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Smart Surveillance Systems: Trends, Challenges and Future Directions

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Abstract

Smart surveillance systems integrate the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), and extensive data processing (big data) to enhance real-time monitoring, automated decision-making, and data analytics across multiple sectors. In security, they improve threat detection through facial recognition and pattern analysis. In power distribution, they enhance grid stability and detect unauthorized electricity usage using predictive analytics and advanced metering infrastructure (AMI). Agriculture benefits from precision farming, optimizing resource use while monitoring crops and livestock.

Despite their advantages, these systems face challenges such as high implementation costs, communication limitations, data privacy concerns, and digital security risks (cybersecurity). Urban areas benefit from high-speed networks like fifth-generation wireless technology (5G) and fiber optics, yet costs and cyber vulnerabilities remain issues. In rural regions, limited internet access hinders adoption, necessitating alternatives like satellite technology and Long-Range Wide Area Network (LoRaWAN). Overcoming these challenges will drive the development of scalable, intelligent monitoring solutions, ensuring broader accessibility and efficiency in various industries.

A. Introduction

Surveillance, is defined as the close observation of people, groups, or environments for security, law enforcement, or data collection and has evolved significantly over the centuries [1,2]. Surveillance originally rooted in rudimentary methods, such as physical monitoring and written reports. Surveillance systems have grown in complexity with technological advancements, shifting from the traditional surveillance methods to highly sophisticated smart systems [3,4]. These modern systems integrate artificial intelligence, machine learning, and Internet of Things (IoT) technologies, transforming how governments, organizations, and individuals monitor activities.

The 20th century saw the first major leap in surveillance technology with the invention of Closed-Circuit Television (CCTV) [5]. Introduced in the late 1940s, CCTV was a groundbreaking solution that allowed organizations to monitor activities in real time without being physically present. This method expanded rapidly across various sectors, including banking, retail, and government facilities. The cameras were typically linked to control rooms where security personnel manually monitored live feeds and recorded footage. Despite its widespread adoption, traditional CCTV had notable limitations, such as the need for human operators to detect anomalies. Additionally, its effectiveness was hampered by poor image quality and storage issues. As technology advanced, surveillance systems evolved further, incorporating digital components, enabling more precise and automated monitoring. A giant leap in transformation occurred with the rise of smart surveillance systems in the 21st century. Smart surveillance systems refer to those that integrate advanced technologies such as: Artificial Intelligence (AI), IOT, cloud computing and biometric system [6].

Smart surveillance systems provide high-definition, real-time video streams, which can be analyzed automatically. Advanced analytics allow these systems to perform functions such as people counting, license plate recognition, perimeter control, and the detection of loitering or unusual behavior [7,8]. Nowadays modern surveillance systems have far-reaching applications across various sectors such as in law enforcement and crime prevention, traffic and transportation monitoring, critical infrastructures protection, healthcare facilities, retail and business environment, agriculture sector, and energy sector [9,10].

Surveillance systems have undergone significant transformations, from the manual observation techniques of ancient civilizations to the sophisticated smart technologies of today. With the integration of AI, IoT, and biometric systems, surveillance is now faster, more efficient, and more intelligent. The wide-ranging applications of surveillance, from law enforcement to national security, reflect its growing importance in modern society. As technology continues to evolve, surveillance systems will likely become even more capable, expanding their role in safeguarding individuals, businesses, and governments. However, as these systems become more ubiquitous, concerns around privacy and data protection will also need to be addressed [10,11]. This review article considered the use of surveillance system in security, agriculture, and energy sector. The importance of smart surveillance in these sectors were considered and the advantages and disadvantages of the smart surveillance system in the sectors are also considered.

B. Research method

The study follows a literature review methodology, analyzing recent advancements in smart surveillance across multiple sectors. Data sources include journal articles, industry reports, and case studies. Comparative analysis is used to highlight differences between traditional and smart surveillance systems, and challenges are identified based on real-world implementations.

C. Results and Discussion

One of the most common uses of surveillance systems is in crime prevention and law enforcement. Police forces and security agencies use surveillance cameras in public places to monitor and deter criminal activity. CCTV systems in urban areas can be networked to provide real-time monitoring of high-risk zones, improving response times to incidents and enhancing public safety. Facial recognition can help identify suspects, while AI-based analytics can predict and prevent criminal activities based on patterns. In recent times surveillance has been integrated into many sectors for monitoring and control of anomalies in processing, reporting and analysis [12].

1. Surveillance System in the Security Sector

Surveillance plays a vital role in national security by enabling governments to monitor potential threats, whether from terrorism, espionage, or internal unrest. In this context, surveillance systems are integrated into border control, airports, seaports, and sensitive government buildings. Additionally, cyber-surveillance is essential for detecting and mitigating digital threats. In military operations, surveillance systems are crucial for intelligence gathering, battlefield monitoring, and reconnaissance. Drones, satellite imaging, and advanced sensors allow military personnel to gain real-time information, making operations more efficient and reducing risks [13,14,15]. Surveillance systems have undergone a profound transformation in security sector over the decades, moving from traditional methods reliant on human oversight and basic technology to advanced systems that leverage AI and the IoT. This review will delve into these evolving approaches, examining their advantages, limitations, and the implications for the security sector.

The use of traditional surveillance systems in security system is based on an analog Cameras which is mounted at a fixed position this provide a limited field of view and rely on video tapes or VCRs for recording, often resulting in cumbersome storage and management. As technology advances, CCTV was introduced which is common in public spaces and businesses. CCTV systems often operate on a loop, continuously recording but offering limited analytic capabilities. Due to the memory issues with analog cameras and CCTV, the human monitoring approach was adopted to improve the traditional approach. In this case a security personnel manually monitor camera feeds in real time, increasing the risk of missed incidents due to fatigue or distraction [16,17,18]. There are several factors associated to the use of traditional approaches in security sector which includes storage constraints, reactive nature, and operational cost because continuous human monitoring is labor intensive and costly with the potential for human error undermining security efforts [19].

Due to the limitation of the traditional surveillance system and with the recent development in technology makes security sectors of many nations to transit into the Smart Surveillance Systems (SSS) [20]. The shift to SSS is marked by the integration of digital technology, AI, and IoT. This transition offers a more proactive, automated, and efficient approach to security monitoring. The approach used for smart surveillance can be described as depicted in Figure 1.

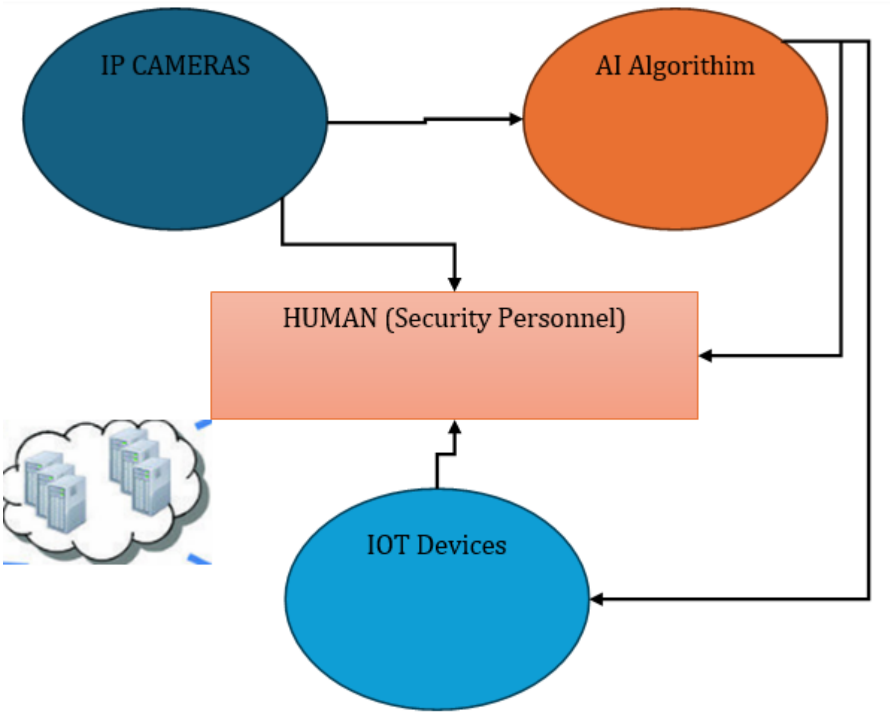

Figure 1. Components of Smart Surveillance System in Security Sector.

In Figure 1, the Digital Internet Protocol (DIP) cameras provide superior image quality and can be accessed remotely, allowing for real-time monitoring and management via web interfaces or mobile applications. The DIP cameras can send information directly to the security personnel to detect anomaly behavior in the location where it is has been strategically positioned. Based on the information received by the security personnel necessary actions can be initiated. In the same manner several algorithms can be trained based on the operation or activities that wants to be monitored by the security agency. The AI algorithm can receive information from the DIP cameras such as video image and analyze for specific behaviors, enabling features like facial recognition, license plate recognition, and crowd behavior analysis. This data helps identify potential threats and unusual activities in the environment were the cameras as installed. The AI algorithm is integrated with IoT devices that will allows communication with other devices such as sensor to send signal for alarming, light indicator or to initiate a control action. For record purpose the information from all these devices is send to the cloud which serve as the memory for the system. In security sector is not advisable to allow full automation without human intervention [21].

The use of smart surveillance system in security system has several advantages: The use of smart systems provides continuous, real-time analytics, enabling security personnel to receive immediate notifications about suspicious activities [22]. AI algorithms can assess and classify incidents, ensuring critical events are prioritized for review. Security managers can monitor facilities from anywhere in the world. This flexibility allows for quick assessments and decision-making, particularly in emergencies, without the need to be physically present. AI technologies reduce false positives, which are common in traditional systems. For instance, smart systems can differentiate between human movement and non-threatening events (like animals), significantly enhancing the accuracy of alerts. Smart surveillance systems can trigger automated responses to specific incidents. For example, if an unauthorized person is detected, the system can lock doors, send alerts to security personnel, and even initiate recorded footage for immediate review. Cloud-based storage solutions allow organizations to securely store and manage vast amounts of video footage without the physical constraints of traditional systems. This facilitates easy retrieval and analysis of historical data, which can be crucial for investigations [22, 23].

The smart system has addressed a lot of issues that cannot be solved by traditional approaches, however, there are limitation in smart surveillance. The pervasive nature of surveillance raises significant ethical concerns regarding individual privacy. In addition, misuse of surveillance data can lead to unauthorized tracking and monitoring of individuals. In addition, smart surveillance systems for security, being networked and often cloud-based, are vulnerable to hacking and cyber-attacks. A compromised Smart Surveillance Security System (SSSS) can lead to data breaches and unauthorized access to sensitive information. Also, the initial investment in smart surveillance technologies, including hardware, software, and training, can be substantial, presenting challenges for smaller organizations or those with limited budgets. Furthermore, smart system is based on the internet. In most rural areas in developing countries, the internet facility is not adequate for implementation of smart surveillance system. These are challenges that are still facing the use of smart surveillance system in security sector, if all the challenges can be addressed, the use of smart surveillance system in security sector will reduce crimes rates [24]. As the landscape of surveillance continues to evolve, finding a balance between leveraging technology and ensuring ethical, responsible use will be essential for the future of security in various sectors.

2. **Surveillance Systems in the Health Sector**

Surveillance systems in the health sector play a crucial role in monitoring public health, tracking diseases, and improving patient care [25]. These systems can range from traditional methods like manual data collection to advanced digital systems that utilize real-time data, IoT devices, and AI for better decision-making and health outcomes. Traditional health surveillance involves the manual collection of data from healthcare facilities, laboratories, and communities to monitor the spread of diseases, track outbreaks, and assess general health trends.

This also, involve health personnel to visit out of seat patient in homes for regular checkup.

The traditional surveillance systems generally require fewer resources in terms of technology and are accessible to low-resource settings. However, there are challenges faces for traditional surveillance in health sector which includes time-consuming; manual data collection and reporting can be slow, leading to delays in response to disease outbreaks or other health threats. Human error, there is a higher likelihood of errors in data entry and reporting, leading to inaccuracies; with the use of traditional surveillance in health sector, it is difficult to achieve real-time or wide-scale monitoring, especially in remote or under-resourced areas. Traditional systems are unable to provide immediate insights into emerging health threats, which limits rapid decision-making. Paper records and manual reporting make it difficult to integrate and analyze data across different regions or systems. The limitation of traditional approach in health sector paves way for smart surveillance system in the health sector.

Smart surveillance systems leverage advanced technologies like IoT devices, AI, Machine Learning (ML), big data analytics, and cloud computing to monitor, analyze, and respond to health-related events. These systems are crucial in disease detection, patient monitoring, and outbreak control, providing real-time insights and faster response times. Figure 2, depicted a typical smart surveillance system for monitoring the health condition of a patient far away from the health personnel. The system allows the health personnel to receive information from the patient [26].

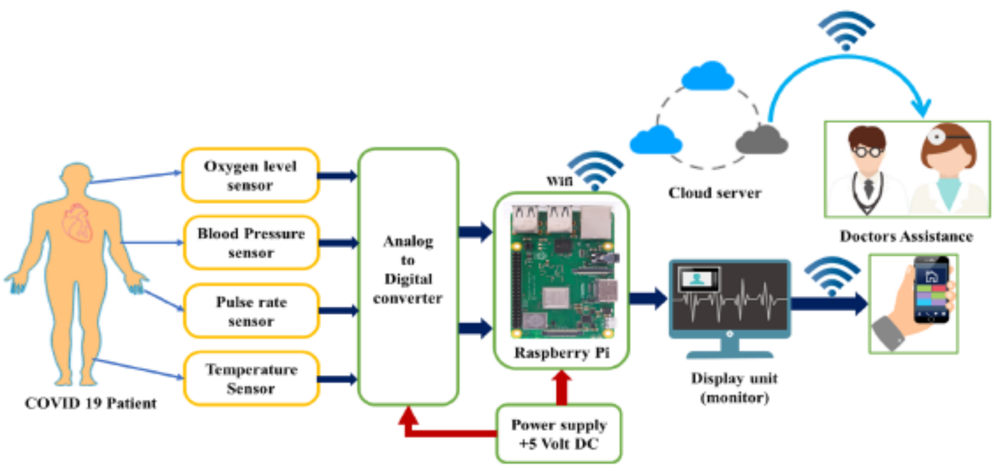

Figure 2. A Typical Smart Surveillance System in Health Sector [26].

In Figure 2, various sensors such as oxygen sensor, blood pressure sensor, pulse rate sensor and temperature sensor are used to obtain the readings from the patients. The readings are converted to a digital signal using Analogue to Digital Converter (ADC), AI and IOT based device such as Raspberry Pi, can be used to determine the health condition of the patient and send it to the cloud and the health personnel can fetch the information from the cloud and make suggestions on what actions the patient can undertake.

The Smart Health Surveillance Monitoring (SHSM) systems allows immediate access to health data for rapid responses to public health emergencies, including disease outbreaks and patient health crisis. It also enhances accuracy due to its automated data collection and AI analysis, which reduce the risk of human error, leading to more accurate monitoring and diagnosis. Since information are send to the cloud in SHSM the systems allow for the seamless sharing of information between hospitals, labs, and public health authorities, leading to better-coordinated care and responses. This also enables systems to predict disease outbreaks, patient deterioration, and other health trends based on historical and real-time data. In addition, it enables healthcare providers to monitor patients without the need for constant in-person visits, improving care for patients in remote areas where there is adequate internet infrastructure [27].

One of the major issues facing the implementation of surveillance system in the health sector is the initial setup and maintenance. The digital health surveillance systems require significant financial investment, which can be a challenge for resource-poor areas. In addition, with vast amounts of sensitive health data being collected and shared, there are concerns about data breaches and patient privacy. Also, healthcare providers may need additional training to use smart systems effectively, which can slow the adoption rates [28]. Since most of the smart health surveillance system used are based on the internet, which uses Wi-Fi technology for communication. Remote areas without the internet infrastructure cannot adopt the needed lifesaving SHSS.

Table 1. Comparison between the Traditional Health Surveillance System and Smart Health Surveillance System [29, 30].

Aspect	Traditional Surveillance	Smart Surveillance
Data Collection	Manual data entry and field surveys	Automated data collection from IoT devices, EHRs, and mobile apps
Monitoring Method	In-person monitoring of patient conditions	Remote monitoring through wearable devices and AI
Response Time	Delayed response due to manual processes	Real-time alerts and rapid decision-making
Data Accuracy	Susceptible to human error	Enhanced accuracy with automation and machine learning
Scalability	Limited to localized settings	Can scale across large populations and regions
Cost	Lower upfront costs, but labor-intensive	Higher initial investment, long-term cost savings with efficiency

There is a need to improve the network and internet infrastructure for smart surveillance system for health sector if it will be adopted in remote areas. The Surveillance systems in the health sector, especially smart systems, have revolutionized how health data is collected, analyzed, and utilized. From real-time monitoring of chronic diseases to the rapid identification of global pandemics, these systems play an essential role in modern healthcare. While traditional systems have been useful in the past, the shift towards smart health surveillance offers greater efficiency, accuracy, and the potential to save more lives, though challenges related to cost, technical complexity, and data privacy remain.

3. **Surveillance Systems in Power Systems:**

In the power sector, surveillance systems are essential for monitoring and managing the distribution, generation, and consumption of electricity. They help utilities detect anomalies, improve efficiency, ensure the stability of power grids, and protect critical infrastructure from potential threats [31]. Advanced surveillance systems in power systems are becoming increasingly smart, incorporating technologies like IoT, AI, and big data analytics to ensure seamless grid operations.

Traditional surveillance systems in power grids have relied on manual monitoring and basic telemetry. Utilities deploy sensors at key points across the network to gather data on voltage, current, and other electrical parameters, which are then transmitted to central control centers for human review to implement necessary actions. Supervisory Control and Data Acquisition (SCADA) is a long-established traditional system used to monitor and control power grids. It collects data from sensors at power plants, substations, and transmission lines and sends it to a central location, allowing operators to control grid operations. Despite the availability of SCADA, some power utilities in developing countries like South Africa and Nigeria cannot avoid the use of SCADA in the distribution part of their network. The Power utilities send technicians to inspect meters, substations, and power lines regularly, looking for anomalies, maintenance issues, or signs of tampering. Also, operators at load dispatch centers manage the real-time operation of the power grid, balancing supply and demand manually, using data from SCADA and metering systems [32,33,34]. There are several challenges facing the traditional systems used in distribution sector in power system in which the system may not provide real-time data or predictive insights, leading to delayed detection of issues. Manual inspections and physical meter readings are labor-intensive and costly. These systems are often limited in terms of scalability and comprehensive data collection, especially over large geographic areas. Traditional surveillance system in power system tends to be reactive rather than proactive, addressing issues after they occur rather than preventing them. This limitation paves ways for smart surveillance system in power system [35].

Smart surveillance systems in power grids involve real-time data collection and automated analysis, allowing utilities to detect issues and inefficiencies much faster than traditional methods. These systems leverage technologies like IoT, AI, ML, and Advanced Metering Infrastructure (AMI) for predictive analytics, fault detection, and even theft detection. The key components of smart surveillance system in power grids is discussed as follows:

Smart Meters: Smart meters provide real-time data on electricity consumption at the household and industrial levels. They transmit usage data to utilities automatically and can detect anomalies in power consumption patterns.

Advanced Metering Infrastructure (AMI): AMI systems use a network of smart meters, sensors, and communication devices to collect, monitor, and analyze energy data. AMI enables two-way communication between the utility and end-users, allowing utilities to perform remote meter reading, disconnect or reconnect services, and detect tampering.

Phasor Measurement Units (PMUs): PMUs monitor the stability of the grid by measuring the voltage, current, and frequency in real-time. These devices are deployed at key points in the power grid, such as substations, to detect potential disturbances and optimize power flow.

IoT Devices and Sensors: Sensors installed at critical points in the grid continuously monitor parameters like voltage, current, frequency, and temperature, feeding real-time data into AI systems for analysis.

AI: AI models analyze the data collected from meters and sensors to detect patterns, predict failures, and identify abnormalities like energy theft, equipment malfunctions, or overloaded circuits.

Energy Management Systems (EMS): EMS systems help utilities optimize energy distribution, ensuring a balanced grid by responding in real time to changing load conditions.

Drone Surveillance: Drones equipped with cameras and sensors are increasingly used to inspect power lines, substations, and transmission towers. They can capture detailed images and provide real-time data, reducing the need for human intervention in hazardous areas.

According to [36,37,38], smart surveillance has several advantages in power system which include the following:

Real-Time Monitoring: Continuous, automated monitoring helps detect faults or inefficiencies immediately, reducing downtime and improving response times.

Predictive Maintenance: Machine learning models can predict equipment failures, allowing utilities to perform maintenance before issues arise, avoiding costly outages.

Energy Theft Detection: Smart meters and AI-powered analytics help identify patterns of energy theft, allowing utilities to intervene quickly.

Cost Savings: Automated systems reduce the need for labor-intensive inspections, meter readings, and manual intervention, saving costs.

Grid Optimization: Data from smart meters and sensors help utilities optimize energy distribution, improving overall grid efficiency.

Scalability: These systems can easily scale to cover vast geographic areas, providing detailed insights into power consumption patterns across entire regions.

Many developing countries are faced with energy theft, the implementation of smart surveillance system in distribution networks can help in solving the problem of energy theft in power system which serve as revenue loss in the network. The smart surveillance systems, have proven to be highly effective in detecting and mitigating energy theft in power system network and smart grid [39, 40]. It has been adopted in smart grid management in many countries as presented in Figure 3.

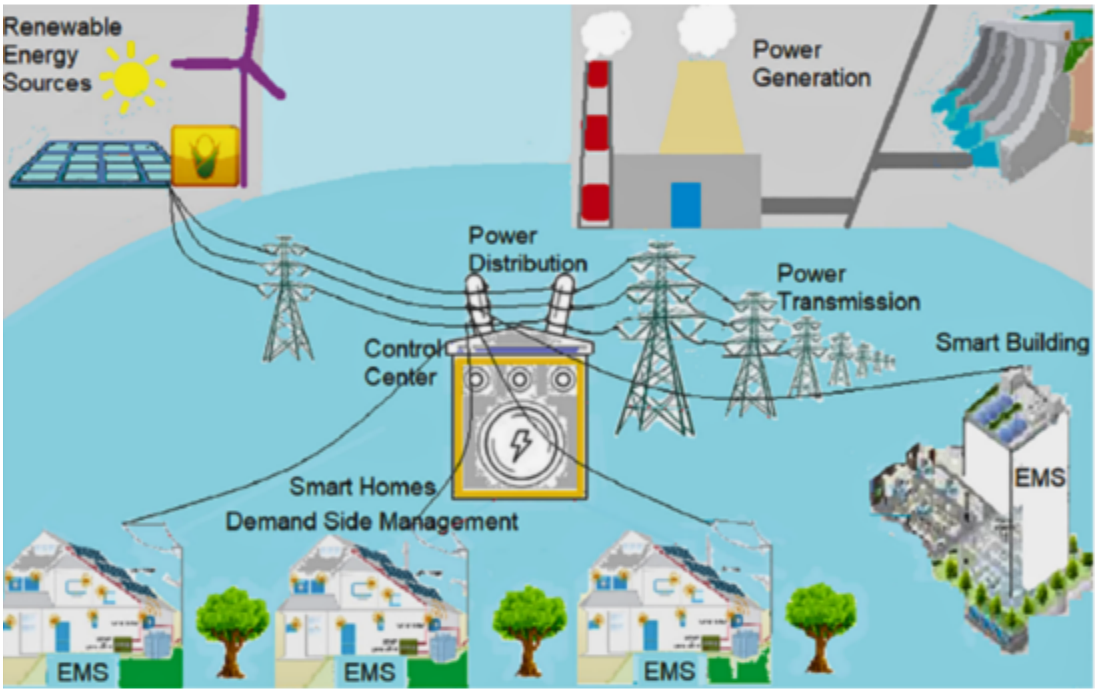

Figure 3. Smart Surveillance System for Energy Management [41].

Figure 3, illustrates the structure of the Smart Grid (SG), which consists of various power sources, transmission lines, Renewable Energy Sources (RES), energy management systems (EMS), and a central control center [41]. Demand-Side Management (DSM) and Smart Energy Surveillance Systems (SESS) are essential concepts in the field of Energy Management (EM). EM involves monitoring, controlling, and optimizing energy usage in organizations, facilities, or industrial processes to reduce costs, maximize efficiency, and minimize energy consumption while maintaining a productive and comfortable environment [42]. The SESS collects, processes, and analyzes real-time (RT) energy consumption data and take decision based on the operational rules in the network helps to maximize energy efficiency (EE) and reduce waste [43].

One of the issues with SESS is the communication approach used within the network. The internet approach based on Wi-Fi can be an issue for the implementation of SESS in remote areas that does not have access to the internet facilities. This is a major challenge in energy system, many users of energy in remote areas perform energy theft due to inability of SESS system. Energy theft results when users deliberately tamper with their meters to record less electricity usage, users make unauthorized connections to the grid, bypassing meters entirely and older meters that malfunction may not record usage accurately, resulting in unbilled electricity.

Apart from the internet infrastructure challenges, another significant hurdle in implementing smart surveillance systems in distribution networks is the high cost of deployment and maintenance. Additionally, these systems are susceptible to hacking and cyber-attacks, which can disrupt grid operations or result in data breaches. Implementing smart surveillance systems also demands a high level of technical expertise and may require extensive training for utility workers to ensure proper operation and management. Smart surveillance systems offer significant advantages in improving the efficiency, reliability, and security of power systems. By providing real-time monitoring and predictive analytics, they allow utilities to manage grid operations more effectively and detect energy theft swiftly. While traditional systems have their place, the shift towards smart technologies has revolutionized how utilities address challenges such as theft, grid optimization, and equipment maintenance. However, challenges related to cost and communication are issues in implementation of smart surveillance system for distribution network in remote location. The communication mode of many researches on smart surveillance in power sector is based on internet facilities and this has limited the implementation in rural areas which pave way for energy theft. More research should be considered on the communication mode for smart surveillance in power system for implementation in both urban and rural area.

4. Surveillance Systems in the Agricultural Sector

Surveillance systems in agriculture serve to monitor various aspects of farming operations, from crop health to animal welfare, and even environmental conditions [44]. These systems can range from traditional methods like manual inspections to modern, smart surveillance technologies that use IoT, sensors, cameras, drones, and AI for better management and productivity.

Traditional agricultural surveillance relies heavily on human labor and basic tools to monitor crop growth, detect pest infestations, and ensure the well-being of livestock. The major approach of traditional surveillance involves the following [45]:

- **Manual Inspections**: Farmers or agricultural workers manually inspect crops, soil, or animals for signs of disease, pests, or other issues. This is time-consuming and labor-intensive.
- **Simple Tools**: Devices like thermometers, rain gauges, or basic soil moisture meters have been historically used to monitor environmental factors, but these tools require regular human intervention.
- **Fencing and Physical Barriers**: Fencing is used to keep animals and within designated areas and prevent predators from entering. However, this doesn't provide real-time alerts or information about breaches or hazards.

- **Use of Scarecrows or Decoys**: Basic techniques like scarecrows are employed to keep birds and other wildlife away from crops, but their effectiveness is often limited.
- **Simple Alarm Systems**: Farmers may employ basic alarm systems triggered by movement or the opening of gates to secure livestock.

The major advantages of traditional systems are the minimum cost of investment as they rely primarily on human labor and basic tools. However, there are several disadvantages in traditional farming which involves constant manual monitoring, making it inefficient and time-consuming; human error in detecting issues can result in delays in addressing critical problems like pest infestations or livestock illness. It is challenging to monitor large areas or farms with traditional methods. Also, potential issues such as disease outbreaks or water shortages might not be identified quickly enough to prevent damage. This challenges of traditional approach in farming leads to the adoption of smart surveillance system in agriculture [46].

Smart surveillance systems integrate advanced technologies like sensors, drones, AI, ML, and IoT to automate and optimize monitoring in the agricultural sector. These technologies provide real-time, remote monitoring, data analytics, and automated decision-making, making agriculture more efficient and sustainable. The major components used in smart surveillance for agriculture is listed as follows [47, 48]:

- **IoT Sensors**: These sensors monitor variables like soil moisture, temperature, humidity, and crop growth. Placed throughout the field, they send real-time data to cloud-based platforms for analysis.
- **Drones and Aerial Surveillance**: Drones equipped with high-resolution cameras and multispectral sensors can cover large areas and detect issues like pest infestations, plant diseases, or water stress that may not be visible from the ground.
- **CCTV and Thermal Cameras**: High-definition cameras and thermal imaging systems can monitor animal welfare, crop fields, and detect intruders or predators.
- **AI and ML**: AI algorithms analyze the data collected from sensors and cameras to predict crop diseases, livestock health, and even optimal harvest times. Machine learning helps in making sense of patterns in the data to improve efficiency and decision-making.
- **Automated Alarms and Notifications**: If a problem is detected, such as a drop-in soil moisture or an increase in pest activity, the system automatically sends notifications to farmers or triggers automated irrigation systems.
- **Satellite Monitoring**: Satellite data provides broad-scale insights into environmental conditions, soil health, and weather patterns that can be used to optimize planting and harvesting.

- **Smart Fencing and GPS Tracking**: Livestock can be monitored in real-time using GPS trackers, and smart fences can alert farmers if animals stray or predators are near.

With the use of smart surveillance system farmers can get immediate updates on the state of their crops or livestock, allowing for rapid interventions. Also, automation reduces the need for manual inspections and can control systems like irrigation and pest control based on real-time data. Continuous data collection enables predictive analytics, helping farmers anticipate and prevent issues before they become serious. Also, it allows farmers to monitor their fields or livestock from anywhere, reducing the need to be on-site all the time. By analyzing data, farmers can better manage resources like water, fertilizer, and pesticides, reducing waste and increasing sustainability [49, 50].

Smart surveillance systems in agriculture, while highly beneficial in terms of monitoring crop health, optimizing resource use, and improving productivity, come with several disadvantages. One of the major challenges is the high initial cost of installation, which includes the purchase of surveillance equipment such as drones, sensors, and cameras, as well as the necessary software for data processing and analysis [51]. For many small-scale farmers, these costs can be prohibitive, limiting access to advanced technologies that could otherwise enhance their operations. Additionally, smart surveillance systems require reliable internet connectivity for real-time data transmission and remote monitoring.

In rural areas, where agricultural activities are most prevalent, internet access is often unreliable or completely unavailable, which severely limits the effectiveness of these systems. Maintenance and operational costs also pose ongoing challenges, as the equipment requires regular updates, repairs, and calibration to function optimally [52].

Another significant concern is data security and privacy. The constant surveillance of farmland and the collection of large amounts of data about crop yields, soil conditions, and farm activities can be vulnerable to hacking or unauthorized access, leading to the theft of sensitive information or sabotage of agricultural operations. Lastly, there is the issue of technological complexity. Farmers, especially those in rural or less technologically advanced regions, may lack the technical expertise needed to operate, interpret, and fully benefit from these sophisticated systems, leading to underutilization or inefficiency in their application.

Table 2. Comparing Traditional vs. Smart Surveillance Systems in Agriculture [50,51,52].

Aspect	**Traditional Surveillance**	**Smart Surveillance**
Monitoring Method	Manual observation, basic tools	Automated IoT sensors, cameras, drones, AI
Data Handling	No data storage, human-based decision-making	Continuous data collection, automated analysis and response

Accuracy	Prone to human error, low precision	High accuracy with real-time monitoring and predictive insights
Coverage	Limited to smaller areas, manual inspection	Large-scale coverage with drones and sensors
Response Time	Delayed due to manual intervention	Immediate with automated alarms and decision-making
Cost	Low initial investment, labor-intensive	High initial cost, but long-term savings in efficiency
Ease of Use	Simple, requires no technical expertise	Requires technical know-how, maintenance

Smart surveillance systems in agriculture offer numerous advantages such as real-time data, automation, and increased efficiency. However, they come with challenges such as cost and technical complexity. While traditional systems are still widely used, smart systems are rapidly gaining popularity, especially as precision farming becomes more important in addressing the challenges of food security and sustainability using smart surveillance system.

5. Overview Challenges facing the application of smart surveillance systems

Smart surveillance systems have revolutionized the way we monitor, secure, and manage various sectors including security, healthcare, agriculture, and energy. By leveraging the advanced technologies such as AI, ML, and the IoT, these systems provide real-time monitoring, predictive analytics, and automated decision-making [53]. However, their effectiveness heavily relies on the communication infrastructure in place. There are several challenges that smart surveillance systems face, particularly regarding communication in urban and rural settings. There is a need to discuss on how the communication challenges in urban and rural area can be solved.

Communication infrastructure is one of the most critical components of a smart surveillance system. A reliable, fast, and secure network is required to transmit real-time data from surveillance devices to central monitoring systems. However, the choice of communication technology varies significantly between urban and rural areas due to the digital divide that exists, the differences in infrastructure, population density, and geographic challenges [53].

6. Urban Communication Challenges and Suitable Communication Modes for Smart Surveillance System

Urban areas, with their dense infrastructure and high population density, offer unique challenges and opportunities for smart surveillance systems. The large number of connected devices and the demand for high-speed, low-latency communication place heavy demands on existing networks. The following communication challenges are faced for implementation of smart surveillance system [52, 54]:

- **High Data Traffic and Network Congestion:** urban areas experience high data traffic due to the concentration of devices such as surveillance cameras, sensors, and mobile devices, all connected to the same network. This congestion can result in slow data transmission and delayed responses, which are critical drawbacks for real-time surveillance systems.
- **Interference from Other Devices:** The high density of wireless devices in cities can cause interference, particularly in communication systems that rely on radio frequencies, such as Wi-Fi and cellular networks. This interference can degrade the quality of video streams or lead to dropped connections, affecting the reliability of the surveillance system.
- **Security and Privacy Concerns**: urban surveillance systems often capture data from public areas, raising significant concerns about data privacy and security. Hackers can target these systems to steal data or disrupt operations. Ensuring secure communication protocols and encryption for data transmission is essential to prevent unauthorized access.

To overcome the above challenges, a combination of advanced communication technologies can be used in urban environments [42, 55, 56, 57]:

- **5G Networks**: with high bandwidth, low latency, and fast data transmission, 5G is ideal for real-time surveillance in urban areas. It supports large numbers of connected devices and can handle high data traffic efficiently. However, the rollout of 5G infrastructure is still in progress in many regions.
- **Fiber Optics**: fiber-optic communication offers high-speed, reliable data transmission over long distances without interference. This makes it suitable for backbone connections between surveillance cameras and control centers in cities.
- **Wi-Fi 6**: This newer generation of Wi-Fi provides faster speeds and supports more devices simultaneously, reducing network congestion and interference. Wi-Fi 6 is particularly suitable for connecting IoT devices in smart city surveillance systems.
- **Edge Computing**: processing data locally at the edge of the network (i.e., close to the surveillance devices), edge computing reduces the load on centralized servers and minimizes latency. This is especially useful in applications requiring immediate response, such as traffic monitoring or emergency services.

However, in selecting any of the communication mode for smart system in urban area, the adaptability and compatibility with other devices that are the components of the smart system must also be considered for effective communication.

7. Rural Communication Challenges and Suitable Communication Modes Smart System

In rural areas, the lack of robust communication infrastructure poses significant challenges to the deployment of smart surveillance systems. Remote locations often lack high-speed internet access, and the sparse population makes it less economically viable for telecom companies to invest in advanced networks [58]. Several challenges in implementing smart surveillance system for security, health and agriculture and energy sector in rural areas includes the following [58, 59]:

- Limited or No Internet Access: many rural areas still lack access to reliable internet services, especially broadband. This makes it difficult to deploy surveillance systems that rely on cloud-based storage and real-time monitoring. In some areas, even cellular networks are unavailable, complicating communication between surveillance devices and central control systems.
- Geographic Barriers: rural regions often have challenging terrain, such as mountains, forests, or vast agricultural fields, which can impede the transmission of signals. This makes it difficult to establish continuous communication across large distances, especially using traditional communication technologies.
- Cost of Infrastructure Deployment: installing new communication infrastructure, such as fiber-optic cables or cellular towers, can be prohibitively expensive in rural areas due to the low population density. The cost of maintaining these systems over time adds to the financial burden, making it difficult to justify the investment in many cases [60].

Based on the unique challenges faced in rural areas, different communication technologies can be employed to ensure effective data transmission for smart surveillance systems [60,61,62]:

- **LoRa (Long Range):** LoRa is a low-power, long-range wireless communication technology ideal for transmitting data over large distances with minimal power consumption. It is suitable for remote agricultural surveillance, where devices are spread across wide areas and need to operate on battery power for extended periods.
- **Satellite Communication**: In areas with no terrestrial internet or cellular coverage, satellite communication provides a reliable alternative. Satellites can provide internet access and data transmission to even the most remote locations, although the cost and latency of satellite services can be higher than terrestrial solutions.
- **Mesh Networks**: Mesh networks involve multiple nodes (such as surveillance cameras or sensors) communicating with each other to form a decentralized network. This type of network is resilient and can cover large areas without the need for extensive infrastructure, making it ideal for rural or agricultural settings.
- **4G LTE (Long Term Evolution):** In rural areas where 5G networks are unavailable, 4G LTE remains a viable option for surveillance systems. It

offers decent speed and coverage, especially when paired with repeaters or boosters to extend the signal range in remote locations.

However, in the use of any of the communication technology for rural area, other devices that made up the smart surveillance system must be put into consideration for effective usage. For smart surveillance systems to be effective in remote or underserved areas, alternative communication technologies must be considered.

- **Hybrid Communication Systems**: combining multiple communication technologies such as LoRa for low-power, long-range communication and satellite networks for high-bandwidth data transfer can provide a robust solution in remote areas.
- **Local Data Storage and Processing**: in rural areas with limited connectivity, surveillance systems could store data locally and process it on-site using edge computing. This minimizes the need for constant internet access while still providing valuable insights.
- **Private LTE Networks**: for critical applications in remote areas, deploying private LTE networks can provide reliable communication without relying on public cellular networks.

Smart surveillance systems have the potential to transform various sectors, but their effectiveness is largely dependent on the communication infrastructure available. Urban areas benefit from advanced technologies like 5G, fiber optics, and edge computing, while rural areas face greater challenges due to limited internet access and geographical barriers. By leveraging alternative communication technologies such as LoRa, mesh networks, and satellite communication, smart surveillance systems can be implemented effectively in remote areas. However, to maximize the impact of smart surveillance systems, there must be a concerted effort to overcome these communication challenges, particularly in underserved regions.

D. Conclusion

This comprehensive review of smart surveillance systems highlights their transformative potential across various sectors, including security, healthcare, agriculture, and energy. In the security sector, smart surveillance enhances real-time monitoring, threat detection, and response, improving public safety. However, challenges such as high implementation costs and cyber-security risks limit its broader deployment. In the healthcare sector, smart systems can monitor patient conditions and improve hospital management. Still, concerns regarding data privacy and the complexity of integration with existing medical systems present significant hurdles. In agriculture, smart surveillance promotes precision farming by monitoring crops, livestock, and environmental conditions, but rural areas with low or no internet connectivity hinder its widespread use. Similarly, in the energy sector, smart surveillance helps detect energy theft, optimize grid performance, and enhance maintenance efficiency, yet the high cost of deployment and cyber-security concerns remain critical obstacles. One key limitation in all these sectors, especially in remote areas, is the reliance on stable and fast internet connectivity. Rural and underserved regions often lack the infrastructure needed for the effective deployment of smart surveillance systems. For these areas, alternative communication technologies such as LoRa (Long Range), mesh networks, and satellite-based communication could offer viable solutions. These systems can enable data transmission over long distances without the need for traditional internet access, making it feasible to implement smart surveillance in remote locations. To overcome the challenges faced in remote regions and sectors with limited resources, leveraging non-internet-based communication systems, reducing costs through scalable solutions, and improving cyber- security frameworks will be key steps in advancing the adoption of smart surveillance systems across all the industries.

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