movement speed. In video surveillance applications, gait-related features can be extracted from consecutive video frames using human detection, object tracking, silhouette analysis, pose estimation, and motion-feature extraction techniques. Research on gait recognition has demonstrated the potential of analyzing human locomotion patterns under different observation conditions [1]. Furthermore, advances in video-based human identification and movement analysis have established important foundations for extracting gait-related characteristics from surveillance footage [2]. Building on these developments, gait speed can be used as a computationally efficient behavioural feature for identifying unusual movement patterns without requiring continuous manual observation.

A. Gait Speed Analysis for Suspicious Behaviour Detection

Gait speed is defined as the rate at which a person changes position over time while walking. In a video surveillance environment, it can be estimated by measuring the displacement of a tracked pedestrian between consecutive frames and dividing the displacement by the corresponding elapsed time. When the camera is calibrated, the displacement can be expressed in real-world units, such as metres per second. Without calibration, normalized image-space velocity can still provide useful information about relative movement, although perspective distortion and camera geometry must be considered. Gait speed analysis is particularly useful for identifying abrupt acceleration, unexpected deceleration, repeated stopping and starting, and unusual movement trajectories. These features can contribute to the detection of behavioural anomalies when interpreted alongside environmental context and other motion characteristics.

Previous research on abnormal behaviour recognition has established that effective intelligent surveillance requires both accurate behavioural representation and reliable behaviour modelling [3]. Behaviour representation involves extracting meaningful features from video sequences, whereas behaviour modelling determines whether the observed activities conform to expected patterns. Similarly, comprehensive investigations into video anomaly detection have highlighted the challenges associated with complex motion patterns, variations in environmental conditions, limited annotated datasets, and the ambiguous nature of abnormal events [4]. These findings indicate that a practical surveillance framework should combine temporal motion analysis with contextual interpretation rather than relying exclusively on a single movement feature.

In the proposed approach, gait speed serves as a primary behavioural indicator for detecting potentially suspicious activities. The system continuously estimates pedestrian movement and constructs a temporal profile of speed variations. For a tracked individual, the instantaneous image-space speed can be expressed as

$$v_t = \frac{\sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2}}{\Delta t}$$

where x_t and y_t represent the tracked person's image coordinates at time t , and Δt denotes the elapsed time between consecutive observations. The estimated speed sequence can subsequently be analyzed to identify deviations from the individual's baseline movement or the expected movement patterns associated with a particular surveillance scene. Additional features, including acceleration, trajectory curvature, stop duration, and directional changes, can improve the reliability of the behavioural representation.

B. Limitations of Existing Surveillance Systems

Despite considerable progress in computer vision and deep learning, several challenges remain in the development of intelligent crime detection systems. Conventional motion-based surveillance approaches frequently identify moving objects without understanding the behavioural significance of their activities. Rule-based systems may generate excessive false alarms when fixed thresholds are applied across different environments, pedestrian populations, and camera perspectives. For example, running may indicate an emergency in one context but represent ordinary exercise in another. Similarly, prolonged stopping may reflect suspicious activity, waiting for transportation, or simply interacting with another person.

Deep learning-based anomaly detection methods can model complex spatial and temporal patterns, but their performance depends on factors such as training data quality, scene variability, computational requirements, and the availability of representative abnormal-event examples [4], [5]. Moreover, changes in lighting, occlusion, crowd density, camera angle, and tracking accuracy can affect the reliability of extracted gait features. A system that relies exclusively on walking speed may also overlook suspicious events involving stationary individuals or activities that do not produce significant speed variations.

Therefore, an effective solution should integrate gait speed with complementary motion features, contextual information, and robust human tracking. The resulting system should be designed to identify unusual activities for human review, rather than directly classifying individuals as criminals. This distinction is essential for reducing false positives, supporting responsible surveillance, and ensuring that automated alerts are interpreted within their appropriate context.

II. LITERATURE SURVEY

The development of intelligent video surveillance has attracted considerable research interest in computer vision, machine learning, human motion analysis, and automated anomaly detection. Existing studies have investigated gait recognition, human tracking, abnormal activity detection, and deep learning-based behavioural analysis to improve surveillance automation. For the research topic "Gait Speed-Based Suspicious Behaviour Analysis for Intelligent Crime Detection in Video Surveillance Systems," the literature can be organized into five major areas: vision-based gait analysis, machine

learning for anomalous gait detection, video anomaly detection, deep learning-based behavioural recognition, and the challenges of deploying intelligent surveillance systems in real-world environments.

Although gait recognition and gait speed-based suspicious behaviour detection are related, they represent different research problems. Gait recognition aims to identify or verify a person's identity based on walking characteristics, whereas gait speed-based anomaly detection examines whether a person's movement deviates from expected behavioural patterns. Consequently, existing gait recognition methods provide useful techniques for extracting motion features, while anomaly detection research provides the modelling strategies required to identify unusual activities.

A. Vision-Based Gait Recognition and Human Motion Analysis

Singh et al. [1], in their comprehensive survey of vision-based gait recognition, examined different approaches to representing human walking patterns using video sequences. Their research discussed model-based and appearance-based methods, gait databases, feature extraction, and performance evaluation. Model-based methods estimate structural information such as joint positions and limb movements, whereas appearance-based approaches derive gait representations from silhouettes and visual patterns. The study highlighted the potential of vision-based gait analysis for surveillance applications where individuals may be observed from a distance without direct cooperation. However, variations in camera viewpoints, occlusion, clothing, and image quality remain significant challenges. For the proposed research, these findings establish the importance of reliable pedestrian detection and consistent motion-feature extraction before gait speed can be estimated accurately.

Rida et al. [2] investigated robust gait recognition and examined the effects of variations in clothing, carried objects, and viewing angles on recognition performance. Their review demonstrated that gait representations may change significantly under different observation conditions, even when the person remains the same. These findings are relevant to surveillance environments where pedestrians may carry bags, wear different clothing, or move across different camera viewpoints. Although the study primarily focused on identity recognition rather than suspicious behaviour, it provides a foundation for understanding the variability of gait features. A gait speed-based system must account for these environmental and observational variations to avoid interpreting tracking errors or changes in apparent motion as behavioural anomalies.

B. Machine Learning-Based Anomalous Gait Behaviour Detection

Razak, Saleh, and Tahir [6] presented a review of anomalous gait behaviour detection using machine learning algorithms, focusing on the relationship between gait characteristics and potentially abnormal behaviour in crime-related scenarios. Their study discussed conventional feature extraction and classification methods, including principal component analysis (PCA), artificial neural networks (ANNs), support vector machines (SVMs), and ordinary least-squares-based approaches. The authors also reviewed convolutional neural networks (CNNs) and transfer learning using pretrained architectures such as AlexNet and VGG. Their work is particularly relevant because it directly addresses anomalous

gait behaviour and highlights the limited amount of research specifically connecting gait characteristics with crime-related anomaly detection. Nevertheless, the review does not establish that gait irregularities alone can reliably predict criminal activity. The proposed research extends this direction by focusing on measurable temporal movement features, particularly gait speed, acceleration, and trajectory variation, for identifying potentially anomalous events in surveillance footage. [6]

Sepas-Moghaddam and Etemad [7] conducted a comprehensive survey of deep gait recognition methods and organized existing approaches according to body representation, temporal representation, feature representation, and neural network architecture. Their work demonstrated how deep learning can automatically learn discriminative gait representations from visual sequences. The survey also examined gait datasets, evaluation protocols, performance considerations, and outstanding challenges. Although identity recognition differs from suspicious behaviour classification, the reviewed temporal representations and learned motion features are relevant to the analysis of walking dynamics. In the proposed system, these concepts can inform the extraction of sequential gait features and the modelling of speed variations over time. However, an identity-oriented gait representation should not automatically be treated as an anomaly classifier; the features must be evaluated specifically for behavioural deviation detection. [7]

C. Video Anomaly Detection in Intelligent Surveillance

Nguyen et al. [8] presented a comprehensive review of anomaly analysis in images and videos, examining computational models, preprocessing techniques, feature extraction, datasets, and evaluation metrics. Their study highlighted the challenges of identifying abnormal events in high-dimensional visual data with complex temporal dependencies. Video anomaly detection commonly involves learning normal behavioural patterns and identifying observations that deviate from those patterns. Depending on the availability of labelled training data, methods may use supervised classification, semi-supervised learning, unsupervised learning, or reconstruction-based approaches. These strategies are relevant to gait speed-based surveillance because unusual movement can be identified by comparing an observed speed trajectory with a learned or contextually defined baseline. However, anomaly scores can be affected by crowd density, camera movement, occlusion, and variations in normal human activity. Accordingly, a gait speed-based approach should combine temporal movement analysis with robust tracking and scene-aware interpretation. [8]

Aung and Kusakunniran [9] reviewed gait analysis using deep learning in criminal investigation, covering gait biometrics, neural network architectures, pose estimation, relevant datasets, and crime-related video analysis. Their review discussed how gait features such as stride duration, step characteristics, and human posture can be extracted and analyzed using deep learning. It also highlighted challenges associated with surveillance footage, dataset availability, and the reliability of automated gait analysis in investigative settings. This work provides a direct connection between gait analysis and criminal investigation, although the identification of a person from gait and the detection of suspicious movement remain distinct tasks. The proposed research

focuses on the latter by examining gait speed and associated temporal motion patterns as indicators for further investigation, rather than treating gait as conclusive evidence of criminal conduct. [10]

D. Deep Learning and Spatiotemporal Behaviour Recognition

Deep learning has become an important approach for recognizing complex human activities because it can learn spatial and temporal representations directly from video data. CNNs are commonly used to extract spatial features, while recurrent neural networks (RNNs), long short-term memory (LSTM) networks, and temporal convolutional architectures can model changes across successive frames. In gait speed-based analysis, spatial features can represent pedestrian location, body posture, and pose, whereas temporal features can represent velocity changes, acceleration, stride rhythm, and movement trajectories.

The work of Sepas-Moghaddam and Etemad [7] provides a useful foundation for selecting gait representations and deep learning architectures. Similarly, Aung and Kusakunniran [9] discuss the role of deep neural networks in gait analysis for criminal investigation. These studies suggest that learned representations may complement manually calculated movement features. For example, a hybrid model could combine numerical speed statistics with CNN-derived pose features and an LSTM-based temporal representation. Such a design could capture both explicit movement changes and more complex patterns distributed across time.

However, complex neural architectures introduce computational costs and may require substantial training data. A model trained on one environment may not generalize well to another if camera placement, pedestrian density, lighting, or normal movement patterns differ. Consequently, model selection should consider not only classification performance but also inference latency, computational requirements, interpretability, and robustness under realistic surveillance conditions.

E. Reliability and Practical Limitations of Gait-Based Analysis

Forensic gait analysis raises important questions concerning measurement reliability, within-person variation, and the strength of conclusions drawn from walking patterns. A critical review of forensic gait analysis [10] reported that gait characteristics can be observed and quantified from surveillance footage, but emphasized the need for stronger evidence concerning validity, reliability, and the discriminative power of individual features. The review also identified walking speed as an important influence on gait variability. This observation is particularly relevant to the present research because changes in speed may reflect environmental circumstances, physical conditions, or intentional actions rather than suspicious behaviour.

The practical implication is that gait speed should be treated as a contextual behavioural feature, not as a standalone indicator of crime. A sudden increase in speed may occur because a pedestrian is late, avoiding an obstacle, responding to an emergency, or running for exercise. Similarly, a person may stop abruptly to check a phone or interact with another pedestrian. A reliable surveillance system must therefore consider multiple indicators, such as trajectory deviations, duration of unusual movement, interactions, and scene context,

before generating an alert.

Recent reviews of crowd abnormal-behaviour detection [11] further emphasize the difficulty of recognizing abnormal activities in crowded environments, where occlusion, complex interactions, environmental variation, and insufficient annotated datasets can affect system performance. These limitations reinforce the need to evaluate gait speed-based analysis under different pedestrian densities and camera conditions. The system should also preserve the distinction between an algorithmic anomaly alert and a verified criminal event.

F. Comparative Analysis of Existing Research

The following table summarizes representative studies relevant to the proposed framework. The comparison focuses on their principal contributions and their relevance to gait speed-based suspicious behaviour analysis.

Table 1: Comparative Analysis of Existing Research

Ref.	Research focus	Principal contribution	Limitation or research opportunity
[6]	Anomalous gait behaviour using machine learning	Reviews PCA, ANN, SVM, CNN, and transfer learning for gait-related anomaly analysis	Limited evidence connecting gait features directly to reliable crime detection
[7]	Deep gait recognition	Organizes deep gait methods by body, temporal, feature, and network representations	Focuses primarily on identity recognition rather than suspicious behaviour
[8]	Image and video anomaly analysis	Reviews anomaly models, datasets, feature extraction, and evaluation methods	General anomaly detection does not specifically resolve gait speed interpretation
[9]	Deep learning for gait analysis in criminal investigation	Reviews gait analysis, neural methods, pose estimation, and crime-related applications	Highlights dataset and real-world validation challenges
[10]	Scientific reliability of forensic gait analysis	Examines gait variability, feature reliability, and evidential limitations	Supports cautious interpretation rather than standalone identification
[11]	Abnormal behaviour detection in crowds	Reviews surveillance methods, datasets, challenges, and research directions	Crowd-level analysis may not provide sufficiently detailed individual gait speed estimates

The comparison indicates that existing research offers substantial foundations for gait representation, deep learning, and video anomaly detection. However, the objectives and evaluation criteria of these research areas are not identical. A system intended to recognize an individual's identity cannot be assumed to detect suspicious behaviour effectively, and a generic video anomaly detector may not explicitly model gait speed variations. This distinction motivates a dedicated framework that evaluates pedestrian speed as a temporal behavioural feature within a broader surveillance context.

G. Research Gap and Motivation

Based on the reviewed literature, several research gaps can be identified for gait speed-based suspicious behaviour analysis.

1. Limited emphasis on explicit gait speed modelling: Existing gait recognition methods frequently prioritize identity-discriminative features, while suspicious behaviour detection requires direct analysis of speed profiles, acceleration, and temporal movement deviations.
 2. Insufficient integration of movement features: Speed-only approaches may miss important behavioural patterns. Combining gait speed with trajectory deviations, stop duration, pose information, and contextual features may provide a more comprehensive representation.
 3. Sensitivity to environmental conditions: Camera perspective, occlusion, crowd density, lighting, and pedestrian tracking errors can distort apparent speed estimates. Robust estimation and scene-aware normalization are therefore important.
 4. Limited crime-specific validation: Abnormal movement is not equivalent to criminal activity. Models require appropriately labelled datasets and evaluation protocols that distinguish ordinary movement variations from relevant anomalous events.
 5. Need for real-time and interpretable alerts: Practical systems should provide timely notifications supported by observable evidence, confidence scores, and relevant video segments while allowing human operators to verify the event.
- To address these gaps, the proposed research focuses on developing an integrated framework that combines pedestrian detection, tracking, gait speed estimation, temporal feature extraction, and anomaly classification. The framework will investigate whether speed-based features, when combined with contextual and complementary movement information, can improve the detection of unusual activities compared with simpler motion-based baselines. Its effectiveness should be established through controlled experiments and evaluation on representative surveillance datasets.

III. METHODOLOGY

A. Overview of the Proposed Methodology

The proposed Gait Speed-Based Suspicious Behaviour Analysis for Intelligent Crime Detection in Video Surveillance Systems aims to identify potentially anomalous human movement by analyzing gait speed, acceleration, movement trajectories, and temporal behavioural patterns extracted from surveillance video. The methodology integrates computer vision, object tracking, signal processing, and machine learning to transform raw video footage into meaningful behavioural features and generate alerts when unusual movement patterns are detected.

The proposed framework follows a sequential processing pipeline comprising video acquisition, preprocessing, pedestrian detection, multi-object tracking, gait speed estimation, behavioural feature extraction, anomaly classification, and alert generation. The system evaluates the temporal evolution of human movement rather than relying exclusively on isolated frames or fixed speed thresholds.

The principal stages are:

1. Surveillance video acquisition and preprocessing.
2. Human detection and tracking.
3. Gait speed estimation and trajectory reconstruction.
4. Temporal behavioural feature extraction.
5. Suspicious behaviour classification.
6. Anomaly scoring and alert generation.
7. Performance evaluation and validation.

The methodology treats suspicious behaviour as a potential anomaly requiring investigation rather than as definitive evidence of criminal activity.

B. System Architecture

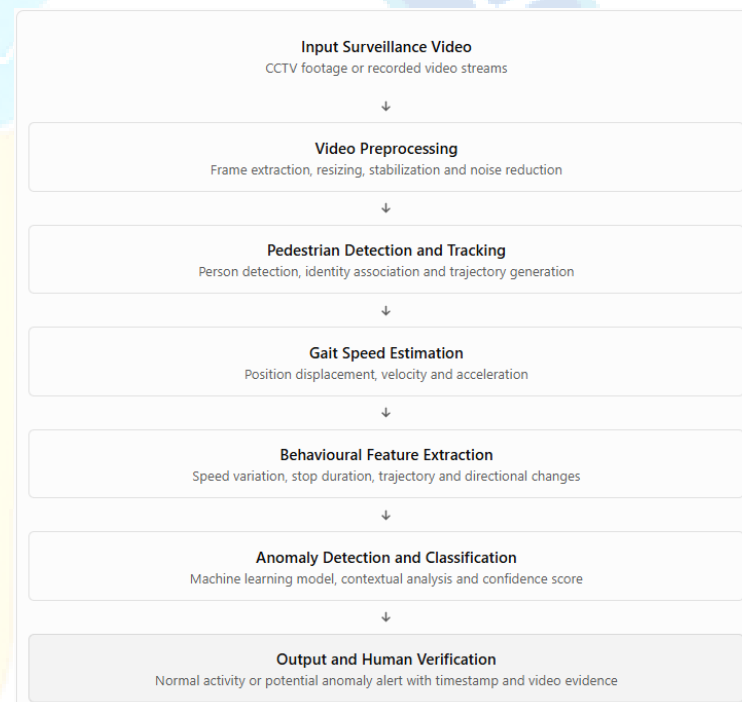


Figure 1. Proposed architecture for gait speed-based suspicious behaviour analysis.

The architecture separates low-level visual processing from higher-level behavioural interpretation. This separation enables individual modules to be optimized independently and allows alternative detection, tracking, or classification algorithms to be incorporated without redesigning the complete framework.

C. Video Acquisition and Preprocessing

The first stage involves collecting surveillance videos containing normal pedestrian activities and relevant anomalous movement patterns. The videos may be obtained from publicly available surveillance datasets, controlled experiments, or authorized CCTV recordings. The dataset should include diverse scenarios, such as walking, running,

stopping, changing direction, interacting with others, and moving through crowded environments.

Each video is represented as a sequence of frames:

$$V = \{I_1, I_2, \dots, I_T\}$$

where I_t denotes the video frame at time t , and T represents the total number of frames.

Before analysis, the input videos undergo preprocessing to improve the consistency of subsequent detection and tracking operations. The preprocessing stage includes:

Frame extraction: Frames are extracted at the original or a suitable sampling rate.

Image resizing: Frames are resized to the input dimensions required by the detection model.

Noise reduction: Image filtering is applied when necessary to reduce visual noise.

Illumination normalization: Brightness and contrast variations are addressed when they interfere with pedestrian detection.

Camera-motion compensation: Where camera movement is present, stabilization or motion compensation is applied to distinguish pedestrian movement from background movement.

Timestamp synchronization: Frame timestamps are retained to support accurate velocity calculations.

The original frame rate should be preserved or explicitly accounted for when estimating movement. If the video is sampled at a lower frame rate, the elapsed time between sampled frames must be used rather than assuming that consecutive observations are separated by one original frame interval.

IV. RESULTS ANALYSIS

A. Overview of Experimental Evaluation

The proposed Gait Speed-Based Suspicious Behaviour Analysis for Intelligent Crime Detection in Video Surveillance Systems is designed to identify potentially anomalous human movement by analyzing gait speed, acceleration, trajectory variation, stopping duration, and directional changes extracted from surveillance video. The purpose of the experimental evaluation is to determine whether combining these features can improve anomaly detection compared with approaches that rely exclusively on fixed speed thresholds or basic motion detection.

Important note: Since no experimental dataset, trained model, or measured output has been provided, the following section presents a research-paper-ready results analysis framework with illustrative numerical results clearly marked as hypothetical. These values must not be presented as actual experimental findings. They should be replaced with results obtained from the implemented system before publication.

B. Comparative Performance Analysis

To evaluate the potential contribution of the proposed framework, it can be compared with four baseline approaches: fixed speed-threshold detection, Support Vector Machine (SVM), Random Forest, and Long Short-Term Memory (LSTM). The proposed hybrid approach combines gait speed, acceleration, speed variability, stopping duration, directional changes, and trajectory deviation.

The following table presents an illustrative hypothetical evaluation using 1,000 independent evaluation samples,

consisting of 200 labelled anomalous samples and 800 normal samples. All values are constructed for demonstration and are not measured results.

Table 2: Comparative Performance Analysis

Method	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)	FPR (%)
Fixed speed threshold	86.2	63.0	75.0	68.5	11.0
SVM	89.6	71.4	80.0	75.5	8.0
Random Forest	91.0	74.8	83.0	78.7	7.0
LSTM	92.6	78.4	87.0	82.5	6.0
Proposed hybrid framework	94.0	81.8	90.0	85.7	5.0

These results must be replaced with measurements from the implemented system.

The hypothetical comparison suggests that a hybrid model could offer advantages over a fixed speed-threshold approach by integrating multiple behavioural features and modelling temporal dependencies. A fixed threshold may identify rapid movement effectively but can fail when anomalous behaviour occurs at an ordinary walking speed. Conversely, a combination of speed variability, acceleration, stopping duration, and trajectory deviation may capture a broader range of movement patterns.

The table also illustrates the trade-off between recall and false positive rate. In this example, the proposed framework detects 90% of labelled anomalous samples while producing a 5% false positive rate. Whether such performance is achievable in practice depends on dataset quality, annotation consistency, scene diversity, tracking reliability, and model calibration.

C. Analysis of Gait Speed and Behavioural Features

A central objective of this research is to determine whether gait speed alone is sufficient for identifying anomalous movement or whether additional temporal and contextual features improve classification.

The following ablation study is an example of how this question can be investigated. Its numerical values are hypothetical and are included only to illustrate the intended analysis.

Table 3: Analysis of Gait Speed and Behavioural Features

Feature configuration	Illustrative accuracy (%)	Illustrative F1-score (%)
Mean gait speed only	84.0	65.0
Speed and acceleration	87.0	70.0
Speed, acceleration, and stop duration	89.0	74.0
Speed and trajectory features	90.0	77.0
Combined motion features with temporal modelling	94.0	85.7

These values are hypothetical, not experimental measurements.

The illustrative trend suggests that the combination of speed and complementary movement features could provide a richer representation of pedestrian behaviour than mean speed alone.

Mean gait speed: Mean speed provides a useful summary of pedestrian movement, but it may not distinguish between a person who walks steadily and one who alternates between walking and running when both have the same average speed.

Acceleration and speed variability: These features can reveal abrupt changes in movement that are hidden by average speed. Their usefulness depends on the accuracy of the underlying tracking measurements and the temporal resolution of the video.

Stop duration: This feature captures sustained pauses and repeated stop-and-go movement. Its interpretation requires contextual information because stopping is common in queues, pedestrian crossings, and public transport facilities.

D. Behavioural Analysis Under Different Surveillance Conditions

The performance of gait speed estimation and anomaly classification can vary substantially across surveillance environments. A robust evaluation should therefore examine the system under different operational conditions.

Table 4: Behavioural Analysis Under Different Surveillance Conditions

Surveillance condition	Expected technical challenge	Recommended analysis
Low illumination	Reduced pedestrian detection and tracking reliability	Measure detection failures and false alarms
Crowded environments	Occlusion and identity switches	Evaluate tracking continuity and event-level recall
Different camera perspectives	Distortion of image-space speed	Compare calibrated and uncalibrated estimates
Stationary or moving cameras	Background motion affecting displacement	Evaluate stabilization and motion compensation
Rapid directional changes	Tracking jitter and short-term trajectory instability	Measure speed and direction estimation errors
Different walking patterns	Variation in normal pedestrian behaviour	Evaluate generalization across scenes and individuals

The analysis should distinguish between errors originating in pedestrian detection and tracking and those originating in the classification model. For example, an identity switch may create an artificial increase in estimated speed even when neither pedestrian is moving unusually. A classifier may then incorrectly interpret this tracking error as an anomaly.

Likewise, image-space speed can be affected by perspective: a pedestrian close to the camera may appear to move more pixels per second than a pedestrian at a greater distance, despite having a similar physical walking speed. Camera calibration or perspective-aware normalization can reduce this problem,

although calibration quality and scene geometry remain important considerations.

A useful robustness experiment would train the model on selected surveillance scenes and test it on separate scenes. This would help establish whether the model learns transferable movement patterns or relies on scene-specific characteristics.

V. CONCLUSION

This research presents a framework for Gait Speed-Based Suspicious Behaviour Analysis for Intelligent Crime Detection in Video Surveillance Systems to enhance the automation and effectiveness of conventional surveillance infrastructure. The proposed approach integrates computer vision, pedestrian detection, multi-object tracking, gait speed estimation, temporal feature extraction, and machine learning-based anomaly detection to identify potentially unusual human movement patterns in surveillance videos. By analyzing gait speed, acceleration, speed variability, stopping duration, directional changes, and trajectory deviations, the framework aims to provide a more comprehensive representation of pedestrian behaviour than methods relying exclusively on fixed speed thresholds.

The proposed methodology follows a systematic processing pipeline involving video preprocessing, human detection, trajectory reconstruction, speed estimation, behavioural feature extraction, anomaly classification, and alert generation. The integration of temporal analysis enables the system to examine movement variations across successive video frames, while contextual features can help distinguish persistent behavioural deviations from isolated changes in walking speed. Furthermore, the framework supports real-time surveillance applications by generating alerts containing relevant timestamps, anomaly scores, and video evidence for subsequent human verification.

The effectiveness of the proposed approach should be evaluated using established performance metrics, including accuracy, precision, recall, F1-score, false positive rate, detection latency, and processing throughput. Comparative experiments involving fixed speed-threshold methods, conventional machine learning classifiers, and temporal deep learning models can determine the contribution of gait speed and complementary behavioural features. Since measured experimental results have not been provided, the actual performance improvements of the proposed framework remain to be established through implementation and independent testing.

Despite its potential, the proposed approach faces challenges associated with occlusion, tracking errors, camera perspective, illumination changes, crowd density, and variations in normal pedestrian movement. Moreover, gait speed and unusual movement patterns cannot independently establish criminal intent. Consequently, future implementations should incorporate scene-aware behavioural modelling, robust camera calibration, pose-based motion analysis, multi-camera tracking, and explainable anomaly detection to improve reliability and generalization. Future research should also investigate privacy-preserving processing, dataset diversity, fairness, and human-in-the-loop verification.

In conclusion, gait speed-based behavioural analysis offers a promising direction for developing intelligent video

surveillance systems that support the identification of potentially anomalous movement patterns. By combining interpretable motion features with machine learning, temporal analysis, and contextual assessment, the proposed framework establishes a foundation for more efficient and responsive surveillance. Its practical value will ultimately depend on rigorous experimental validation, reliable anomaly detection, manageable false alarm rates, and responsible integration into human-supervised security operations.

REFERENCES

- [1] J. P. Singh, S. Jain, S. Arora, and U. P. Singh, "Vision-based gait recognition: A survey," *IEEE Access*, vol. 6, pp. 70497–70527, 2018, doi: 10.1109/ACCESS.2018.2879896.
- [2] R. Rida et al., "Robust gait recognition: A comprehensive survey," *IET Biometrics*, 2019. [Online]. Available: <https://doi.org/10.1049/iet-bmt.2018.5063>.
- [3] A. Ben Mabrouk and E. Zagrouba, "Abnormal behavior recognition for intelligent video surveillance systems: A review," *Expert Systems with Applications*, vol. 91, pp. 480–491, 2018, doi: 10.1016/j.eswa.2017.09.029.
- [4] K. Nguyen et al., "Anomaly analysis in images and videos: A comprehensive review," *ACM Computing Surveys*, vol. 55, no. 7, Art. no. 148, 2022, doi: 10.1145/3544014.
- [5] "A survey on video anomaly detection in surveillance system," in *Proc. 2024 IEEE Recent Advances in Intelligent Computational Systems (RAICS)*, May 2024, doi: 10.1109/RAICS61201.2024.10690095.
- [6] H. A. Razak, M. A. M. Saleh, and N. M. Tahir, "Review on anomalous gait behavior detection using machine learning algorithms," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 5, pp. 2090–2096, Oct. 2020, doi: 10.11591/eei.v9i5.2255.
- [7] A. Sepas-Moghaddam and A. Etemad, "Deep gait recognition: A survey," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 45, no. 1, pp. 264–284, Jan. 2023, doi: 10.1109/TPAMI.2022.3151865.
- [8] K. Nguyen et al., "Anomaly analysis in images and videos: A comprehensive review," *ACM Computing Surveys*, vol. 55, no. 7, Art. no. 148, 2022, doi: 10.1145/3544014.
- [9] S. T. Y. Aung and W. Kusakunniran, "A comprehensive review of gait analysis using deep learning approaches in criminal investigation," *PeerJ Computer Science*, vol. 10, Art. no. e2456, 2024, doi: 10.7717/peerj-cs.2456.
- [10] N. M. van Mastrigt, K. Celie, A. L. Mieremet, A. C. C. Ruifrok, and Z. Geradts, "Critical review of the use and scientific basis of forensic gait analysis," *Forensic Sciences Research*, vol. 3, no. 3, pp. 183–193, 2018, doi: 10.1080/20961790.2018.1503579.
- [11] A. Jency and K. Ramar, "A review of abnormal behaviour detection in crowd for video surveillance: Advances and trends, datasets, opportunities and prospects," *Expert Systems*, vol. 42, no. 4, Art. no. e70013, 2025, doi: 10.1111/exsy.70013.