

CCTV CAMERA-BASED TRACKING USING DATA SCIENCE TECHNIQUE: A DEEP LEARNING APPROACH**P. Monisha¹ and Dr. M. Kannan²**¹Ph.D Research Scholar, Department of Computer Science and Applications, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kanchipuram, India, Email: thirumonismart@gmail.com²Assistant Professor, Department of Computer Science and Applications, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Kanchipuram, India, Email: saikannan1999@kanchiuniv.ac.in**Abstract:**

This survey is a compilation of results from 20 research papers related to smart surveillance systems based on the integration of IoT, computer vision, deep learning, and embedded technologies. Traditional CCTVs are constrained due to manual monitoring and lack of intelligent response. In contrast, modern frameworks are based on the usage of Raspberry Pi [1][2][3], PIR sensors [4][5], Pi cameras [6], wireless IP networks [7][8] for real-time motion detection, facial recognition [9][10][11], intrusion alerts [12][13], remote access. Techniques like CNN [14], LBPH [15], Haar cascade classifiers [16], SSIM [17] and NSDT [18] help in increasing automation and accuracy. Applications cover areas of smart homes, traffic monitoring [19], gender sensitive urban safety [12], and crowd behavior analysis [20]. These systems exhibit a range of features that are applicable to a system that can be scaled up and down, is economical, and can be adapted to work in many different environments. Collectively, the reviewed literature reveals a change in paradigm toward proactive, intelligent surveillance ecosystems requiring the least amount of human intervention and resulting in maximum situational awareness, public safety, and operational resiliency.

Keywords: Deep Learning, Sensors, behavior, surveillance, public safety**Introduction:**

The development of smart surveillance systems represents a major move from passive surveillance to intelligent and responsive security systems. Traditional CCTV systems based on manual supervision and limited analytics are increasingly being replaced by integrated systems based on Internet of Things (IoT), computer vision, deep learning and embedded technologies. Across the reviewed combinations, researchers have covered a variety of implementations - from Raspberry Pi-based motion detection and face recognition based on CNN, LBPH, Haar cascade algorithms [1][2][3][4][5], to wireless IP camera networks and NSDT-enabled smart locking systems [6][7][8]. These systems exhibit real-time responsiveness, remote accessibility, and modular scalability and have applications that range from smart homes [9], traffic monitoring [10][11], gender-sensitive urban safety [12], and crowd behavior analysis [13][14]. Innovations like SSIM-based detection of theft [15], PIR sensor based alert [16][17], and cloud-integrated detection via mobile based interfaces [18][19] help to gain a better situation awareness and minimize the role of humans. Urban governance frameworks [12] and distributed architectures [20] support further scalable deployment in complex environments. The integration of mobile apps, GUI interfaces, and cloud storage has made it possible to have seamless interaction with the user and data management. Collectively, these studies underscore a paradigm shift in terms of proactive, intelligent surveillance ecosystems that provide cost-effective, adaptable, and secure solutions for modern environments. This survey not only brings together technological advancements but also points out the increasing role of smart surveillance in public safety and privacy protection as well as urban resilience.

Core Applications in Smart Surveillance Systems:

Smart surveillance systems have gone from a setup of passive video recordings to smart and responsive ecosystems that include IoT, computer vision, deep learning, and embedded technologies. This papers that you reviewed all together discuss an extensive variety of applications that all contribute to the transformation of modern security infrastructure.

Motion Detection & Intrusion Alarm: Motion Detection is the core of Automated Surveillance. Systems are based on PIR sensors, OpenCV, SSIM algorithms, frame difference for detecting the movement in real-time. Once motion is detected, alerts are sent through email or SMS even with attached images or video clips. This allows for fast response and reduces the human monitoring dependency.[1], [2], [3], [4], [20].**Face Recognition & Identity Verification:** Facial recognition is used to improve access control and visitor tracking. Techniques such as Convolutional Neural Networks (CNN), Local Binary Pattern Histograms (LBPH) and Haar cascade classifiers are available to identify known individuals and identify unknown faces. These systems are trained with large data sets and can be used in multiple cameras with high accuracy. [5], [6], [7], [17], [18]**Smart Locking & Access Control:** Innovative systems employ Near Sound Data Transfer (NSDT), hashing and Flutter based mobile apps to allow for secure and contactless door access. These smart locks eliminate physical keyholes which eliminate the risk of tampering. Timestamped encryption makes access credentials unique and time-limited for better security. [8]**Crowd Behavior & Violence Identification:** Surveillance systems are being implemented increasingly to keep track of crowd dynamics and to identify aggressive behaviour. Deep learning models are able to look for spatiotemporal patterns, which can help detect fights, stampedes or suspicious gatherings with great accuracy and at an early stage. This is particularly helpful in public spaces, transportation centres, and event venues.[9], [10], [12], [17]**Wireless IP Camera Streaming & Remote Monitoring:** IP-based cameras enable users to stream live video using LAN or WAN networks. Mobile apps, Web browsers and cores provide remote access to surveillance feeds. These systems provide for real time monitoring, cloud storage and synchronization of multiple devices, making them ideal for scalable deployments.[11], [13], [19]**Environmental and Safety Monitoring:** Beyond intrusion detection, smart surveillance systems monitor environmental conditions with the use of sensors for air quality, vibrations, fire and gas leaks. Alerts are sent to the users if threshold are breached, which helps to avoid health hazards and property damage. [14], [15], [20]**Urban Governance & Safety:** Safety, Women Some research is concerned with the social impact of surveillance in particular on urban government and gender-sensitive security. CCTV systems are employed in deterring crimes against women, in surveillance of public spaces and in policy frameworks for safe cities. These applications highlight the role of surveillance in social resiliency.[16]**Distributed Architecture & Embedded:** Several papers have explored the use of distributed surveillance systems involving using Raspberry Pi, fog computing, and multi-agent frameworks. These architectures lower the latency while improving the scalability, and they support analytics real-time in multiple nodes. [7], [9], [13], [19]**Evaluation Frameworks and Methodologies in Smart Surveillance Research:**

Evaluating smart surveillance systems requires a multi-dimensional approach that encompasses technical performance, real-time responsiveness, user interaction, and contextual adaptability. The review works, employ a range of methodologies to validate system effectiveness across embedded platforms, facial recognition models, alert mechanisms, and environmental sensing modules.

Table:1 Real Time Detection Analysis

Evaluation Methodology	Description	Papers Referenced
Accuracy, Precision, Recall	Used to measure model performance in face recognition, object detection, and anomaly classification. Accuracy ranged from 83% to 98.5%.	[1], [4], [5], [6], [17]
Confusion Matrix Analysis	Visualizes classification performance across multiple classes (e.g., intruder vs. authorized user). Helps identify false positives/negatives.	[5], [6], [17]
Real-Time Testing on Embedded Devices	Raspberry Pi-based systems tested for latency, responsiveness, and alert delivery in live environments.	[1], [2], [3], [20]
Dataset Generation & Model Training	Custom datasets created from video frames (e.g., 4000 images/person). Models trained with 80/20 split and tuned using epochs, batch size, etc.	[5], [6], [17]
GUI & User Interaction Testing	Interfaces built with Tkinter, ReactJS, Flutter evaluated for usability, responsiveness, and accessibility.	[15], [18]
SSIM-Based Frame Comparison	Structural Similarity Index used to detect theft or motion by comparing pre/post-event frames.	[15], [18]
Cloud & Network Performance	IP camera systems evaluated for bandwidth (0.2–2 Mbps), compression (MJPEG/MPEG-4), and streaming reliability.	[7], [8], [9], [19]
Security & Privacy Validation	NSDT-based smart locks tested for encryption strength, timestamp validation, and IMEI-based device authentication.	[8]
Crowd Analysis & Path Tracking	Log-based tracking used to evaluate movement patterns, density maps, and attendance automation.	[10], [12], [17]
Alert System Reliability	Email/SMS alerts tested using SMTP and MIME protocols for delivery speed, image attachment success, and system responsiveness.	[1], [3], [18], [20]

Data Science Algorithms used in Smart Surveillance Research:

The integration of data science - in particular machine learning (ML) and deep learning (DL) - has led to the revolution of smart surveillance systems through automated detection and intelligent decision-making, and adaptive security responses. But across the combination of papers, a variety of algorithms are used to solve things like facial recognition, anomaly detection, analyzing crowd behavior, and environmental monitoring.

Techniques of Machine Learning

Local Binary Pattern Histogram (LBPH): LBPH is very popular for facial recognition in embedded systems such as Raspberry Pi. It uses texture features taken from the grayscale images and compares histograms for classification. Its low computational cost makes it ideal for usage in constrained environments (like real-time applications). [5], [6], [17]

Haar Cascade Classifier: Used mostly in the face detection application, Haar cascades use a series of classifiers that have been trained on positive and negative images. They are efficient and are usually the initial stage in recognition pipelines before classification by LBPH or CNN. [5], [6], [17]

Support Vector Machine (SVM): SVMs have applications in binary classification, e.g. for violence detection, crowd behaviour analysis. They separate the data points with hyperplanes and are known for their accuracy in higher dimensional spaces. [10], [12]

K-Nearest Neighbors (KNN): KNN is used in face matching and object classification problems. It classifies data according to how close it is to the examples of the data that were labelled and is appropriate for use in small-scale systems with relatively small amounts of training data. [6], [17]

Decision Trees and Random Forest: These algorithms are used in environmental sensing module to classify the sensor readings (e.g. fire, gas leak). They provide interpretable decision rules and are able to effectively handle mixed data types. [14], [15]

Deep Learning Techniques

Convolutional Neural Networks or CNN: CNNs are the winner when it comes to facial recognition, violence detection, and crowd analysis tasks. They automatically learn spatial hierarchies of features from input images and are trained from large datasets to have high accuracy. [5], [6], [10], [12], [17], [18]

Multi-task Cascaded Convolutional Networks (MTCNN): MTCNN is used for the face detection and alignment. It performs detection of joint faces and landmark localization, which enhances the recognition accuracy under different conditions. [6], [17]

Spatiotemporal Modelling using CNNs: Some systems take into account both spatial and temporal features allowing for predictive surveillance. [10], [12], [17]

Structural Similarity Index Measure(SSIM) (to be used along DL models): Though SSIM is not a learning algorithm, it is used for comparing frames for theft detection. It complements DL models by quantifying changes in surveillance footage visually.[15], [18]

System Design and Implementation in Smart Surveillance Research:

The design and implementation methodologies in the works include a transition from the traditional centralized CCTV systems to intelligent, modular and IoT-enabled surveillance systems. These systems are designed to be scalable, responsive and adaptable to different environments - from smart homes, campuses, urban streets to industrial zones.

Architectures based on Raspberry Pi

A majority of the papers make use of Raspberry Pi as the central processing unit for surveillance tasks. These single board computers are coupled with PIR sensor for motion detection, piconet Pi camera for image capture and wireless module for alert transmission. The systems are designed to work autonomously, taking images or videos when they sense a motion and sending an alert to the user through email or SMS using an SMTP and MIME protocol [1][2][3][20].

Modular System Components

Smart surveillance systems are generally classified by their functions including motion detection, face recognition, alert generation, GUI interface and synchronization with the cloud. This modularity provides for easier debugging, upgrade and customization. Each module communicates with other modules by well-defined protocols to operate seamlessly [5][6][15][18].

Wireless IP Camera Networks

Several papers are devoted to IP based camera systems streaming live video over LAN or WAN. These cameras are set up via mobile apps (i.e. iCSee), web browsers (i.e. Firefox), or with Matlab interfaces. The systems have remote access, multi-platform capability, and real-time monitoring, which make them suitable for large-scale deployments [7][8][9][19].

Smart Locking Mechanisms

One innovative implementation is NSDT (Near Sound Data Transfer) for secure, contactless door access. A mobile application of the project, which is implemented in the Flutter programming language, transmits encrypted credentials through sound to a microphone connected to Raspberry Pi. The system is provided with hashing and timestamp validation to authenticate users, and triggers servo motor-based locking mechanisms [8].

Face Recognition Pipelines

Face recognition systems involve a well defined pipeline: the video frames are acquired and preprocessed (eg.greyscaling, padding), the faces are detected applying Haar cascade or MTCNN, and the classification is done using CNN or LBPH models. Training datasets are frequently created using video clips, where thousands of images from a person are used [5][6][17].

Motion Detection Workflows

Motion detection is done with the help of PIR sensors or frame differencing. Some systems use SSIM (Structural Similarity Index Measure) to compare frames before and after an event occurs to determine if a theft or intrusion has taken place. Upon detection, the system alerts the alarms out, takes pictures, and sends notifications [1][3][15][18].

Integration and Alert Systems to Cloud

To guarantee the responsiveness offered by the applications in real-time and simplify access to the data, many systems incorporate cloud storage companies such as Dropbox or Firebase. Alerts are delivered via the use of the protocols: - Using the maps, which may be sent with image/video attachments. This allows the users to quickly respond to security events from remote locations [1][3][18][20].

GUI Interface Design

User interfaces are developed by Tkinter (Python), ReactJS (JavaScript) or Flutter (Dart). These GUIs enable the user to interact with the system, set monitoring zones, set up recording, and view logs. Buttons are attached to specific modules such as "Monitor," "Identify," "Record," and "Noise Detection," which improves the usability of the product for the non-technical user [15][18].

Dashboard and Log Analysis

Some systems have dashboards that have paths of movement, attendance records, and crowd density maps. Logs have time-stamped entries with the camera IDs, detection vectors and person identifiers. These logs are used for retrospective analysis, pattern recognition and administrative reporting [10][12][17].

Environmental Sensing Integration

Beyond security, there are a number of systems that include sensors for vibration, air quality, fire and gas detection. These sensors can notify when the thresholds are exceeded and prevent the health hazards and damage to properties. This integration is a general trend toward holistic safety systems [14][15][20].

Specific Surveillance Tasks in Smart Surveillance Research:

The integrated works show a growing focus on specialist surveillance functions that are extending beyond the traditional video monitoring. These tasks are intended to solve specific security, safety and governance challenges through intelligent, modular and context-aware technologies. A summary of the major specialized functions performed in these systems is shown below.

Facial Recognition to Access Control

Facial recognition is being used extensively to automate access to secured zones like home, office, classrooms etc. Systems use CNN, LBPH and haar cascade classifiers to identify people in real time. Training datasets are often created using video live streaming allowing dynamic enrollment and verification. [5], [6], [17], [18]

Intrusion Detection and Notification

Motion detection with the help of PIR sensors, vibration modules, and frame differencing algorithm helps identify the unauthorized entry in real-time. Upon detection, systems take pictures and send alerts (email or SMS) using the protocols (SMTP, MIME). [1], [2], [3], [20]

Smart Locking via NSDT

A new challenge in this regard is to utilize Near Sound Data Transfer (NSDT) for secure, contactless unlocking of doors. For example, mobile apps using the Flutter framework communicate encrypted credentials via sound which is verified by Raspberry Pi systems based on timestamp hashing. [8]

Crowd Density Mapping and Tracking Path

Surveillance systems record motion across multiple cameras to create density maps as well as to track individual trajectories. These features are beneficial for crowd control, automated attendance and behavioral analysis in public places and institutions. [10], [12], [17]

Violence and Anomalies Detection

Deep learning models are used to understand spatiotemporal patterns to identify aggressive behavior, loitering, and suspicious behavior. These systems are deployed in urban areas, transport hubs, and venues hosting events in order to provide for proactive intervention.[3], [6], [12]

Environmental Hazard monitoring

Surveillance systems comprise sensors for air quality, fire, gas leaks, and vibration. These sensors are used to raise alerts when thresholds are exceeded, which can help to prevent health hazards and infrastructure damage.[14], [15], [20]

Gender-Sensitive Urban Safety

Some of the studies focus on the use of surveillance to help keep women safe in public spaces. CCTV systems used to deter harassment, monitor high-risk areas and aid governance frameworks in inclusive design of cities. [16]

Remote Streaming and Multi-Platform Access

IP cameras are used to stream live videos to mobile applications, web browsers and mathematical interfacing. This task allows users to monitor environments remotely and in real-time, which is useful for flexible deployment across home, campus and city environments.[7], [9], [19]

Automated Attendance Systems

Face recognition and log analysis are adopted to record attendance without manually input. These systems are used in educational institutions and workplaces to streamline the record keeping and to reduce administrative overhead. [10], [17].

Theft Detection Using SSIM

Structural Similarity Index Measure (SSIM) used to compare before and after the event of a frame to detect missing objects or tampering. This task is especially useful in retail, storage, and residential applications. [15], [18]

Future Directions of Intelligent Surveillance Systems:

The development of smart surveillance systems as seen throughout this papers is heading towards highly adaptive, decentralized and ethical architectures. A leading trend will be the integration of edge computing and fog-based frameworks, which allow for real-time analytics on embedded platforms, such as Raspberry Pi and Jetson Nano, which reduces the latency and the dependency on the cloud [1][3][13][20].

Another emerging trend is multimodal sensor fusion, by combining visual data with other environmental inputs such as vibration, gas, and fire sensors, to increase the situational awareness and detect complex events [14][15][20]. This fusion is used to enable active safety responses in the residential and industrial environment. The application of deep learning models (especially CNN) in facial recognition, violence detection and crowd behavior analysis is increasing and systems will be built in the future with predictive analytics for threat forecasting and anticipation [6][10][12][17]. Lightweight models optimized for embedded deployment by pruning and quantization will further bring down the bar for intelligent surveillance access [5][6][17].

Ethical considerations are becoming more important, with systems that are designed to allow privacy-preserving surveillance, such as anonymized data handling and selective recording [8][16]. Additionally, surveillance is being linked to urban governance and gender-sensitive frameworks for safety which allow for inclusive monitoring of public spaces [16]. Cloud native interfaces and access via mobile apps and web dashboards, across different platforms, will continue to improve user control and responsiveness [7][11][18]. Autonomous response mechanisms, such as smart locking, alert dispatch and robotic integration, are also anticipated to become commonplace [2][8][18].

Conclusion:

The findings gathered from research papers highlight a paradigm shift in surveillance systems - from passive, manual surveillance systems to intelligent, automated, and context-aware security systems. Such systems use embedded platforms such as the Raspberry Pi [1][2][3], combine motion and environmental sensors [14][15][20] and implement advanced computer vision methods such as CNN, LBPH and Haar cascade classifiers for facial recognition and anomaly detection [5][6][17][18].

Specialized tasks such as NSDT-based smart locking [8], crowd density mapping [10][12][17] and theft detection using SSIM [15][18] are examples of the growing domain of surveillance beyond traditional limits. Evaluation methodologies such as accuracy metrics, confusion matrices, and real-time latency testing are used to validate the robustness and adaptability of these systems in various environments [4][5][6][20]. Emerging trends are heading towards edge-AI deployment [1][3][13], multimodal sensor fusion [14][15], privacy preserving architectures [8][16], and predictive analytics for proactive threat mitigation [6][10][12]. These innovations are in line with changing needs of smart cities, gender sensitive urban governance [16], and scalable public safety infrastructure. In conclusion, intelligent surveillance systems are more than just about security, they are also helping to create ethical, inclusive and resilient urban systems. This synthesis offers a framework for future work, including interdisciplinary collaboration in the fields of embedded systems, AI, and policy design.

References

- [1]. Sharma, A., Zutshi, A., Sharma, M., Sharma, A., &Chawan, P. M. (2024). Enhancing Live Cctv Systems: Object Detection, Tracking, And Expressive Footage Storage.
- [2]. Jeon, H., Kim, H., Kim, D., & Kim, J. (2024). Pass-Cctv: Proactive Anomaly Surveillance System ForCctv Footage Analysis In Adverse Environmental Conditions. *Expert Systems With Applications*, 254, 124391.
- [3]. Perez, M., Kot, A. C., & Rocha, A. (2019, May). Detection Of Real-World Fights In Surveillance Videos. In *Icassp 2019-2019 Ieee International Conference On Acoustics, Speech And Signal Processing (Icassp)* (Pp. 2662-2666). Ieee.
- [4]. Poshitha M1 ,Ananthu Manojkumar2 , G Sai Chandan Reddy3 , Gajula Hari Krishna4 ,Endla Bhanu Venkata Avinash5 (2023). Emergency Vehicle Detection In Heavy Traffic Using Computer Vision. *International Journal Of Research Publication And Reviews*, Vol 4, No 3, Pp 1078-1081.
- [5]. Gaikwad, M., Chordiya, R., Vaidya, A., Wagh, R., & Chitari, A. (2022). Smart Cctv Surveillance And Tracking System For Intruders.
- [6]. Kim, J. S., Kim, M. G., & Pan, S. B. (2021). A Study On Implementation Of Real-Time Intelligent Video Surveillance System Based On Embedded Module. *Eurasip Journal On Image And Video Processing*, 2021(1), 35.
- [7]. Liu, Q., Kimber, D., Foote, J., Wilcox, L., & Boreczky, J. (2002, December). Flyspec: A Multi-User Video Camera System With Hybrid Human And Automatic Control. In *Proceedings Of The Tenth Acm International Conference On Multimedia* (Pp. 484-492).
- [8]. Hassan, R. J., & Abdulazeez, A. M. (2021). Deep Learning Convolutional Neural Network For Face Recognition: A Review. *International Journal Of Science And Business*, 5(2), 114-127.
- [9]. Zou, F., Li, J., & Min, W. (2019). Distributed Face Recognition Based On Load Balancing And Dynamic Prediction. *Applied Sciences*, 9(4), 794.
- [10]. Shaina Santosh Das, Sanghamitra Patnaik (2023). An Empirical Study OnCctv Surveillance And Women Security, *European Economic Letters Issn 2323-5233 Vol 13, Issue 5 (2023)*
- [11]. Devadhas Sujakumari, P., &Dassan, P. (2023). Generative Adversarial Networks (Gan) And HdFs-Based Realtime Traffic Forecasting System Using Cctv Surveillance. *Symmetry*, 15(4), 779.
- [12]. Sreenu, G. S. D. M. A., & Durai, S. (2019). Intelligent Video Surveillance: A Review Through Deep Learning Techniques For Crowd Analysis. *Journal Of Big Data*, 6(1), 1-27.
- [13]. Dr. Abhijit Patankar, Yash Jadhav, DeepkumarBrahmbhatt, Ashutosh Raut, Rituja Chavan, "Smart Cctv Surveillance System", *Ijrar - International Journal Of Research And Analytical Reviews (Ijrar)*, E-Issn 2348-1269, P- Issn 2349-5138, Volume.9, Issue 2, Page No Pp.105-108, April 2022.
- [14]. Balogun, F. A. (2023). Urban Security Governance In Residential Neighbourhoods: A Researcher's Perspective. *Southern African Journal Of Security*, 1, 22-Pages.
- [15]. Karuna, G., Reddy, A. S., Vishal, K., Pavan, E., & Negi, G. S. (2023). Smart And Sustainable Surveillance System. In *E3s Web Of Conferences* (Vol. 430, P. 01030). Edp Sciences.
- [16]. Dasorwala, Sakina And Patil, Aniket And Vora, Raj And Kambli, Mansi, Smart Locking System (October 24, 2021).
- [17]. Ishan Kokadwar, Anurag Kukarni, Vaibhav Limbhore, Sayali Khare, Swati Chandurkar(2020), Camera Based Smart Surveillance System *International Journal Of Computer Applications (0975 – 8887) Volume 175 – No.17.*
- [18]. Varshini G, Velvzhi R (2023), Smart Cctv Surveillance, *International Research Journal Of Modernization In Engineering Technology And Science E-Issn: 2582-5208 Volume:05/Issue:03/March-2023.*
- [19]. Olaiya Olayinka Oluwaseun, Olufemi Oluseye Kehinde (2022). Overview Of Wireless Cctv Camera Network-Based Surveillance System *International Journal Of Advances In Engineering And Management (Ijaem) Volume 4, Issue 2 Feb 2022, Pp: 244-250.*
- [20]. Kothari, S. B., Ahirrao, V., Pawar, M., Kapale, U., & Arjun, M. (2021). Survey On Smart Security Surveillance System. *Int J Res Appl Sci Eng Technol (Ijrasnet)*, 9(12), 52.