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Smart Algorithm and Informatics Technology for Public Safety

White Paper

Smart Algorithm and Informatics Technology for Public Safety: An IEEE Public Safety Technology Initiative Report

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ABSTRACT

Technologies for public safety include innovative strategies leveraging Internet of Things (IoT), AI, and data analytics for community safety. They provide rapid and efficient catastrophic responses while enhancing prevention, protection, mitigation, response, and recovery. Compatibility, interoperability, data security, and changing standards are all difficulties. Cooperation is required to standardize technology, establish frameworks, and provide data protection priority. To keep up with innovations, agile techniques must be used to evaluate, update, and create new standards. The five mission areas of prevention, protection, mitigation, response, and recovery are discussed in the white paper. It addresses UAVs for protection, emergency mitigation techniques, facial recognition and surveillance for reaction, and the function of smart cities in assisting with recovery operations.

1. INTRODUCTION

Technologies for public safety include a wide range of innovative strategies aimed at improving community safety and security. These technologies leverage the use of developments in Internet of (IoT), AI, and data analytics to assist a range of mission areas, including prevention, protection, mitigation, response, and recovery. These technologies offer rapid and more effective responses to catastrophes, from preventative measures that reduce risks and losses to intelligent systems that watch over them. They are also essential in the recovery stage, helping resource allocation as well as coordination to return things back to normal after a disaster. As public safety technologies grow, they provide complete solutions that enable government agents, businesses, and people to enhance public safety and the general welfare of society.

However, creating standards and simplifying public safety technology presents significant challenges. Compatibility issues and interoperability constraints may arise because of the diversity of technological solutions, providers, and systems. Collaboration amongst stakeholders, including governmental organizations, business leaders, and standards organizations, must happen to harmonize various technologies and establish frameworks for seamless integration. Securing data privacy and security is another challenge. Technologies for public safety produce enormous volumes of private information, which generate concerns about data breaches and unauthorized access. Striking the ideal balance between offering data to enable efficient response and maintaining individual privacy is a difficult challenge that necessitates stern security precautions and compliance with regulations. In addition, maintaining standards can be challenging considering the rapid speed of technological improvements. As new technologies are developed, current standards may become obsolete or inadequate. It is essential to establish agile procedures to evaluate, update, and develop new standards with the objective of keeping up with technological developments and preserve the compatibility of systems.

Across a range of mission areas, public safety technology is vital for ensuring the safety of communities. This white paper explores five key mission areas: prevention, protection, mitigation, response, and recovery.

- The development of preventive measures to reduce crises, dangers, and losses is the primary goal of the prevention section. IoT technology is emphasized as a useful tool, providing reliable and quickly available data for locals' safety. Public safety officials may receive regular information and security assurances because of the incorporation of IoT connectivity, which offers affordable and user-friendly solutions.
- The protection mission area highlights the crucial role that UAVs play in supply delivery, healthcare communication, and disaster management, ultimately enhancing public safety. To effectively implement new technologies and IoT networks in the field of public safety, the study emphasizes the significance of managing energy usage and optimizing connection.
- The third mission area, mitigation, acknowledges that, despite the significance of protection and prevention, emergencies can still happen. The magnitude of such catastrophes can be mitigated significantly by the application of mitigation methods. For instance, prompt notification of a traffic accident to the control center ensures swift action from the rescue crew members. In order to ensure public safety, efficient mitigation methods must be used to reduce reaction times.

- The public safety technology response mission area aims to address facial recognition, drowsiness driver detection, and license plate recognition (LPR). The study demonstrates how preprocessing methods and CNN-based algorithms can recognize drivers even in severe light conditions. These technologies significantly improve the capacity for identification, alerting, and monitoring, which ultimately assists in swiftly responding to catastrophes.
- Finally, the recovery mission area emphasizes the value of smart cities in enhancing public safety while also acknowledging that they are not immune to catastrophic events. In the aftermath of disasters, recovery activities have become crucial for restoring order and maintaining public safety. Coordinating many organizations, resources, and money is crucial for effective disaster recovery. Planning and coordination are essential for providing impacted populations with appropriate support during recovery.

This white paper provides insights into the importance of public safety technology in preventing emergencies, safeguarding people, managing risks, successfully reacting, and supporting recovery operations by looking at five key mission areas.

2. INDUSTRY LANDSCAPE

2.1. Prevention

Prevention is an important part of public security management. It can prevent emergencies and reduce threats and losses to society. Public safety officials need to provide as much help as possible in developing preventive measures when providing services to citizens, and IoT technology can provide important solutions when needed. Especially when it comes to the safety of residents, data needs to be reliable and easily accessible. IoT connectivity offers a low-cost, low-power, and user-friendly experience, providing an integrated solution for the constant updates and security assurances that public safety officials expect. In the following, we will elaborate on what public safety officials need to be aware of when developing preventive measures and the IoT technologies that can help with public safety prevention.

IoT is a huge dynamic global network infrastructure of Internet-enabled physical and virtual objects/entities with web services which contains embedded technologies and all types of information devices such as global positioning system (GPS), infrared devices, scanners, radio frequency identification (RFID) tags/devices, sensors, actuators, smartphones, and the Internet to sense, identify, locate, track, connect, monitor, manage, communicate/interact, cooperate, and control of objects/things in physical, digital, and virtual world [1].

2.1.1. Challenges

2.1.1.1. Precision Warning

The most essential function of the urban public safety early warning mechanism is pre-forecasting public safety incidents. Prevention focuses on anticipating public crisis events within a specific time frame, i.e., accurately distilling information and data. The prediction and research, anti-micro-duration, to get the time and opportunity for early preparations for various precautions. The concept of precision warning is to require the early warning mechanism to monitor the abnormal situation accurately and comprehensively, to carry out scientific grading according to the scope and degree of impact of the crisis event, to issue alarms according to different levels, and to guide the relevant government departments to formulate science, reasonable grading plan, take appropriate measures to prevent and control the crisis.

In the process of public safety prevention, the role of IoT technology should be fully utilized. By deploying many IoT devices in various places, all-around monitoring can be implemented, and loophole-free management of potential safety hazards can be realized so that the overall security network of the city can operate normally and orderly. Finally, a smart city system will be formed. In addition, public safety prevention also needs to do a good job in publicizing the safety of citizens and cultivating a keen sense of safety protection and safe escape skills. An excellent application in this regard is the AMBER alert program popular in North America.

2.1.1.2. Collaborative Warning

The urban public security early warning mechanism is a highly complex system that requires the participation and cooperation of departments, governments, and multiple entities to achieve efficient operation of the early warning mechanism. The concept of coordinated early warning first requires strengthening the coordination and sharing of early warning data, early warning information, early warning technology, early warning funds, and early warning personnel in the era of big data. Secondly, it is necessary to build an urban public security early warning unified command and coordination organization to realize various resources and timely dispatching and sharing of information, clarifying the responsibilities and authorities of different departments, and preventing the phenomenon of multiple outs of government and mutual suspicion affecting resource utilization efficiency.

2.1.1.3. Rapid Warning

The outbreak of public safety events in most cities is very rapid, and early warning mechanisms need to be able to respond quickly. This requires us to use the concept of rapid warning to guide the optimization of urban public safety early warning mechanisms, adhere to the concept of rapid warning, and establish the concept of time first. Ensure that public safety incidents are controlled in a timely manner to minimize or reduce the economic and personnel losses caused by the outbreak of public security incidents, maintain the stability of social order, protect the public from harm, and promote the orderly development of security measures. Second, we must uphold the concept of decisive decisions. When urban public safety incidents occur, decisions must be made decisively, and the opportunities must not be delayed. Ensure that all departments work together, communicate effectively, and respond promptly and accurately.

2.1.1.4. Specification Warning

To realize the optimization of urban public security early warning mechanisms in the era of big data, the opening and sharing of data are indispensable, and to realize the opening of all kinds of big public data, it is necessary to have laws to follow, to achieve openness and evidence, and to share effectively. The harmonious situation. In addition, the construction of urban public security early warning mechanisms is a comprehensive system involving government, society, citizens, and other subjects. Without unified standards and normative regulations, all kinds of information will be disordered, and public security management will develop orderly. To this end, it is necessary to use laws and regulations as a guide to improve the relevant rules and regulations of the urban public safety early warning mechanism from the national and individual levels, clarify the responsibility of each department, and standardize the operation of various information and processes.

2.1.1.5. Privacy Warning

The issue of privacy and security is an important consideration in the process of public safety prevention. On the one hand, public safety prevention often requires the collection and storage of large amounts of personal data, such as identity information, communication records, location data, etc. The collection and storage of this data require compliance with privacy protection regulations and best practices. On the other hand, public safety prevention often involves data sharing and cooperation between multiple departments, agencies, or organizations. In data sharing and collaboration, it is critical to establish secure data transmission and access mechanisms to ensure the confidentiality and integrity of data. As a result, it is necessary to adopt encryption techniques, access control, and auditing mechanisms, to limit the scope of access to data and the purposes for which it can be used, and to sign appropriate agreements to regulate the scope and conditions of data sharing. In addition, even where data is anonymized, malicious users or technologists may be able to restore personally identifiable information by correlating and extrapolating multiple data sets. For example, the analysis of location data and other social media information recorded by public safety cameras may reveal an individual's whereabouts and identity, thereby affecting personal privacy.

2.1.1.6. Unified Standard for IoT in Public Safety

A unified standard is necessary to develop IoT for public safety and improve its efficiency. But, having one standard for IoT in public safety in the world and one common agreed IoT architecture among academia, industries, and organizations is very difficult. Also, safety standards should be investigated.

2.1.1.7. Privacy and Security

A lot of personal information is gathered by different sensors. Security breach and unauthorized access to sensors increase personal information vulnerability and leakage. So, confidentiality, privacy, and security issues should be addressed. Also, cybercrime and cybersecurity need to be investigated.

2.1.1.8. Public Regulations and Rules

Due to rapid development of IoT devices, required public rules have not been developed which will cause ethical issues. So, related policies, public regulations and rules must be established.

2.1.1.9. Management of Heterogeneous Devices

Since many static and mobile heterogeneous devices use IoT, their management will cause many issues. So, management of IoT heterogeneous devices needs new regulations and solutions.

2.1.2. Potential Solutions

With the fast advancement in technology, IoT has proved its significance in all sectors, and it can make life easier [2]. Thanks to the rapid development of IoT and artificial intelligence (AI) technologies, more and more industries have begun to use these technologies to establish corresponding security prevention systems.

2.1.2.1. Face Recognition

Face recognition is a biometric technology that automatically recognizes people based on their facial features (such as statistical or geometric features, etc.), and it's very significant owing to its varied range of law enforcement applications. In the traditional investigation method of public security, photo comparison can only be carried out manually, which has a huge workload, slow speed, low efficiency, and cannot meet business needs. The high-speed automatic recognition capability of the face recognition system can largely free the public security and security departments from the previous "crowd tactics", greatly improving the security level of the entire country and society to deter crimes and punish criminals, maintaining social stability, and safeguarding national security. The application of face recognition in the field of public security focuses on the registration and management of offenders, online pursuit, comparison and verification, and post-processing. At the same time, portrait comparison can also be used in criminal investigations and in maintaining social stability.

The face recognition photo comparison system is used for rapid identification, searching, and retrieving of the identity of a specific person in many databases. It makes full use of the valuable facial photo clues to greatly speed up the identification process of suspects by public security investigators, providing an effective technical means to accelerate the process of "strengthening the police with science and technology" and to form a highly intelligent, social and large-scale public security prevention system. To strengthen the role of face recognition technology in public safety, some authors design robust face recognition systems, which can be utilized for face recognition based on sketches that should be implemented to assist police in recognizing the suspect [3].

2.1.2.2. License Plate Recognition (LPR)

Along with the increase in the number of cars in the world, urban traffic conditions have become increasingly important to people, and how to effectively carry out traffic management has become more the focus of attention of the relevant departments of governments. In response to this problem, people run advanced information processing technology, navigation, and positioning technology, wireless communication technology, automatic control technology, image processing, vehicle number plate recognition technology, computer network technology, and other science and technology, have developed a variety of traffic road monitoring and management systems, vehicle control systems, and public transport systems. A license plate recognition (LPR) system is a technology that can detect vehicles on the monitored road and automatically extract vehicle license plate information for processing [4]. LPR technology is based on digital image processing, pattern recognition, computer vision, and other technologies and analyses the vehicle images or video sequences taken by the camera to obtain a unique license plate number for each vehicle, thus completing the recognition process and is one of the important components of modern intelligent transportation systems. Moreover, LPR plays a significant role in the development of smart cities, and it has been utilized in many commercial applications, such as searching for stolen vehicles, automating parking systems, and speed monitoring. For the LPR system to have high recognition accuracy in poor lighting conditions and extreme weather conditions, an efficient license plate recognition system uses convolution neural networks and retrieves license plates from vehicles to reduce false positives on plate detection [5].

2.1.2.3. Drowsiness Detection

Lack of sleep is a major cause of motor vehicle accidents. When a person does not get enough sleep, their coordination is affected, their reaction time is longer, and their judgment and memory are reduced [6] [7]. According to a 1998 survey, 23% of adults would fall asleep while driving [8]. According to the US Department of Transportation, male drivers fall asleep at the wheel twice as often as female drivers. To reduce road accidents, efficient driver drowsiness detection systems are required. The Drowsy Driver Detection System (DDS) is a system that detects that a driver is driving fatigued according to the PERCLOS algorithm and then issues a warning signal. The system uses radar to scan the pupil condition and determine the driver's fatigue status through data analysis. Once the driver is in a state of fatigue and drowsiness, the system will give advance warning to the driver, who may suddenly fall asleep while driving due to fatigue. Specifically, authors have proposed a real-time driving drowsiness detection algorithm that considers individual driver differences and builds a deep cascaded convolutional neural network to detect face regions, avoiding the problem of a poor accuracy due to artificial features [9].

2.1.2.4. Smart Emergency Response System

Establishing an effective intelligent emergency response system can prevent some natural disasters or social threats. For example, in fire safety and management, the IoT provides appropriate solutions in a secure manner for the protection of city assets such as local departmental information systems, transport systems, schools, libraries, hospitals, power plants, and other community services. Therefore, IoT can play an effective role in achieving a smart city vision. An effective fire hazard intelligent emergency response system based on the IoT is proposed, which is composed of an ESP-32 single-chip microcomputer, combustible gas detection sensor, flame detection sensor, smoke detection sensor, and GPS module [10]. Sensors are used to detect hazards and notify the fire department. Moreover, the system can send the location of the hazard to the cloud. In addition to fire safety, an average of 128 bridges collapse in the United States every year, and some serious cases will cause death. The effective way to avoid such disasters is to carry out preventive maintenance. Using data generated by sensors from IoT devices to drive artificial intelligence and machine learning algorithms, managers can make predictions about urban infrastructure and detect damage by measuring structural displacements and vibrations, which can indicate the state of cracks, stretching, or excessive deformation of buildings. This enables managers to identify potentially life-threatening problems early and carry out preventive maintenance. For example, IoT sensors on bridges connected via the Internet allow municipal officials and construction workers to continuously monitor all bridges throughout the city. If there is a dangerous situation, such as a widening crack or deformation, the sensors will immediately send an alert to the responsible officer, making the level of accident risk much lower.

2.1.2.5. Worker Safety Monitoring

Construction safety management is an important part of project management, and unsafe behavior of workers on construction sites is one of the main causes of construction accidents. Therefore, real-time monitoring of workers' unsafe behaviors and timely issuance of early warning information will help prevent accidents and improve the safety management level of construction sites. Worker unsafe behavior monitoring often includes safety helmet recognition, reflective clothing recognition, environmental risk recognition, and personnel behavior recognition. Specifically, a safety helmet automatically identifies workers on site and detects how they are wearing their helmets. When a worker is not wearing a helmet in a construction area, it immediately triggers an alarm alert to notify safety management personnel. Reflective clothing recognition is used to detect the wearing of reflective clothing on construction sites at night, effectively preventing accidents caused by the wearing of reflective clothing and enabling cost-effective supervision. Environmental risk recognition monitors the camera video in real-time. When smoke or flames appear in the video, the system actively triggers an alarm and notifies by text message, phone call, alarm voice, etc. Personnel behavior recognition will automatically identify smoking and mobile phone behaviors in the construction inspection area. When a person is detected smoking or playing with a mobile phone, an alarm is triggered immediately to avoid potential safety accidents. To this end, some have proposed an IoT-based system that provides smart fog computing-based personal protective equipment designed to monitor the safety of lone workers [11]. The system alerts safety managers when a worker is not wearing the required personal protective equipment and provides rapid rescue in the event of a worker seeking assistance or an accidental fall.

2.1.2.6. Federated Learning Prevention Mechanisms

First proposed by Google in 2016, Federated Learning was originally designed to address the problem of collecting data on multiple Android devices to train a model while avoiding violating user privacy. Federated Learning is a distributed machine learning approach that aims to allow multiple participants to jointly train a global model while protecting the data privacy of all parties. Unlike traditional centralized machine learning, federated learning shifts the training of a model from a central server to a local device, allowing participants to train the model while keeping the data local. In federated learning, the participants are usually end devices in a distributed system, such as smartphones, sensor nodes, or edge computing devices. These devices store their own data, such as personal information, images, and text of the user. Moreover, the participants communicate and update their models with a central server through a federated learning framework. The main processes of federal learning are as follows: the central server initializes a global model and distributes it to all participating parties. Participants train the global model locally using their own data. In this process, participants only use their own local data for model training and do not transfer raw data to the central server. Participants transfer updates to the model such as weight parameters back to the central server after local training. The central server uses an aggregation algorithm such as the federated averaging algorithm to consolidate the participant's model updates to generate a new global model based on the participant's model updates received. Finally, the above process is repeated for multiple rounds, with each participant updating the model after local training and then aggregating the model updates to a central server to continuously improve the global model.

In a word, federated learning is suitable for scenarios where multiple parties collaborate on data for training, such as in healthcare where multiple healthcare providers work together to train models without pooling all the data into one place. This approach can improve the performance and generalization of models and facilitate a balance between data collaboration and privacy protection. In public safety prevention, it is common practice to use machine learning and data analytics techniques to train models and assess risk. Federal learning or differential privacy can be applied during model training and evaluation to avoid the disclosure of personal data.

2.1.2.7. City Management Architecture

City management architecture can be used to cooperate in different levels, ensure successful monitoring and decisions, improve coordination, prevent information congestion and inconsistency.

2.1.2.8. Warning Systems

IoT devices can collect a lot of information from different sensors to detect normal or abnormal activities and alarm the people to prevent any dangerous situations or death, e.g., seat belt alarm, tire air-pressure indicator in car, or vital health monitoring, etc.

2.1.2.9. Smart Cities

Smart cities can be considered as a connected ecosystem of ecosystems [14]. Smart cities can manage public safety complexity and enhance public safety security by using a network of sensors to detect safety related issues, prevent some crimes, and react to emergency situations more quickly.

2.2. Protection

With the fast advancement in technology, IoT has proved its significance in all sectors. It can make life easier [15]. An IoT-based system which can monitor the safety of lone workers has been proposed [16]. This system provides smart and affordable personal protection equipment based on Fog-Computing. It was found that this system can detect human falls and call the rescue automatically. Although there are several research works for enhancing the safety of workers, it was noted that only few research works that targets the safety of lone workers were proposed. Thus, more solutions are needed to enhance the safety of lone workers.

Machine learning (ML) and IoT play a significant role in smart farming. They can offer intelligent solutions to the issues of traditional agriculture. Plant disease can affect productivity. Thus, effective systems for detecting plant disease early are required [15]. A crop disease prediction system based on Convolutional Neural Networks (CNN) and IoT has been proposed [17]. In this system, drones were employed for capturing images for the crops. In addition, sensors have been utilized for capturing the moisture, salinity, and other data of soil. It was noted that the transmission of data from sensors can be stopped owing to the damage of sensors whey they are utilized for a long time. Thus, regular checking of sensors is needed. A CNN-based system has been proposed to determine the degree of disease of crop leaves. For this purpose, ResNet50 has been employed and it has achieved an accuracy of 95.61% [18].

2.2.1. Challenges

The next generation envisioned wireless technologies aim to enable ubiquitous connectivity, energy efficient designs, enhanced capacity, high speed, high reliability and low latency-oriented communications, such as among vehicles and other autonomous connected devices [19]. These advanced technical solutions based on smart algorithms and automated designs will not only provide anytime and anywhere connectivity but also assist massively the public safety operations. To fulfil this vision, unprecedented surge in data volumes, transmissions and energy consumption are expected for wireless connected applications used in protection and response of natural calamities. Precisely, it is expected that only fifth generation (5G) connections will constitute towards 1.4 billion mobile devices by 2023 [20], and there will be 4.4 billion 5G subscriptions worldwide presenting faster growth than previous generation standards [21]. One can understand the ongoing global activities in 6G mobile communications, next generation technology enablers, recent trends, use cases and networks requirements towards the year 2030 [22]. The ongoing standardization for 5G and 5G-Advanced systems and networks is being offered to mobile consumers with smart-phones, however there is an expected gradual shift towards fulfilling the enhanced user demands which utilize massive IoT and massive machine type communication (mMTC) devices. For high reliability of protection and response to public safety emergencies can lead to even more enhanced demand of all-time and fast connectivity. The ever-increasing growth and user demand in 5G-Advanced and 6G systems will lead to service providers finding smart algorithmic solutions to make use of available resources for maximum capacity possible.

2.2.2. Potential Solutions

2.2.2.1. Wireless Technologies

One of the advanced approaches is the implementation of integrated sensing and communication (ISAC) technology, which provides a potential solution towards efficient use of hardware and spectral resources, while decongesting the crowded sub-6 GHz spectrum used for most of the mobile communications [23] [24]. For ISAC designs, there have been recent technical advancements in terms of achieving energy and hardware efficient systems and optimal waveform designs [25] [26] [27], which are all useful in carrying out wireless connectivity required for public safety operations. Besides spectrum and hardware sharing, non-terrestrial networks (NTNs) such as the use of low-Earth orbit (LEO) satellites and unmanned aerial vehicles (UAVs) can provide high connectivity, where these flying platforms can act as relays and help transceivers build reliable communication links with remote areas such as over the disaster-effected regions. The overview, use cases, deployment scenarios, and various architectures on 5G-envisioned NTNs are provided [28]. In terms of the Third Generation Partnership Project (3GPP) work on the evolution of the 5G technologies, there has been a recent focus on NTNs for their latest release, i.e., Rel-17, where Rel-16 addresses the enabling 5G New Radio (NR) support for NTN technology including architecture, higher-layer protocols and physical layer (PHY) aspects [29]. The current trends of NTNs in 5G, 5G-Advanced and 6G-envisioned communications is highlighted [30] [31] [32]. The demand for the evolution of NTN-based communication arises extensively in remote areas, including forests and deserts, where it is still difficult to provide high coverage leading to advanced wireless-enabled solutions for public safety.

2.2.2.2. Role of Non-Terrestrial Networks

The advanced technical approaches in NTNs enable possible resources and solutions for these issues such as aiming for hardware-efficient NTNs which reduce deployment cost against conventional satellite networks. Accordingly, there are some initial indications that upcoming wireless standards are assisting public safety paradigms while leveraging full potential of NTNs. Both academia and industry have started taking a keen interest in utilizing flying platforms such as UAVs, drones, and unmanned balloons for wireless communications, which can further be employed for public safety operations. Such flying platforms can be manually controlled but are mainly designed for autonomous pre-determined flights. Latest flying platforms can carry radio frequency (RF)/millimeter-wave/free space optics (FSO) payloads along with an extended battery life [33]. Since their flying altitude range, flying platforms are categorized into: i) low-altitude platform (LAP) (less than 5km), ii) medium-altitude platform (MAP) (between 5km-10km), and iii) HAP (greater than 10km). Timely warnings and relief operations using NTNs/UAVs can play a significant role in mitigating damages caused by disasters. Disaster management and rescue operations can effectively utilize emerging 6G technologies and IoT networks. UAVs featured with small size, low weight, flexible mobility and aerial capabilities are often employed for surveillance in areas where access of humans or ground nodes is challenging [34]. For example, UAVs can provide connectivity in disasters and harsh environments when ground infrastructure is either damaged or prone to destruction. Real time monitoring and surveillance of affected areas through electronic sensors and communicating warnings via UAVs is one of the feasible solutions to disaster-related challenges.

For instance, autonomous drones and UAVs can assist in different scenarios where any sort of patient-to-hospital communication is involved such as IoT which accounts for data collection, delivery and processing, cellular networks, satellite and wireless communications, and UAV-UAV communications for better planning of drone flights avoiding mid-air collisions. Another example is that autonomous UAVs can provide a more portable and faster reach of medical supplies to hospitals locally. The energy consumed by autonomous UAVs for proper functioning is quite critical and fundamental to designing cost-effective UAVs. The UAV-assisted communication and control operations, cellular network-based UAVs or IoT-inclined UAVs, irrespective of their application scenario, require considerable power which is consumed by communication operations or the system architecture such as signal processing, digital and analog circuitry, radio frequency chains and power amplifiers. In different ways, to make UAV-assisted wireless connectivity for public safety operations more effective, energy consumption can be optimized using solutions such as RF chain optimization, optimization of low-resolution sampling units in the UAV system hardware and exploiting hardware impairments in beamforming designs.

2.3. Mitigation

Although prevention, on one hand, helps in reducing the chances of emergency incidents for public safety, however it is difficult to fully prevent emergency incidents from happening. On the other hand, protection helps in defining procedures and strategies of public safety to protect oneself when emergency incidents happen, however, it does not provide full support to cope with the emergency situations. Therefore, a response for public safety is needed when emergency incidents happen to handle the situation. However, there could be some delay in responding to emergency incidents and therefore, mitigation plays an important role in public safety. Mitigation helps in reducing the seriousness or severity of an emergency incident. For example, when a road accident occurs, such information must be transmitted to the control center so that a rescue team can be sent to the place of incident in response. Here, a mitigation strategy can help in sending the information of an accident to the control center with minimal delays so that the rescue team can arrive as soon as possible.

Public safety is required in various sectors ranging from healthcare, transportation, education, firefighting to wildlife, etc. Many technologies are critical to meet the safety demands of humans, systems, and data (HSD). The number of technologies that deal with all aspects related to HSD is too large to be discussed here; therefore, our focus in this section is on data and information. This section focuses on mitigating algorithmic and informatics related risks in key sectors. The connection between public safety and informatics and algorithms has become stronger over the past few years. Dealing with such risks is critical to support law enforcement bodies in dealing with public safety.

The reminder of this section first provides an overview of the need for mitigation strategies from the algorithmic and informatics perspectives for some sectors of public safety. Next, it discusses challenges of some sectors associated with mitigation and provides proposed solutions that can help in solving these challenges.

- **Transportation:** There are four main modes of transportation: road, rail, air and maritime. Public safety is a major concern in all these modes of transportation because any serious incident in the sector of transportation directly affects the safety of the public. With the advancement of recent technologies, current transportation systems are equipped with the latest technologies (such as sensors, cameras and communication systems). These technologies can help in mitigating the severity of incidents mostly with the help of informatics and algorithms. Therefore, mitigation techniques are required to deal with public safety in transportation.
- **Education:** Public safety is a major concern in education, as the severity of incidents involving violence, theft, and other criminal activities continues to occur. To make schools more resilient against potential threats, careful consideration must be given to the infrastructure of the school. In addition, it is important to have an emergency response plan in place so that if an incident does occur, it can be handled quickly and effectively. Smart algorithms can play a significant role in enhancing public safety and mitigating risks at education institutions. These algorithms can be used to analyze data from a variety of sources, including security cameras, social media platforms, and other sensors, to detect potential threats and alert authorities immediately. In addition, smart algorithms can provide insights into how to avoid such incidents by identifying patterns of behavior that could be a sign of a potential threat. Public safety systems may become more proactive in recognizing and preventing risks before they develop into dangerous situations by harnessing the power of machine learning and artificial intelligence. This can contribute to

making educational institutions safer for students, teachers and staff while maintaining a high standard of teaching.

- **Healthcare:** Healthcare data has become the focus of attackers in recent years. Healthcare data is a prime target due to the nature of data collected and the number of involved parties such as patients, doctors, hospitals, pharmaceutical companies, billing agencies, governmental systems, software companies, etc. The interactions amongst all involved systems and the attack surface have become too complicated to be managed with traditional computing. Therefore, innovative mitigation techniques are needed to deal with potential risks.
- **Telecommunications:** The telecommunication infrastructure involves many partners such as customers (wired and wireless), service providers, manufactures from different countries, governments, standardization agencies, banks and credit card companies, to name a few. Designing a resilient telecommunication infrastructure is a top priority for each involved partner. Therefore, mitigating the potential attacks on telecommunications informatics and algorithms needs clear attention.
- **Banking:** Banking is a sector that is highly involved with the public in terms of their data and money. Nowadays, banking all around the world is mostly online (i.e., accessible through the Internet), which imposes a great danger to public safety. Even though more powerful security protocols are being developed and deployed in the banking sector every day, however, we still face new attacks (e.g., hacking, spam, fraud etc.) in banking frequently. Therefore, public safety requires careful consideration in the banking sector. It is not guaranteed to completely avoid the attacks in banking; however, the informatics and algorithms can help in mitigating the potential risks and attacks on banking for public safety. Therefore, mitigation techniques are highly needed to deal with potential risks in banking.
- Public safety and security is an important issue for any society. It involves a variety of measures to protect citizens from crime, natural disasters, and other threats. Smart algorithms have revolutionized the way safety and security are managed in various fields, including surveillance, intelligence, policing, fire departments, emergency response, and natural disasters. These algorithms use advanced machine learning techniques to analyze vast amounts of data and identify patterns that can help prevent or mitigate potential threats. For instance, in surveillance systems, smart algorithms can detect suspicious behavior or objects and alert security personnel in real-time. In intelligence gathering, these algorithms can be examined through large volumes of data to identify potential threats or suspects. In policing, smart algorithms can help predict crime hotspots and allocate resources accordingly. Fire departments and emergency response teams can utilize smart algorithms to determine the ideal action plan for rescue operations. Smart algorithms can help in disasters predict and give citizens in affected areas early warning signals during natural disasters, such as earthquakes or hurricanes. Overall, by enabling quicker response times and more effective decision-making processes, smart algorithms have emerged as a critical tool for maintaining safety and security in many domains.
- The increasing cybersecurity incidents leads a serious threat to the public safety. Cyberattacks can result in data leakage, financial loss, and even physical harm. Therefore, it is important that companies take action to reduce the risks caused by cyber disasters.

Using smart algorithms is one way to achieve this. By analyzing data and seeing patterns that may indicate an imminent attack, these technologies may help identify and stop cyberattacks before they happen. In addition, by automatically isolating affected systems, it can be used to quickly respond to attacks and limit damage. After an attack has occurred, it is necessary to take action to reduce the possibility of additional attacks. Stronger security measures, including firewalls and encryption, may be implemented, in addition to routine system monitoring for indications of unusual activity. We can ensure that public safety is trustworthy and secure in the face of cyber risks by implementing these measures.

2.3.1. Challenges

2.3.1.1. Lack of Cellular Coverage

Although the network operators have good cellular coverage in urban and densely populated areas, however, in some areas (such as rural areas), there is either no cellular coverage or is very limited. In such areas, transmitting information of an emergency incident (such as road accidents) to the control centers is a challenge because such information needs to be received by the control centers as soon as possible so that rescue teams can arrive at the place of incidents quickly to mitigate the loss. Hence, some mitigation strategies are required to overcome the problem of lack of cellular coverage for public safety.

2.3.1.2. Interference in Congested Environments

We are highly dependent on wireless communication networks. This dependency has become clearer over the past few years due to the diversity of wireless technologies in our lives. Additionally, the number of wireless users has dramatically increased in most populated areas. One of the key challenges that any wireless communications system faces is interference. Interference simply refers to the effect of unwanted electromagnetic signals on the wanted in transition signal. The unwanted signal can affect the different characteristics of the wanted signal, and this can weaken it, eliminate it, or change it. This, in turn, affects the performance of wireless communications systems and networks. Depending on the nature of interference impact and the risk level on systems performance, interference mitigation techniques are needed to minimize the impact. With the rapid increase in the number of IoT devices, the interference challenge has become more serious [35].

2.3.1.3. Cyber-attacks in Connected and Autonomous Vehicles (CAVs)

The next-generation cars come with advanced technology that increases their autonomy and connectivity. However, this also leaves them vulnerable to cyberattacks [36]. There are many challenges in mitigating cyber-attacks on these cars. First, it is difficult to find and address security vulnerabilities due to the complexity of the hardware and software systems in these cars. Second, the lack of industry standards makes it difficult to develop a unified defense against hackers because many car manufacturers use different security measures. Third, as connected car technology expands, hackers will have more access points to take advantage of. Finally, because car owners are might not be aware of the threats associated with cybersecurity, they may not take precautions to protect their vehicles. Automakers must prioritize cybersecurity in their design and development processes and collaborate with other stakeholders to establish applicable industry-wide safety standards and protocols if they are to successfully address these issues. In addition, car owners need to be informed about cybersecurity risks and how to defend their vehicles.

2.3.2. Potential Solutions

2.3.2.1. Vehicular Communication

The challenge of lack of cellular coverage can be potentially solved by using vehicular network that uses vehicle-to-vehicle (V2V) communication (for communication among vehicles) and vehicle-to-infrastructure (V2I) communication (for communication of vehicles with RoadSide Units (RSUs)). The vehicles in vehicular networks are equipped with On Board Unit (OBU) that has the capability of wireless communication. The vehicles communicate with each other and with RSUs using Dedicated Short-Range Communication Technology (DSRC) that is based on IEEE 802.11p standard [37]. Hence, without using cellular coverage, a vehicular network can transmit critical information to RSUs through V2I communication which can forward the information to the control centers either directly using wired connection or indirectly through other RSUs. If vehicles are not in the coverage of RSU, they can use V2V communications to forward data in a multi-hop manner to RSUs. A data offloading scheme has been proposed for vehicular networks with Quality of Service (QoS) provisioning that can be considered as a potential solution to mitigate the challenge of lack of cellular coverage [37].

2.3.2.2. Device-to-Device (D2D) Communications

D2D communications can also be used to solve the challenge of lack of cellular coverage. In D2D communications, the D2D users, known as User Equipment (UE) can communicate in a multi-hop manner without needing cellular Base Station (BS). Hence, in case of emergency incidents or even in a natural disaster, when cellular infrastructure is damaged or is over-crowded, D2D users can use D2D communications as a mitigation scheme to relay information to the control centers, as well as to create a local network to communicate with each other. Routing plays a vital role in D2D networks to relay messages in a multi-hop manner. A survey on routing schemes for D2D networks is provided that can serve as a guideline to identify a relevant routing scheme for D2D networks to mitigate the challenge of lack of cellular coverage [38].

2.3.2.3. Interference Mitigation

Various interference mitigation techniques and algorithms are available to deal with interference risks. These techniques can involve adjusting power levels, using frequency assignment procedures, and using suitable filters and equalizers. The noticeable dependency on wireless systems and the diversity of wireless applications in many critical sectors require devising more intelligent interference mitigation techniques to eliminate the impact of interference (co-channel or adjacent channel). This involves integrating AI into interference mitigation techniques to better assign channels, adjust power levels, and design effective filters and equalizers [35] [39] [40].

2.3.2.4. Proactive Measures to Prevent Cyber Attacks

As the automotive industry continues to embrace IoT and connected technologies, it is essential to develop robust solutions and mitigation techniques to prevent cyber-attacks in next-generation vehicles. One potential solution is to implement a multi-layered security approach that includes secure communication protocols, encryption, and authentication mechanisms [41]. Additionally, manufacturers can leverage machine learning algorithms and artificial intelligence (AI) to detect anomalies in the vehicle's behavior and identify potential security breaches [42]. Regular software updates and patches can also help mitigate vulnerabilities in the system. Finally, educating drivers on safe cybersecurity practices, such as not sharing personal information with unknown sources, can help prevent cyber-attacks from occurring in the first place. By implementing these measures, manufacturers can ensure that next-generation vehicles are secure and safe for drivers and passengers alike.

2.4. Response

Face recognition is a significant biometric technology which can identify the facial features of an individual [43]. The usage of face recognition technology has grown significantly during the past several years in various countries [44]. It is a hot topic and it's very significant owing to its various range of law enforcement applications [45]. This technology lies in the identification of a face in a digital image or video image against a pre-stored database of faces. It represents a significant advancement in artificial intelligence (AI) technology. Thus, precise, adaptable and rapid recognition systems are required [43]. These systems should mimic the capability of humans to identify an individual from the face without difficulty in the case of significant changes in expression [46]. The most significant stage in face recognition system is facing detection. The research of face detection has significant research value owing to the diversity of facial expression, illumination and skin color [47].

Numerous road accidents have occurred worldwide due to driver drowsiness [48]. To reduce road accidents, efficient driver drowsiness detection systems are required. These systems are very significant to enhance traffic safety [49]. Drowsiness detection systems can monitor, detect and alert the drivers by generating an alarm if drowsiness is detected [50].

License plate recognition (LPR) plays a significant role towards the development of smart cities. It has been utilized in many commercial applications such as searching for stolen vehicles, automating parking systems and speed monitoring. LPR is an image processing technology that consists of three phases which are license plate localization, characters' segmentation and characters' recognition [51] [52] [53].

IoT can play an effective role in achieving smart city vision. An effective smart emergency response system for fire hazards based on IoT has been proposed [54]. The system consists of ESP-32 microcontroller, flammable gas detection sensor, flame detection sensor, smoke detection sensor and a GPS module. Sensors were employed to detect the hazards and alerting the fire department. In addition, the hazard location is sent to the cloud. In this system, MQTT was utilized for rapid and trustworthy communication.

2.4.1. Challenges

While the current research has demonstrated significant advancements, there are still major challenges which need to be addressed. Several approaches were proposed to address the challenges of face recognition after plastic surgery. Plastic surgery has gained widespread popularity in recent years. People perform face plastic surgery to enhance their appearance and confidence or to fix feature imperfections [55]. There are limited amounts of research work in the field of face recognition after plastic surgery since plastic surgery alters the geometric relationship between the main facial features significantly. In addition, there is a lack in publicly available face plastic surgery databases [56]. Thus, more research work about face recognition algorithms which can recognize human faces after plastic surgery is needed. In addition, Illumination variation can seriously affect the system accuracy. Thus, there is an urgent need for systems which can effectively recognize faces under various illuminations [57]. Despite advancements in sketch-based facial recognition, there are still several challenges with current methods [58]. Thus, robust face recognition systems which can be utilized for face recognition based on sketches should be implemented to assist police in recognizing the suspect [59]. Moreover, powerful systems that can recognize faces under various poses are needed [60]. Pose variation is a crucial factor which can influence the performance of face recognition [61]. In addition, ageing has a significant impact on the accuracy of face recognition systems. Recognizing the face of the same individual across different ages remains a challenging task owing to significant changes caused by age progression. Aging face recognition has many applications such as verifying individuals from their passports and identifying missing children [62].

Driver drowsiness detection is one of the significant applications of ML and image processing [63]. Hence, detecting driver drowsiness is one of the most active areas of research. Driver drowsiness detection in low light conditions and in the nighttime is a challenging task [64] [65]. There are several studies on driver drowsiness detection. However, these research studies tend to ignore poor-light conditions [66].

Further research on developing effective LPR systems that can overcome illumination and weather changes is desirable. These systems should perform well with high recognition accuracy in poor illumination conditions and extreme weather conditions [51] [52] [67].

2.4.2. Potential Solutions

The accuracy of face recognition systems depends on good image quality specifically in various lighting conditions [68]. One of the emerging solutions in face recognition research is three-dimensional (3D) face recognition which builds on the benefits of 2D face recognition. It is becoming trendy owing to its capability to cope with poor lighting conditions or the differences in facial expressions and poses [69] [70]. 3D facial data contains geometric information which can enhance the recognition accuracy under poor light conditions [70]. face recognition system for low lighting condition has been proposed by merging image enhancement technique with contrast adaptive histogram equalization contrast technique for creating good quality lighting images [69]. This system has achieved an accuracy of 76.92%.

Depth and texture have been combined into a single framework utilizing joint Bayesian classifiers to solve large pose variation issue in face recognition [71]. This system takes an RGB-D face image that facing any direction (from -90 degree to 90 degree) and the output is the identity of the individual. The results shows that this approach can handle large pose variation.

Weighted Component-Based Approach (WCBA) has been employed to find the most discriminative facial components. It was found that this approach has achieved promising performance [72].

A behavioral based driver detection system has been proposed [66]. The first stage of this system is preprocessing phase which enhances illumination. In this system, Haar Cascade classifiers have been utilized for eyes detection. Also, CNN model was employed for predicting the state of the eyes of the driver. The proposed CNN has been tested in different poor light conditions, and it achieved an accuracy of 97.92% on the testing dataset. It was found that the system has the ability of identifying the state of the driver even in severe low light conditions.

2.1 Recovery

Smart cities are increasingly being adopted around the world, bringing together various technologies to improve the quality of life of its citizens. The rapid growth of smart cities has created new opportunities to improve public safety. However, like any other system, smart cities are not immune to disasters, natural or man-made. In such situations, recovery operations become crucial to restore normalcy and ensure public safety [73].

Recovering from a disaster is a complex task that places heavy demands on a wide range of resources and organizations. This may include local and international emergency responders, NGOs, and armed forces, each with their own specific skills, equipment, and resources. Coordinating these different groups is challenging, it also puts pressure on the limited resources available, like funding, personnel, and equipment. Thus, proper planning and coordination is crucial to make the most of the resources and ensure the best possible outcome in disaster recovery [74].

In the event of a natural disaster such as an earthquake, multiple agencies must work together, sharing resources and information to quickly assess the situation and develop a response plan. When a large-scale disaster happens, it requires a major effort to help those affected, which can be difficult to organize and need many resources. This type of recovery operation can be demanding and require coordination among multiple groups and long-term funding. It can be challenging to anticipate and plan for all necessary resources as the requirements of impacted communities evolve during the recovery process [75]. Recovery operations can be divided into three phases: pre-disaster, during disaster, and post-disaster [76].

Pre-disaster planning is a critical component of recovery operations in smart cities. The objective of pre-disaster planning is to prepare the city for disasters and minimize their impact. This involves identifying potential hazards and vulnerabilities and developing a plan to mitigate the risks.

Pre-disaster planning also involves developing emergency response plans that can be executed during a disaster. Emergency response plans should include communication strategies, evacuation plans, and emergency shelters. These plans should be tested regularly to ensure their effectiveness.

During a disaster, recovery operations in smart cities are focused on minimizing damage and ensuring public safety. This involves activating emergency response plans developed during the pre-disaster phase.

During a disaster, communication becomes crucial. Smart cities use various technologies, such as social media, to provide real-time updates to citizens. Communication channels should be accessible to all citizens, including those with disabilities.

After the disaster, recovery operations shifted to restoring normalcy and rebuilding the city. This involves assessing the damage caused by the disaster and prioritizing recovery efforts. The primary objective of post-disaster recovery is to ensure public safety and minimize damage.

Post-disaster recovery operations involve a multi-disciplinary approach, including government agencies, private organizations, and citizens. Recovery efforts should be coordinated and well-planned to avoid duplication of efforts.

2.4.1 Challenges

Smart cities are vulnerable to various emergencies, such as natural disasters, cyberattacks, terrorist attacks, and pandemics. These incidents can cause significant damage to the city's infrastructure, disrupt essential services, and pose a threat to public safety [77]. The following are some of the challenges faced by smart cities during emergencies:

2.4.1.1 Communication Breakdown

During an emergency, communication is essential to coordinate rescue and recovery efforts. However, communication infrastructure such as cell towers and internet services can be damaged or overloaded, leading to a breakdown in communication.

2.4.1.2 Lack of Situational Awareness

Smart cities rely on data from various sensors and IoT devices to monitor city services. However, during an emergency, this data may not be available, leading to a lack of situational awareness.

2.4.1.3 Cybersecurity Threats

Smart cities are vulnerable to cyberattacks, which can disrupt essential services, compromise sensitive data, and pose a threat to public safety.

2.4.1.4 Limited Resources

Recovery operations require significant resources such as personnel, equipment, and funding. However, smart cities may have limited resources, making it challenging to respond effectively to emergencies.

2.4.1.5 Data Management

One of the key challenges in disaster recovery efforts is managing the large amount of data that is collected from IoT devices. This data can include information from a variety of sources, such as traffic cameras, weather sensors, and pollution monitors. In High-stress and high-consequence disaster scenarios, the data need to be analyzed quickly and accurately to inform decision-making and resource allocation, but doing so requires navigating tradeoffs between processing speed, the proximity to the data source and the accuracy of the processed information. This requires exploring new solutions for information processing and dissemination, that can handle the volume and speed of incoming data while maintaining a balance between processing speed, proximity, and accuracy.

2.4.1.6 Origin of Data

When designing federated applications that incorporate information obtained from various sources, several objectives related to security, privacy, and trust should be considered. In fact, some of these objectives can be conflicting and might require the implementation of sophisticated cryptographic mechanisms to fulfill the expectations of all stakeholders.

2.4.2 Potential Solutions

2.4.2.1 Role of IoT

IoT has a significant role to play in recovery operations in smart cities for public safety. IoT refers to the interconnectedness of devices, sensors, and systems that can communicate with each other and exchange data. In a smart city context, IoT can be used to monitor and control various systems, such as traffic management, energy usage, and public safety [78].

During a recovery operation, IoT can be used to provide real-time information on the status of various systems and infrastructure. For example, sensors can be deployed to monitor the structural integrity of buildings and bridges, and alert authorities if there are any signs of damage or potential collapse. This can help ensure that emergency responders are able to respond quickly and effectively to any potential threats [79].

IoT can also be used to monitor and manage traffic flow during recovery operations. Sensors can be used to detect congestion and adjust traffic signals accordingly to help minimize delays and ensure that emergency responders can move quickly through the city.

In addition, IoT can be used to monitor and manage public safety during recovery operations. For example, sensors can be used to detect hazardous materials or dangerous gases, and alert authorities if there is any potential danger to the public. This can help ensure that emergency responders are able to respond quickly and effectively to any potential threats.

Overall, IoT can play a critical role in recovery operations in smart cities for public safety. By providing real-time information on the status of various systems and infrastructure, IoT can help ensure that emergency responders are able to respond quickly and effectively to any potential threats and help minimize the impact of any disruptions on the public.

IoT devices in the affected area, like traffic cameras and sensors, can provide valuable information by identifying potential dangers such as toxic gases, trapped individuals, and power grid status. This information can help agencies make better decisions and take more effective actions in the recovery effort. The incorporation of IoT can provide increased situational awareness during a crisis, leading to more efficient disaster response and recovery.

The use of IoT technologies in smart cities has the potential to significantly improve many aspects of urban life, including the economy, safety, public space management, and transportation. Smart lighting systems, for example, can help reduce energy consumption and costs, while smart waste management systems can reduce expenses associated with garbage collection, resulting in a more sustainable and efficient city [80]. Furthermore, IoT technologies can improve public safety by monitoring traffic, crime, and emergencies in real time, as well as optimize public transportation systems by providing commuters with real-time information about bus and train schedules, ultimately leading to a more connected and efficient city. Overall, IoT has the potential to transform urban life by improving how we live, work, and move around cities but there are certain challenges associated with it as well.

2.4.2.2 Role of Big Data Analytics

The use of big data analytics in recovery operations in smart cities for public safety can have significant benefits. Smart cities can use data from various sources, such as sensors, cameras, and social media, to analyze the impact of disasters and emergencies, identify areas that require immediate attention, and make informed decisions about resource allocation [81] [82]. Some ways in which big data analytics can be used in recovery operations in smart cities for public safety include:

- **Identifying Hotspots:** Big Data Analytics can be used to identify areas that are most affected by disasters. This can help in prioritizing the recovery efforts and allocating resources more efficiently.
- **Real-time situational awareness:** With the help of sensors, cameras, and other data sources, big data analytics can provide real-time situational awareness to emergency responders, enabling them to quickly identify areas that require immediate attention and allocate resources accordingly.
- **Predictive analytics:** By analyzing historical data and trends, big data analytics can help predict future disasters and emergencies, allowing for proactive measures to be taken to mitigate their impact.
- **Resource optimization:** Big data analytics can help optimize the allocation of resources during recovery operations, ensuring that resources are allocated to the areas that need them the most.
- **Communication and collaboration:** Big data analytics can facilitate communication and collaboration between different stakeholders involved in recovery operations, such as emergency responders, city officials, and residents.
- **Improved decision-making:** By providing insights and data-driven recommendations, big data analytics can help city officials make informed decisions during recovery operations, leading to better outcomes for public safety.

Overall, big data analytics can play a crucial role in recovery operations in smart cities for public safety by providing real-time situational awareness, predictive analytics, resource optimization, communication and collaboration, and improved decision-making.

2.4.2.3 Role of Drones

Drones have gained significant attention for research and a range of applications due to their versatility and ability to access areas that are otherwise challenging to reach quickly. Their flexibility has made them appeal for a variety of uses, including security, monitoring, control, and exploration of terrain that may be difficult to access by other means [83]. Additionally, the use of drones is transformative technology that can enhance the ability of first responders to carry out rescue missions at disaster sites, improving the overall effectiveness and efficiency of emergency response efforts [84]. Here are some ways that drones can be utilized in such operations:

- **Search and Rescue:** Drones can be equipped with cameras and thermal imaging sensors that can detect the heat signatures of humans in distress, making them very useful for search and rescue operations. They can cover large areas quickly and can locate people who might not be visible from the ground.
- **Traffic Management:** In the aftermath of a disaster or emergency, traffic congestion can be a major problem. Drones can be used to monitor traffic and provide real-time updates to drivers, helping to reduce congestion and improve traffic flow.
- **Mapping:** Drones can be used to create high-resolution maps of disaster zones, which can help emergency responders to better understand the extent of the damage and plan their response accordingly.
- **Inspections:** Drones can be used to inspect damaged buildings and infrastructure, helping to identify areas that may be unsafe for rescue workers or residents. This can also help to speed up the process of damage assessment, which is critical for recovery operations.
- **Delivery of Supplies:** Drones can be used to deliver critical supplies such as food, water, and medical equipment to people in hard-to-reach areas, especially during disasters or emergencies.
- **Communication:** Drones equipped with communication devices can be used to establish communication links in areas where traditional communication infrastructure has been damaged or destroyed. This can be critical in coordinating rescue and recovery efforts.

Overall, drones can be an important tool for public safety in smart cities, especially in recovery operations after a disaster or emergency. However, it is important to ensure that their use is carefully managed to avoid any potential privacy or safety concerns.

2.4.2.4 Role of Artificial Intelligence

Artificial intelligence (AI) can play a significant role in recovery operations in smart cities for public safety [85]. Recovery operations refer to the actions taken to restore normalcy after a disaster or crisis. Here are some ways AI can be used in recovery operations in smart cities:

- **Predictive Analytics:** AI can be used to analyze data from various sources, including social media, weather reports, and sensor networks, to predict the impact of disasters and emergencies. This information can help city authorities and emergency responders to prepare for potential disasters and mitigate their effects.

- **Monitoring and Analysis of Infrastructure:** AI can be used to monitor critical infrastructure, such as power grids, water supply systems, and transportation networks. By analyzing real-time data from sensors, AI can detect anomalies and alert authorities of potential problems, allowing them to act before a disaster occurs.
- **Search and Rescue:** AI can be used to identify people who are trapped or in need of help after a disaster. For example, drones equipped with AI-powered cameras can search for people in inaccessible areas or where visibility is low.
- **Communication:** AI can be used to improve communication during recovery operations. Chatbots and virtual assistants can help citizens get the information they need and connect them with relevant resources. AI-powered translation tools can also help people communicate across language barriers.
- **Disaster Prediction and Management:** AI can be used to predict natural disasters like floods, earthquakes, and hurricanes, and provide early warning alerts to citizens and recovery teams. Additionally, AI can help manage the disaster response by identifying areas that need immediate attention and prioritizing resources accordingly.
- **Decision Making:** AI can assist decision-makers in identifying the most effective recovery strategies. By analyzing data on previous disasters, AI can help authorities determine which actions are most likely to be effective in each situation.

In summary, AI can be a powerful tool in recovery operations in smart cities. By providing predictive analytics, intelligent monitoring, search and rescue capabilities, communication tools, and decision-making assistance, AI can help authorities and emergency responders to more effectively manage recovery efforts and ensure public safety.

2.4.2.5 Role of Mobile Applications

Mobile applications can play a crucial role in recovery operations in smart cities for public safety. These applications can provide real-time information to both first responders and citizens, enabling them to make informed decisions during an emergency [86] [87]. Here are some of the ways mobile applications can contribute to recovery operations:

- **Emergency Alerts:** Mobile applications can send out alerts to citizens in case of an emergency, including natural disasters or man-made disasters. These alerts can provide important information such as the location of the disaster, the severity of the situation, and instructions on what to do next.
- **Geolocation:** Mobile applications can use geolocation technology to track the location of first responders, volunteers, and victims in real-time. This information can help rescue teams locate individuals in need of assistance quickly.
- **Communication:** Mobile applications can facilitate communication between first responders, volunteers, and victims during an emergency. These applications can provide a platform for individuals to communicate their needs and provide updates on the situation.

- **Resource Management:** Mobile applications can help manage resources during an emergency. These applications can provide a way to track the availability and allocation of resources such as food, water, and medical supplies.
- **Recovery Assistance:** Mobile applications can aid during the recovery phase of an emergency. These applications can provide information on available resources, support services, and help citizens navigate the recovery process.

Overall, mobile applications can be a valuable tool in recovery operations in smart cities for public safety. By providing real-time information and facilitating communication, mobile applications can help save lives and mitigate the impact of disasters on communities.

Role of Blockchain in Recovery Operations in Smart Cities for Public Safety:

Blockchain technology can play a significant role in recovery operations in smart cities for public safety [88]. Here are some of the ways that blockchain can help:

- **Data management:** In times of emergency, there is often an overload of data generated from various sources such as social media, IoT sensors, and emergency response teams. Blockchain can help in managing this data by providing a decentralized platform for storing and sharing data securely. This can help in ensuring that critical data is available to all stakeholders in real-time.
- **Supply chain management:** In times of disaster, the supply chain is often disrupted, leading to delays in the delivery of essential goods and services. Blockchain can help in tracking the movement of goods and services from the point of origin to the destination, providing real-time updates to all stakeholders. This can help in ensuring that critical supplies are delivered to the affected areas on time.
- **Identity management:** In times of crisis, there is often a need to quickly verify the identity of individuals involved in rescue and recovery operations. Blockchain can help in creating a decentralized identity management system that can provide secure and tamper-proof identification of individuals involved in recovery operations.
- **Smart contracts:** Smart contracts can be used to automate certain tasks involved in the recovery operations. For example, smart contracts can be used to automatically release funds for the purchase of essential supplies when certain conditions are met, such as the delivery of goods to a specific location.
- **Transparency and accountability:** Blockchain can help in ensuring transparency and accountability in the recovery operations. By providing a decentralized platform for data sharing, blockchain can help in ensuring that all stakeholders have access to the same information, reducing the chances of miscommunication or mismanagement.

In conclusion, blockchain can play a vital role in recovery operations in smart cities for public safety by providing a secure, decentralized platform for data management, supply chain management, identity management, smart contracts, and transparency and accountability.

2.4.2.6 Role of Augmented Reality

Augmented Reality (AR) has a significant role to play in recovery operations in smart cities for public safety. AR is a technology that superimposes computer-generated information onto the real world, thereby enhancing the user's experience of the real world [89]. Here are some ways in which AR can be beneficial:

- **Navigation:** AR can help navigate first responders to the location of an incident by providing real-time data, such as building layouts, street names, and hazard zones, to assist in route planning.
- **Enhancing situational awareness:** AR can provide real-time data on an incident, including 3D visuals and live video feeds from drones or other sources to first responders. This information can help them to understand the nature of the incident and respond accordingly.
- **Providing training:** AR can be used to simulate emergency situations, providing a safe and controlled environment for first responders to train and prepare for real-life situations.
- **Communication:** AR can facilitate communication between first responders, emergency management teams, and citizens during an emergency, enabling them to share critical information quickly and effectively.
- **Real-time data analysis:** AR can assist first responders and emergency management teams in analyzing real-time data, such as environmental conditions and health status, to make informed decisions.
- **Post-event analysis:** AR can also be used to analyze the damage caused by an incident, which can help with the planning of recovery efforts and reconstruction.

Overall, the use of AR in recovery operations can help to increase public safety in smart cities by providing first responders and emergency management teams with real-time data and enhanced situational awareness to respond quickly and effectively to emergency situations.

2.4.2.7 Role of Broadband Communication Technologies

Effective communication between victims and first responders is essential for search and rescue operations. To establish a public safety communication network that can support these efforts, it is important to have reliable and fast emergency communication capabilities [90] [91]. Efficient communication technology can save lives and improve connectivity among search and rescue teams. Various broadband communication technologies, such as WiMAX, Wi-Fi, ad hoc, and long-term evolution (LTE), have been identified as potential options for public safety networks.

Broadband communication technologies play a crucial role in recovery operations in smart cities for public safety. In the aftermath of a disaster, broadband communication technologies can provide critical connectivity for emergency response teams, city officials, and affected individuals. Here are some ways in which broadband communication technologies can aid in recovery operations:

- **Rapid communication:** Broadband communication technologies can facilitate rapid and reliable communication between emergency response teams and city officials. This can help coordinate rescue and relief efforts, share information about the status of the disaster, and ensure that resources are allocated efficiently.

- **Remote monitoring:** Broadband communication technologies can enable remote monitoring of critical infrastructure, such as power grids, transportation networks, and water supplies. This can help identify damage and prioritize repair efforts and prevent further damage to infrastructure.
- **Data analysis:** Broadband communication technologies can facilitate the collection and analysis of data on the disaster and its impact. This can help city officials make informed decisions about resource allocation, emergency response, and recovery efforts.
- **Information dissemination:** Broadband communication technologies can enable the dissemination of critical information to affect individuals, such as evacuation orders, safety instructions, and updates on the status of the disaster. This can help prevent panic and ensure that individuals take appropriate action to protect themselves.
- **Resilience planning:** Broadband communication technologies can help city officials plan for future disasters by analyzing data on past disasters and identifying vulnerabilities in critical infrastructure. This can help ensure that cities are better prepared to respond to disasters and recover quickly.

Overall, broadband communication technologies play a vital role in recovery operations in smart cities for public safety. They enable rapid communication, remote monitoring, data analysis, information dissemination, and resilience planning, all of which are critical for effective disaster response and recovery.

3 Conclusions and Recommendations

3.4 Conclusions

Smart algorithms such as AI algorithms and informatics technology are crucial for ensuring public safety. This white paper discusses five key mission areas of public safety technology (i.e., prevention, protection, mitigation, response, and recovery), and it provides insights into the importance of public safety technology in preventing emergencies, safeguarding people, managing risks, successfully reacting, and supporting recovery operations by looking at five key mission areas. The following summarizes the five key mission areas.

- The primary goal of prevention is the development of preventive measures to reduce crises, dangers, and losses. In the prevention section, IoT technology is emphasized as a useful tool for providing reliable and quickly available data for locals' safety, and challenges (precision warning, collaborative warning, rapid warning, specification warning, privacy warning, unified standard for IoT in public safety, privacy and security, public regulations and rules, management of heterogenous devices) and potential solutions (face recognition, license plate recognition, drowsiness detection, smart emergency response system, worker safety monitoring, agricultural safety monitoring, federated learning prevention mechanisms city management architecture, warning systems, and smart cities) are discussed.
- For the protection mission area, the paper highlights the crucial role that UAVs play in supply delivery, healthcare communication, and disaster management, ultimately enhancing public safety, and emphasizes the significance of managing energy usage and optimizing connection in the implementation of new technologies and IoT

networks in the field of public safety. The paper also discusses the challenges and potential solutions (wireless technologies and role of non-terrestrial networks).

- The mitigation mission area acknowledges that emergencies can still happen despite the significance of protection and prevention, and it emphasizes that the magnitude of such catastrophes can be mitigated significantly through mitigation methods. Also, it discusses the challenges (lack of cellular coverage, interference in congested environments, and cyber-attacks in connected and autonomous vehicles) and potential solutions (vehicular communication, D2D communications, interference mitigation, and proactive measures to prevent cyber-attacks).
- The response mission area focuses on facial recognition, drowsiness driver detection, and license plate recognition. The paper shows the mechanism of preprocessing methods and CNN-based algorithms for recognizing drivers even in severe light conditions and their performance. Also, the challenges (the impact of plastic surgery on face recognition, a lack in publicly available face plastic surgery databases, and the impact of aging on the accuracy of face recognition systems) and potential solutions are discussed.
- The recovery mission area emphasizes the importance of smart cities in strengthening public safety while also acknowledging that they are not immune to catastrophic events, and it also emphasizes the importance of planning and coordination in providing impacted population with appropriate support during recovery. Also, the challenges (communication breakdown, lack of situational awareness, cybersecurity threats, limited resources, data management, and origin of data) and potential solutions (role of IoT, role of big data analytics, role of drones, role of artificial intelligence, role of mobile applications, role of augmented reality, and role of broadband communication technologies) are discussed.

3.5 Future Recommendations

3.5.1 Assistive AI Technology to Ensure Safer Outcomes for Emergency Response

Every city faces public safety emergencies ranging from routine traffic incidents to crime, extreme weather, chemical spills or releases, disease outbreaks, releases of biological agents, explosions involving nuclear or radiological sources and more. Speed, efficiency and effectiveness are crucial for emergency response, and delays or misinformation can be catastrophic to public safety.

Although hundreds or even thousands of daily calls (for service) received by the existing system capture a tremendous amount of data that may be helpful for informing action, there has been a lack of real-time analysis. Much of the analysis call centers is retrospective, and it cannot inform decisions in a live situation. Assistive AI can play a pivotal role in bridging the information gap many public safety agencies face by keeping human operators at the forefront and helping them identify similarities within a cluster of seemingly unrelated events or calls, and it flags insights that are critical to understanding a situation that may have otherwise gone unnoticed until it was too late [92]. Assistive AI helps augment human intuition in critical situations and allowing 911 personnel to see the unseen. To be effective, AI must be integrated into existing processes without distracting from or disrupting workflows [93].

3.5.2 Deep and Transfer Learning for Public Safety

Transfer learning is a new paradigm of learning that learns from previous knowledge and then transfers and employs this knowledge to address new, yet related problems [94]. The main advantage of transfer learning is that the model training phase can be managed with minimum resources (e.g., data) and in less time compared to other deep learning models that use traditional types of learning (supervised/unsupervised/reinforcement). Deep and transfer learning and be used to improve the performance of detection (pothole detection). Several studies investigate the use of deep learning models with transfer learning for public safety [95] [96] [97] [98] [99] [100]. In the future, we expect more applications to use deep and transfer learning for enhancing public safety.

3.5.3 Big Data, ML and IoT Applications for Public Safety

Big data analysis, ML and IoT applications have been used in relation to surveillance systems. This application has been mainly connected with object detection applications using drones and other sensory cameras to detect body temperature and social distancing, as well as tracking infected people in open areas. However, the usage of big data analysis and its application outside of surveillance applications has not been widely studied. There is a need for further research/studies on how to use data analysis, ML and IoT, potentially in the context of digital twins, to prevent emergencies for public safety.

3.5.4 Digital Twins to Enhance Public Safety

It has been a constant challenge for governments and emergency services to respond quickly and effectively to natural disasters. However, the emergence of digital twins brings the hope to these organizations for respond more efficiently and effectively to natural disasters and other emergency situations. A digital twin is a digital representation of a physical object, system, or process, and it allows people to monitor and analyze an environment in real-time, giving them a comprehensive and detailed view of the situation at hand [101] [102]. Digital twins can be used to model and evaluate the performance of emergency response systems and infrastructure, as well as to simulate, plan, and train for emergency scenarios, which allows governments and emergency services to anticipate and plan for potential outcomes. A digital twin of a city can allow emergency services to identify areas of risk before a disaster occurs and quickly respond to the situation as it unfolds. Below are five applications of digital twins in public safety.

(1) Utilize digital twins to track and monitor crime in public spaces: With the help of digital twins, law enforcement can monitor and analyze real-time data (e.g., foot traffic, vehicle movement, and other activities in public spaces) which can be used to identify patterns that may indicate criminal activity or any suspicious behavior. With this information, law enforcement can then better deploy resources and respond quickly to any potential threats that harm public safety [103].

(2) Utilize digital twins to improve public transportation safety: Public transportation has become an indispensable part of many people’s lives, but safety is always a concern. Using digital twins, public transportation safety can be improved. A typical example is that digital twins can help identify potential safety hazards along the routes of buses and trains. Digital twins can also be used to monitor the performance of public transportation systems (e.g., the brakes, engine, and other components), which can help identify and address any potential safety issues. In addition, digital twins can be used to enhance drive safety. For example, digital twins can detect driver fatigue and

alert drivers when they need to take a break by analyzing the data from cameras and other technologies [103].

(3) Leverage digital twins to improve traffic management: Digital twin models generate a digital replica of a city's physical infrastructure based on the real-time data from sensors, cameras, and other devices. The digital replica is then used to simulate traffic flow, calculate journey times, and identify potential bottlenecks. Also, digital twins can enable cities to quickly identify and respond to traffic incidents and accidents. With the help of digital twins, urban planners and traffic engineers can develop and analyze data-driven solutions to improve transit, reduce traffic congestion, and address other transportation issues [103].

(4) Apply digital twins to support fire safety in crowded public spaces: Digital twins, as the digital replicas of physical environments and systems, can be used to simulate and monitor real-world conditions. DT technology has the potential to transform the way public safety professionals respond to disasters (e.g., fires in crowded public spaces). The use of digital twins in fire safety can help prevent and mitigate the risks associated with fire. For example, digital twins can simulate a fire's spread through a crowded space and provide an accurate assessment of the fire's progression and the potential damage it could cause. This information can help inform decisions about evacuation routes, fire containment strategies, and other safety measures [103].

(5) Apply digital twins to manage health care systems: The use of digital twins for health care systems management is an emerging topic. In 2020, the novel Coronavirus disease 2019 (COVID-19) disrupted the health care system and caused an ecosystem crisis, which harmed public safety (e.g., resource shortages, COVID-19 misinformation, and medical errors) [104] [105]. Digital twins could help develop vaccination strategy. Specifically, vaccinations can be targeted based on the number of social contacts of each person, and infections can be restricted to isolated hotspots and delayed by targeted vaccination, inherent immunity, and public health measures that reduce the infection peak. So, DT (digital twin) technology can support decision-making to control the spread of the virus [106]. Therefore, DTs can ensure safety management in health care systems by identifying potential threats, redesigning the systems to mitigate hazards, and improving the safety strategies implemented, which leads to the right care at the right price and time for everyone and everywhere at any point of care in a safe manner [107].

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