

From Theory to Practice: Intelligent Signal Processing in Emergency Communication Systems

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ABSTRACT

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Emergency communication systems play a crucial role in responding to various unexpected incidents by ensuring timely transmission and exchange of information, thereby providing strong support for rescue operations and other emergency actions. As a key technology in emergency communication systems, intelligent signal processing has gradually evolved from theoretical research to practical application, significantly enhancing the performance and reliability of these systems. This paper focuses on intelligent signal processing in emergency communication systems and systematically outlines its development from theory to practice. On the theoretical side, the paper explores the theoretical application of intelligent signal processing in emergency communications, including how intelligent algorithms can improve anti-interference capabilities and enhance signal transmission efficiency. On the practical side, the paper analyzes the current application status of intelligent signal processing technologies in emergency communication systems. Through case studies, it demonstrates the application effectiveness of these technologies in various emergency scenarios, such as natural disasters and public safety incidents. It presents concrete outcomes of intelligent signal processing in enhancing system performance, including optimizing signal quality, achieving fast and accurate signal transmission, and improving system stability. In addition, this paper examines the challenges faced in applying intelligent signal processing to emergency communication systems, such as the complexity of technological implementation, system compatibility issues, and environmental adaptability in real-world scenarios. Corresponding solutions and development suggestions are proposed to address these challenges. By bridging theory and practice, this study seeks to provide a reference for the further development and application of intelligent signal processing in emergency communication systems, supporting continuous improvement and upgrades to better meet actual emergency needs.

Keywords: Emergency Communication Systems, Intelligent Signal Processing, Deep Learning, Anti-Interference Performance, Adaptive Filtering.

1 INTRODUCTION

In today's society, various emergencies occur frequently, such as natural disasters (earthquakes, floods,

typhoons), public health events (epidemic outbreaks), and man-made incidents (terrorist attacks, industrial explosions). These events often pose serious threats to social order and the safety of people's lives and property. In responding to such emergencies, timely and effective communication is one of the key factors, as it ensures coordinated rescue operations, rapid transmission of information, and scientifically informed decision-making. While traditional communication systems are capable of meeting people's needs under normal conditions, they face numerous challenges in emergency scenarios. For instance, natural disasters may destroy communication infrastructure, causing signal interruptions; a large number of people simultaneously using communication devices can result in network congestion; and complex geographical environments along with adverse weather conditions can impact signal transmission quality. To address these issues, emergency communication systems have emerged. These systems aim to rapidly restore and maintain communication capabilities when emergencies occur, providing reliable communication support for rescue and command. Intelligent signal processing technology plays an essential role in emergency communication systems. With the rapid development of information technology, signal processing has evolved from traditional analog methods to digital and intelligent approaches. Intelligent signal processing integrates advanced technologies such as artificial intelligence, machine learning, and deep learning, enabling more efficient and accurate signal analysis and processing. In emergency communication systems, signal quality and reliability directly affect communication performance. For example, at an earthquake rescue site, rescue personnel need to communicate with the command center through various forms of signals such as voice and images to understand the disaster situation and formulate rescue plans. Improper signal processing may result in unclear audio or distorted images, thereby impacting the efficiency and accuracy of rescue efforts. As a result, how to use intelligent signal processing technology to improve the performance of emergency communication systems has become a current research hotspot^[1].

From a theoretical perspective, research teams in some Western countries have achieved significant results in the fundamental theories of signal processing. For example, American researchers have conducted cutting-edge research in adaptive signal processing theory. They proposed new adaptive filtering algorithms capable of quickly adjusting filter parameters according to dynamic changes in emergency communication environments, effectively suppressing noise and interference. These algorithms have substantial application potential in emergency communication scenarios with complex electromagnetic environments, providing a solid theoretical foundation for improving signal quality and reliability. Furthermore, European scholars have made important breakthroughs in the theory of intelligent signal detection and estimation^[2]. By combining methods from information theory and statistics, they have developed more precise signal detection models. These models can accurately detect useful signals and precisely estimate their parameters even under extremely low signal-to-noise ratio conditions, significantly enhancing the signal acquisition capability of emergency communication systems in harsh environments. Although certain research achievements have been made in the fields of signal processing and emergency communication, the theoretical system for deeply applying intelligent signal processing technology within emergency communication systems is still not fully developed. This study explores the mechanisms, application models, and optimization strategies of intelligent signal processing in emergency communication systems, providing new ideas and methods for the theoretical advancement of related fields. In addition, this research promotes interdisciplinary integration. Intelligent

signal processing involves multiple academic areas such as signal and information processing, artificial intelligence, and communication engineering, while emergency communication systems are closely connected to disciplines like disaster science, management science, and sociology. By studying the issues of intelligent signal processing in emergency communication systems, disciplinary boundaries can be broken, enabling knowledge sharing and technological complementarity among different fields and promoting coordinated development of relevant disciplines^[3].

From a practical perspective, intelligent signal processing technologies have already been widely adopted in various real-life emergency communication scenarios around the world. In the United States, for instance, intelligent signal processing has been extensively applied to optimize communication links in emergency communications for natural disasters. Through intelligent signal encoding and modulation, higher data transmission rates can be achieved under limited spectrum resources. Additionally, intelligent beamforming technology allows signals to be directed more precisely toward target users, thereby enhancing the coverage and stability of communication. In Europe, several countries have also employed advanced intelligent signal processing techniques in their public safety emergency communication systems. For example, in urban anti-terrorism emergency communication, real-time monitoring and analysis of communication signals allow for the rapid identification of abnormal signals and potential threats, providing timely intelligence support to security agencies. Moreover, intelligent signal processing has been applied to the self-organizing networks within emergency communication systems, enabling intelligent communication and resource allocation among nodes and improving the overall efficiency of the emergency communication network. In order to standardize the application of intelligent signal processing technologies in emergency communication systems, various organizations and institutions have actively participated in the development of relevant standards^[4]. The International Telecommunication Union (ITU) has issued a series of standards and recommendations concerning signal processing in emergency communications. These standards cover multiple aspects such as signal encoding, modulation, and transmission, ensuring global interoperability and interconnectivity of emergency communication systems. Additionally, some industry associations have also formulated intelligent signal processing standards tailored to specific application scenarios. For instance, the Institute of Electrical and Electronics Engineers (IEEE) in the United States has established relevant standards for natural disaster emergency communication, specifying performance indicators and application requirements for intelligent signal processing technologies in these contexts^[5].

2. EMERGENCY COMMUNICATION SYSTEM COMPOSITION AND ARCHITECTURE

2.1 Definition of Emergency Communication System

An emergency communication system is a specialized communication system designed to ensure smooth communication and enable the rapid and accurate transmission of information during sudden emergencies. Unlike conventional communication systems—which mainly serve daily commercial, social, and other general communication needs—the core mission of an emergency communication system is to ensure the timely delivery of critical information under extreme and complex conditions, providing strong communication support for emergency command, rescue operations, public evacuation, and more.

From a technical perspective, an emergency communication system integrates multiple communication

technologies, including but not limited to wireless communication (such as satellite communication, microwave communication, shortwave communication), wired communication (such as fiber-optic communication and cable communication), and emerging technologies like Internet of Things (IoT) communication. These technologies work collaboratively and complement one another to address communication demands in different scenarios^[6]. For example, when an earthquake severely damages terrestrial communication infrastructure, satellite communication can quickly establish communication links, enabling information exchange between the disaster area and the outside world. Meanwhile, in relatively fixed emergency command centers, fiber-optic communication can offer high-speed and stable communication support.

From a functional perspective, an emergency communication system encompasses a wide range of capabilities, including voice communication, data transmission, image and video transmission. Voice communication enables real-time coordination between commanders and rescue teams, ensuring that rescue operations are carried out in a unified and efficient manner. Data transmission allows for the relay of critical information such as geographic data of the affected area and casualty reports. Image and video transmission enables command centers to intuitively grasp the on-site situation, thereby facilitating more scientific and accurate decision-making.

2.2 Characteristics of Emergency Communication Systems

Reliability is one of the most critical characteristics of emergency communication systems. In emergencies, communication interruptions can delay rescue operations and even result in irreparable losses. Therefore, an emergency communication system must possess a high degree of reliability and be able to operate stably under harsh environmental conditions. To enhance reliability, emergency communication systems often adopt multiple redundancy mechanisms. For example, backup power supplies are provided to prevent communication failures due to power outages; multiple types of communication links—such as satellite, microwave, and shortwave links—are simultaneously established, allowing for rapid switching to backup links in case of failure, thus ensuring communication continuity^[7]. In addition, emergency communication systems use redundant design to back up critical equipment and nodes, thereby improving the system's fault tolerance.

In the aftermath of an emergency, time is of the essence. Emergency communication systems must be capable of rapid deployment to disaster-stricken areas to provide timely communication support for rescue efforts. This requires the system to be highly portable and mobile. Modern emergency communication equipment is typically compact and lightweight, making it easy to carry and transport. For instance, portable satellite communication terminals can be installed and debugged within minutes to establish connections with the outside world. Vehicle-mounted emergency communication systems can quickly travel to disaster areas and provide on-site communication coverage. Moreover, emergency communication systems often adopt modular designs, allowing individual modules to operate independently and be quickly assembled and configured based on actual needs, significantly shortening deployment time.

Emergency communication systems need to be compatible with a wide range of existing communication systems and devices to enable information sharing and interconnectivity. During emergency response operations, communication equipment and systems from various departments and regions—such as fire

services, police, and medical institutions—may be involved. The emergency communication system must interface seamlessly with these systems to ensure information flows freely between them. To achieve compatibility, emergency communication systems typically adhere to unified communication standards and protocols^[8]. For example, commonly used international protocols such as TCP/IP are employed to ensure interoperability between different devices and systems. In addition, dedicated interfaces and middleware are developed to support information conversion and sharing across diverse systems.

Emergency scenarios are diverse and unpredictable, and different emergencies may require different communication solutions. As such, emergency communication systems must be highly flexible and capable of adjusting and configuring themselves to suit various scenarios and demands. Depending on the specific situation, the system can select different communication technologies and equipment. For example, in mountainous regions with complex terrain, a combination of shortwave and satellite communication can be used to enhance coverage and reliability; in urban environments, existing mobile networks and wireless local area networks can be utilized for communication. Furthermore, the system can dynamically allocate communication resources based on changing needs, such as increasing bandwidth for voice communication or enhancing data transmission rates.

The emergency communication process involves a large volume of sensitive information, including rescue plans, casualty data, and geographic information of affected areas. The security of this information is paramount—any leakage could have serious consequences for rescue operations. Therefore, emergency communication systems must be highly secure. Multiple security technologies are employed to safeguard information. For instance, encryption is used to protect communication data from interception and tampering during transmission; identity authentication mechanisms verify users to ensure that only authorized personnel can access the system and obtain information^[9]. At the same time, comprehensive security management systems are implemented to strengthen security monitoring and maintenance, enabling timely detection and handling of potential security threats, see Table 1.

Table 1: Summary of the Characteristics of Emergency Communication Systems

Characteristic	Description
Reliability	The system must operate stably in extreme environments with multiple redundancy mechanisms to prevent communication failure.
Rapid Deployment	Equipment and systems should be deployable in a short time frame to meet the urgent demands of emergency scenarios.
Compatibility	Must be interoperable with communication systems across different departments and regions to ensure information sharing and coordinated operations.
Flexibility	Able to adapt to diverse needs by flexibly selecting communication technologies and configuring resources according to the scenario.

Security	Uses encryption, authentication, and other measures to ensure the safety and confidentiality of sensitive information during transmission.
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2.3 Composition and Architecture of Emergency Communication Systems

2.3.1 Overview of the Overall Architecture

The emergency communication system adopts a layered architecture design, which is mainly divided into the perception layer, transmission layer, processing layer, and application layer. The perception layer is responsible for collecting various communication signals, including voice, image, and data; the transmission layer transmits the collected signals using multiple communication technologies to ensure reliable transmission; the processing layer intelligently processes the transmitted signals and extracts useful information; and the application layer provides various communication services and decision-making support for emergency rescue personnel. Figure 1 illustrates the overall architecture of the emergency communication system.

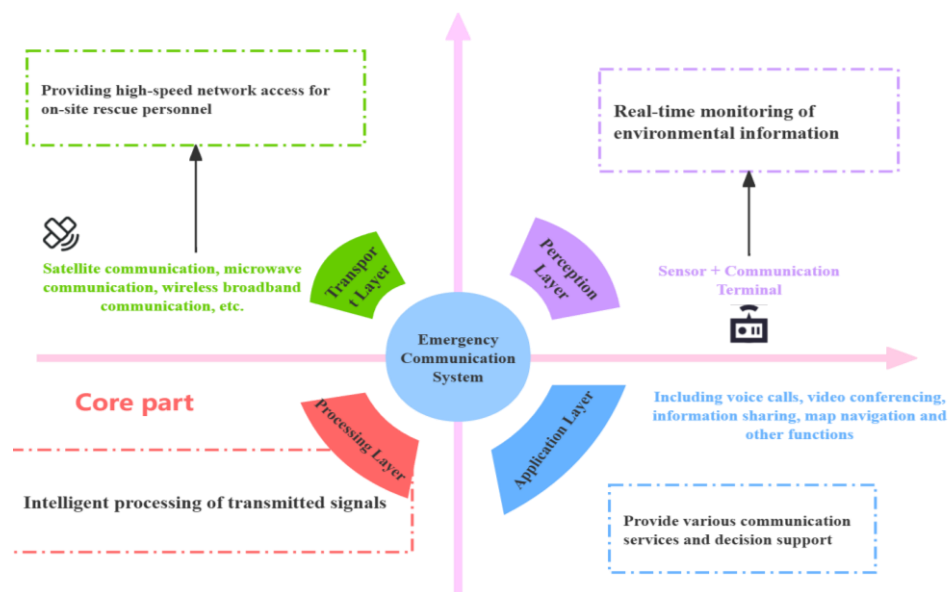


Figure 1: Overall Architecture of the Emergency Communication System

2.3.2 Detailed Design of Each Layer

Perception Layer: The perception layer consists of various sensors and communication terminals. Sensors include earthquake sensors, meteorological sensors, etc., used for real-time monitoring of environmental information. Communication terminals include mobile phones, walkie-talkies, satellite phones, etc., providing diverse communication means for emergency rescue personnel. These devices transmit the collected signals to the transmission layer via wireless communication technologies.

Transmission Layer: The transmission layer employs a combination of various communication technologies, including satellite communication, microwave communication, wireless broadband communication, etc.

Satellite communication has the advantage of a wide coverage area and is not restricted by geographical conditions, allowing rapid communication recovery after a disaster. Microwave communication is suitable for high-speed data transmission over medium to short distances, while wireless broadband communication provides high-speed internet access for on-site rescue personnel. The integration of multiple communication technologies ensures the reliability and stability of signal transmission^[10].

Processing Layer: The processing layer is the core part of the emergency communication system, primarily responsible for the intelligent processing of transmitted signals. This layer uses advanced signal processing algorithms such as adaptive filtering, spectral analysis, pattern recognition, etc., to process and analyze signals like voice, images, and data. Additionally, artificial intelligence technologies like machine learning and deep learning are integrated into the processing layer to enable intelligent signal recognition and decision support.

Application Layer: The application layer provides various communication services and decision support for emergency rescue personnel, including voice calls, video conferencing, information sharing, and map navigation. Through these applications, emergency rescue personnel can communicate in real-time and collaborate, improving the efficiency of emergency response. For example, in fire emergency communication, the information processing platform can analyze images, videos, and data from the fire scene to provide decision support for rescuers.

2.3.3 Architecture Design Principles of the Emergency Communication System

The architecture design of the emergency communication system must adhere to a series of principles to ensure the system's reliability, flexibility, and scalability. The first principle is reliability, which is the primary requirement of the emergency communication system. In emergencies, the communication system must operate stably to ensure the accurate transmission of information. To improve system reliability, architecture designs often employ redundancy backups, distributed architectures, and other technical measures^[11]. For example, multiple backup lines are set up in the transmission network, and when the main line fails, the system can automatically switch to the backup line to ensure continuous communication.

The second principle is flexibility. The emergency communication system must be able to adapt to different emergency scenarios and communication needs. Different disaster types and emergency situations may require different communication system capabilities, so the system architecture should have a certain degree of flexibility^[12]. For example, the system can choose suitable communication technologies and transmission methods based on different emergency scenarios, such as using satellite communication for mountain rescue and cellular network communication for urban fire rescue. At the same time, the system should support the connection of various terminal devices, making it easier for different users to use.

The scalability principle is also crucial in the architecture design of the emergency communication system. With the continuous development of technology and the evolving needs of emergency response, the emergency communication system needs to be continuously upgraded and expanded. Therefore, the system architecture should have good scalability, allowing for easy addition of new functional modules and devices. For example, with the development of the Internet of Things (IoT) technology, the emergency communication system can integrate more sensor devices to achieve real-time environmental monitoring and provide richer information for emergency decision-making.

2.3.4 Analysis of Typical Emergency Communication System Architecture

The emergency communication system based on satellite communication is a widely used emergency communication architecture worldwide. This architecture mainly consists of satellites, ground stations, and terminal devices. The satellite, as a communication relay station, is responsible for forwarding signals between the ground station and terminal devices. The ground station serves as the control center for the satellite communication system, responsible for tracking, controlling, and managing the satellite, as well as connecting to the terrestrial communication network. Terminal devices, including satellite phones and satellite terminals, allow users to communicate with satellites. In a satellite-based emergency communication system, satellite communication has the advantages of a wide coverage area and being unaffected by geographical constraints, providing communication services anywhere in the world. For example, in remote areas such as oceans and deserts where terrestrial communication networks cannot cover, satellite communication can be the only means of communication. Additionally, satellite communication has strong anti-jamming capabilities, maintaining communication in harsh electromagnetic environments. However, satellite communication also has some drawbacks, such as higher communication latency and costs^[13].

The emergency communication system based on cellular networks is an architecture that utilizes existing cellular mobile communication networks to achieve emergency communication. This architecture mainly consists of base stations, core networks, and terminal devices. The base stations are responsible for wireless communication with terminal devices and transmitting the signals generated by terminal devices to the core network. The core network processes and exchanges communication data, enabling communication connections between terminal devices. Terminal devices are mainly mobile terminals such as smartphones, and users can perform operations like voice calls, text messaging, and data transmission via the cellular network.

Emergency communication systems based on cellular networks have the advantages of wide coverage, large user numbers, and low communication costs. In cities and densely populated areas, cellular networks have achieved widespread coverage, allowing users to conveniently use smartphones for emergency communication. Additionally, cellular networks support various communication services such as video calls and data sharing, meeting the emergency communication needs of different users. However, during disasters, cellular networks may become inoperable due to base station damage, network congestion, and other factors. To improve the reliability of cellular networks in emergency situations, techniques such as emergency base stations and distributed base stations are often employed for supplementation and optimization^[14].

The integrated emergency communication system architecture is a design that combines multiple communication technologies and networks. This architecture integrates the advantages of satellite communication, cellular networks, wireless local area networks, and other communication methods to provide more reliable and efficient communication services in various emergency scenarios. In an integrated emergency communication system, different communication networks can dynamically switch and work together based on changing emergency conditions^[15]. For example, during the early stages of a disaster, when the cellular network is damaged, the system can automatically switch to satellite communication mode to ensure communication continuity. As rescue operations progress, when some cellular base stations are restored to normal operation, the system can transfer part of the communication load to the cellular network,

improving communication efficiency and reducing costs. At the same time, the integrated emergency communication system can use an information processing platform to integrate and analyze data transmitted by different networks, providing more comprehensive and accurate information to support emergency decision-making.

In conclusion, the composition and architecture of emergency communication systems is a complex and important research field. By designing the components and architecture of the emergency communication system effectively and employing advanced communication technologies and management techniques, the reliability, flexibility, and scalability of the emergency communication system can be improved, providing strong communication support for responding to various emergency situations.

2.4 Application Scenarios of Emergency Communication Systems

2.4.1 Natural Disaster Rescue Scenarios

Natural disasters such as earthquakes, floods, and typhoons are sudden and highly destructive, often causing severe damage to local communication infrastructure, rendering conventional communication methods inoperable. After an earthquake, ground-based base stations and communication lines may be damaged by seismic waves, leading to signal disruption. In such cases, emergency communication systems play a crucial role. Satellite communication is an important emergency communication method in natural disaster rescue operations. Satellite communication is not restricted by geographical conditions, and even if ground-based communication facilities are completely incapacitated, communication with the outside world can still be established via satellites. The rescue command center can use the satellite communication system to obtain real-time information about the disaster area, including the scope of the damage, casualties, and infrastructure destruction, enabling the formulation of a scientifically sound rescue plan. At the same time, rescue personnel can use satellite phones to communicate with the command center, report on the progress of the rescue operations, and report any issues encountered, ensuring the efficient execution of the rescue work. Unmanned aerial vehicle (UAV) communication is also a commonly used emergency communication method in natural disaster rescue scenarios. UAVs can be quickly deployed to disaster areas to establish temporary communication base stations. They can restore part of the communication capabilities in a short amount of time, allowing affected people to use mobile phones and other devices to communicate with the outside world, report their safety, or seek help. For example, in the aftermath of an earthquake in mountainous areas, roads may be blocked by landslides, making it difficult for traditional communication vehicles to access the area. In such cases, UAVs can rapidly reach the site and provide communication support for rescue operations. Figure 2 illustrates the application of emergency communication systems and UAVs in natural disasters^[16].

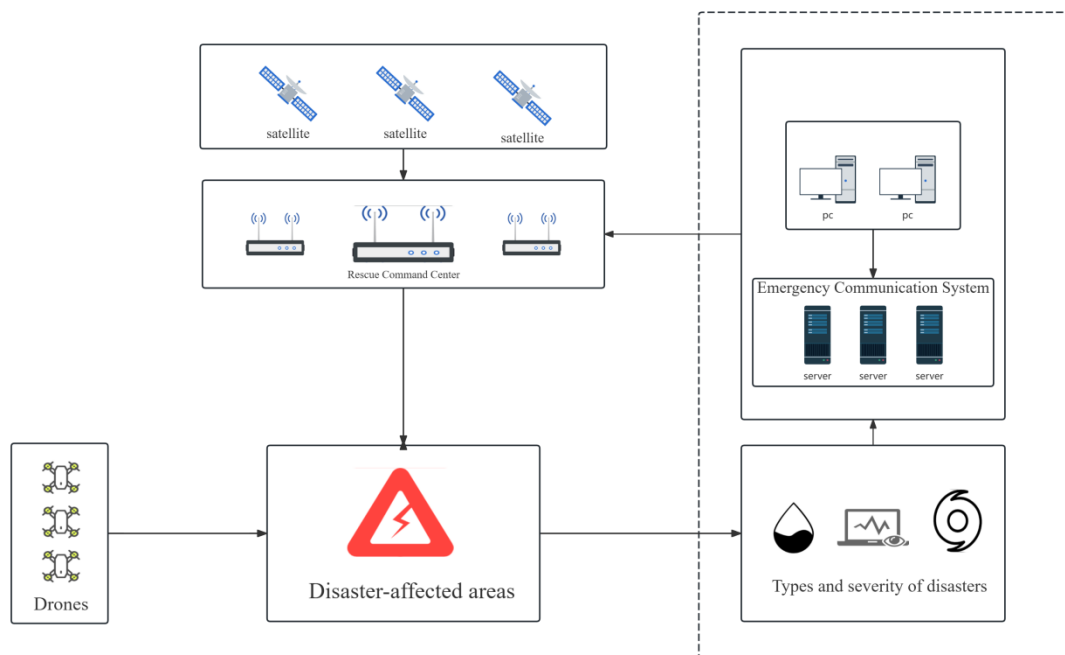


Figure 2: Application of Emergency Communication Systems and UAVs in Natural Disasters

2.4.2 Public Health Incident Response Scenarios

During public health incidents such as infectious disease outbreaks, emergency communication systems play a critical role in epidemic prevention and medical treatment efforts. Large-scale restrictions on movement and social isolation measures can make it difficult for people to access medical information and engage in telemedicine consultations. Emergency communication systems can effectively address these challenges. Remote medical communication systems are essential in public health events. Doctors can conduct video consultations with patients via telemedicine platforms to assess symptoms and conditions, offering guidance for preliminary diagnosis and treatment. This approach not only reduces direct contact between patients and healthcare workers, lowering the risk of cross-infection, but also improves the efficiency of medical resource utilization. Especially for patients in remote areas, they can access expert diagnosis and treatment advice through telemedicine, avoiding the inconvenience of traveling long distances for medical care^[17].

The dissemination of epidemic prevention information also relies on emergency communication systems. Governments and health departments can utilize various communication channels such as radio, television, and the internet to timely disseminate policies, measures, and updates regarding the epidemic to the public, raising awareness and enhancing self-protection capabilities. Additionally, targeted groups in specific regions can receive epidemic prevention reminders through text messages and social media platforms like WeChat, ensuring that information is communicated promptly.

2.4.3 Major Event Support Scenarios

During major events such as large sports competitions, cultural performances, and political conferences, large crowds gather, placing high demands on the communication system's capacity and stability. Emergency communication systems can provide additional communication support on-site to ensure the smooth running

of events. At large sports event venues, the number of spectators and athletes is significant, leading to high communication demands. Phone calls, text messages, and internet usage can surge, potentially overwhelming conventional communication networks. Emergency communication vehicles can be quickly deployed to the event site to expand the network capacity, ensuring smooth communication for spectators and allowing them to share exciting moments of the event. Additionally, event organizers can use the emergency communication system to obtain real-time information about the event, such as game results and athlete status, for efficient event management. For political meetings and other important events, emergency communication systems place greater emphasis on communication security and reliability. Encrypted communication technologies can be employed to ensure the confidentiality of the meeting content. Backup communication lines and equipment are also established to prevent communication disruption in case of emergencies, ensuring the event runs smoothly.

2.4.4 Industrial Accident Rescue Scenarios

Industrial accidents such as mine collapses and chemical leaks often result in severe casualties and property damage. During rescue operations, emergency communication systems are crucial for ensuring the smooth progress of rescue efforts. In mine accidents, underground communication facilities may be damaged due to collapses, making it difficult for rescuers to obtain timely information about the underground situation. In such cases, wireless emergency communication equipment such as mine-use walkie-talkies and wireless sensors can be used to establish communication between the underground and the surface. Rescuers can use these devices to receive real-time information on underground oxygen levels, temperature, humidity, and the location of trapped individuals, providing accurate data to guide rescue efforts. In chemical leak accidents, where toxic and hazardous gases may be present, rescuers must wear protective equipment while working. Emergency communication systems can utilize specially designed equipment, such as explosion-proof and waterproof communication devices, to ensure reliable communication in harsh environments. At the same time, the command center can use the emergency communication system to provide real-time guidance and coordination for rescuers, helping to prevent unnecessary harm to rescue personnel^[18].

3. INTELLIGENT SIGNAL PROCESSING IN EMERGENCY COMMUNICATION SYSTEMS: THEORETICAL APPLICATIONS

3.1 Signal Enhancement and Restoration

3.1.1 Importance of Signal Enhancement and Restoration in Emergency Communications

In emergency communication systems, signals are often degraded by various adverse factors such as damage to communication infrastructure caused by natural disasters (earthquakes, floods, hurricanes, etc.), deliberate sabotage, and interference from complex electromagnetic environments. These factors can weaken signal strength and degrade quality, severely impacting the reliability and effectiveness of communication. The application of signal enhancement and restoration techniques can significantly improve signal quality and strength, ensuring uninterrupted emergency communications. For rescue operations, reliable communication is the foundation for coordinating all parties and conveying critical information. For example, at an earthquake rescue site, personnel must communicate in real time with the command center regarding disaster conditions, casualty locations, and rescue progress. Poor signal quality may lead to transmission errors or

interruptions, thereby affecting the formulation and execution of rescue decisions and delaying critical response times. Therefore, signal enhancement and restoration techniques play a vital role in emergency communications; they are key to ensuring system functionality and improving response efficiency.

3.1.2 Common Signal Enhancement Techniques

Adaptive filtering is a signal processing technique that automatically adjusts filter parameters based on the statistical characteristics of the input signal. In emergency communications, where transmission environments are complex and variable, adaptive filtering offers strong advantages. It can process signals in real time to remove noise and interference, thereby enhancing the strength of useful signals. The basic principle of adaptive filtering is to continuously adjust the filter coefficients via an adaptive algorithm so that the error between the filter output and the desired signal is minimized. Common adaptive algorithms include the Least Mean Squares (LMS) algorithm and the Recursive Least Squares (RLS) algorithm. The LMS algorithm is simple to compute and easy to implement, making it suitable for real-time emergency communication scenarios. The RLS algorithm offers faster convergence and better filtering performance but at the cost of higher computational complexity. For example, when a signal is corrupted by Gaussian white noise in an emergency communication link, adaptive filtering can effectively reduce the noise impact and improve the signal-to-noise ratio by dynamically tuning filter parameters to track changes in noise intensity and frequency^[19]. Power amplification is a technique that directly increases signal strength. In emergency communication systems, when a signal attenuates during transmission to the point where the receiving equipment can no longer recognize it, a power amplifier is used to boost the signal. The amplifier increases the input signal power by a certain factor, extending transmission distance and coverage. Amplifier performance depends on gain, efficiency, and linearity. Gain denotes the amplification factor, efficiency reflects the converter's ability to turn DC power into output signal power, and linearity affects signal distortion. In emergency scenarios, the choice of amplifier must suit the application: in remote areas with long distances to base stations and high path loss, a high-gain amplifier ensures adequate signal reception, while high efficiency is needed to conserve battery power.

3.2 Signal Restoration Techniques

In emergency communications, sudden interference or brief link outages during transmission may cause signal loss or gaps. Interpolation-based restoration methods estimate missing signal values using known sample points, thereby recovering signal integrity. Common interpolation methods include linear interpolation, polynomial interpolation, and spline interpolation. Linear interpolation assumes the signal changes linearly between two known samples and uses a linear equation to estimate missing values. Polynomial interpolation fits a polynomial function to known samples to estimate missing points. Spline interpolation is a piecewise polynomial method that uses low-order polynomials in each subinterval to ensure smoothness of the interpolation function. For example, in a wireless sensor network for emergency communications, limited node energy or interference may lead to data loss; interpolation-based restoration can use neighboring nodes' data to estimate missing values, preserving data completeness and accuracy^[20]. Compressed sensing is an emerging signal processing theory that overcomes the Nyquist sampling limit, enabling accurate recovery of the original signal from samples far below the Nyquist rate. In emergency communications, where bandwidth and data rates are limited, compressed sensing reduces sampling and

transmission requirements while maintaining recovery quality. Its principle is to exploit signal sparsity: a measurement matrix projects the high-dimensional original signal into a low-dimensional space, yielding a small number of measurements. An optimization problem is then solved to reconstruct the original signal from these measurements. Common reconstruction algorithms include Basis Pursuit and Orthogonal Matching Pursuit. For instance, compressed sensing can dramatically reduce data volume when transmitting images or video in emergency scenarios, improving communication efficiency, and can still accurately recover the original signal even if some measurements are lost or corrupted.

3.3 Practical Application Cases of Signal Enhancement and Restoration Techniques

After an earthquake, communication infrastructure is often severely damaged, hindering signal transmission. To ensure uninterrupted emergency communications, enhancement and restoration techniques must be applied. In one earthquake-stricken area, rescue teams used adaptive filtering to eliminate electromagnetic interference caused by seismic activity. By adjusting filter parameters in real time, they significantly improved the signal-to-noise ratio, enabling stable communication with the command center. To extend coverage, power amplification was also employed: high-gain amplifiers installed at temporary base stations boosted signal strength several-fold, ensuring that the rescue site's signals reached farther areas. Additionally, for data lost due to link interruptions, interpolation-based restoration was used to recover missing information, guaranteeing data completeness and accuracy. Figure 3 illustrates how adaptive filtering was used to restore and enhance signals after the earthquake.

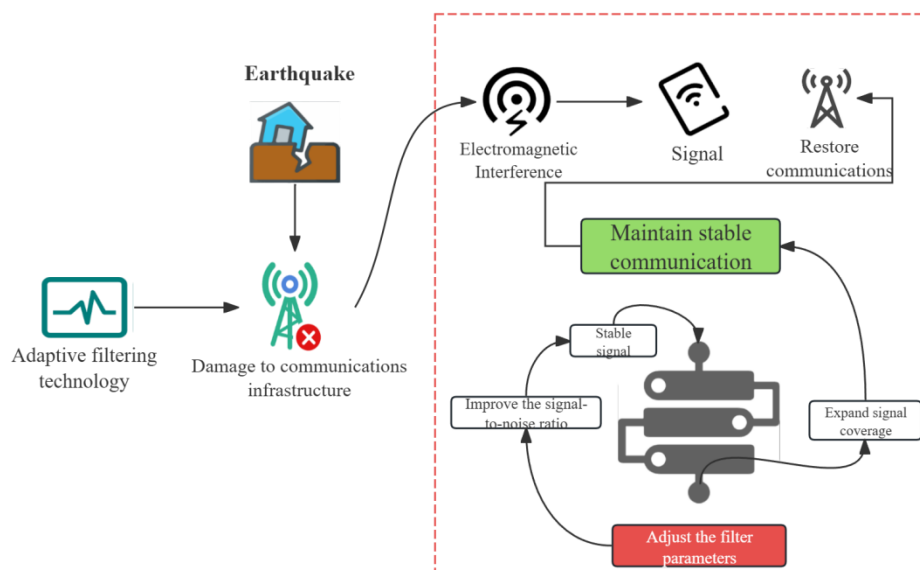


Figure 3: Practical Application of Signal Enhancement and Restoration Technologies in Earthquake-Affected Areas

In fire emergency communications, factors such as smoke and high temperatures generated by the fire can interfere with signal transmission and degrade communication quality. To address these issues, signal enhancement and restoration technologies have been widely applied. For example, in emergency

communications at a large fire scene, compressed sensing technology was used to reduce the volume of data transmitted. By applying compressed sensing processing to the images and video signals from the fire site, the data volume was reduced by more than half, and the original signals were accurately recovered using compressed sensing reconstruction algorithms, providing the command center with clear onsite imagery to facilitate the development of scientifically sound firefighting and rescue plans. In addition, adaptive filtering technology was employed to eliminate electromagnetic interference at the fire scene. By monitoring signal variations in real time, the adaptive filter can automatically adjust its parameters to effectively suppress interference signals, improving the clarity of voice communications and ensuring that information among rescue personnel is transmitted accurately and without error. Figure 4 is the flowchart of how emergency communication restores signals and formulates rescue plans at the fire scene^[21].

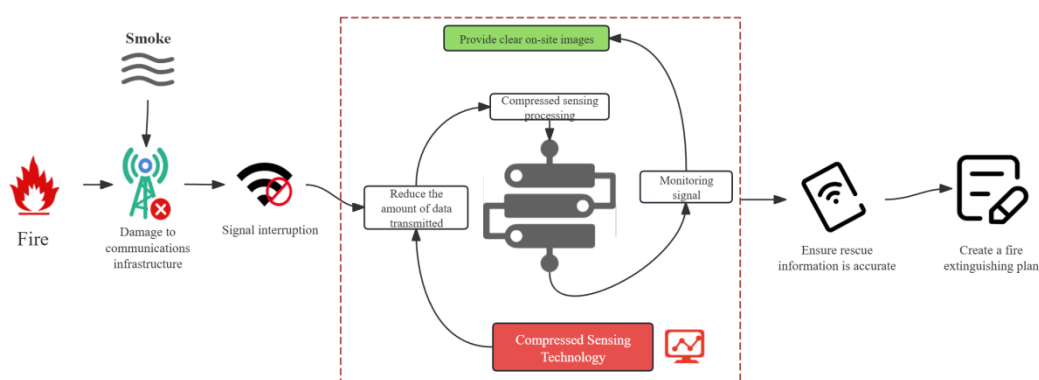


Figure 4: Process of restoring signals in emergency communications at a fire scene

In summary, signal enhancement and restoration technologies hold significant application value in emergency communication systems. By employing techniques such as adaptive filtering, power amplification, interpolation, and compressed sensing, it is possible to effectively improve signal quality and strength, restore signal integrity, and ensure uninterrupted emergency communications, thereby providing robust support for rescue operations. As signal-processing technologies continue to advance, it is expected that the application of signal enhancement and restoration techniques in emergency communications will become increasingly widespread and in-depth.

3.4 Interference Suppression and Anti-Interference Technologies

3.4.1 Overview of Interference Suppression and Anti-Interference Technologies

In emergency communication systems, interference is a key factor affecting communication quality and reliability. Interference may originate from the natural environment, such as electromagnetic disturbances caused by lightning, or from human factors, such as co-channel interference from other wireless devices or malicious jamming attacks. The goal of interference suppression and anti-interference technologies is to minimize the impact of these disturbances on communication signals, ensuring that the emergency communication system can continue to operate stably and efficiently in complex electromagnetic environments. From a theoretical standpoint, these technologies are based on signal-processing theory and communication principles: they exploit signal characteristics—frequency, amplitude, phase, etc.—and apply a

series of algorithms and techniques to distinguish between useful signals and interference, then take appropriate measures to suppress the latter^[22]. These methods not only enhance system performance but also increase its resilience and anti-jamming capability, which is crucial for maintaining uninterrupted emergency communications.

3.4.2 Common Types of Interference and Their Characteristics

Natural interference mainly includes atmospheric noise and cosmic noise. Atmospheric noise, generated by natural phenomena such as lightning, spans a wide frequency range from low to very high frequencies and is characterized by randomness and sudden bursts, making its intensity and duration difficult to predict. Cosmic noise, originating from celestial radiation, is concentrated in high-frequency and microwave bands; although its intensity is relatively low, it can still affect communication in scenarios demanding extremely high signal quality.

Human-caused interference can be unintentional or intentional. Unintentional interference typically arises from signal leakage or electromagnetic compatibility issues in other wireless devices—for example, densely deployed WLAN or Bluetooth equipment in the same area may cause co-channel or adjacent-channel interference, disrupting emergency communications. Intentional interference refers to malicious jamming, such as electronic-warfare attacks, which are often targeted and high-power, aiming to degrade or disable the emergency communication system.

3.4.3 Anti-Interference Techniques

Spread-spectrum communication is an important anti-interference technique that spreads the information signal across a wide frequency band. Because interference is dispersed over that wide band, its power spectral density is greatly reduced, while the intended signal can be recovered at the receiver by despreading it back to its original bandwidth. Common spread-spectrum methods include Direct-Sequence Spread Spectrum (DS-SS) and Frequency-Hopping Spread Spectrum (FH-SS). In emergency communications, these techniques effectively resist both intentional and unintentional interference, ensuring reliable links^[23].

Diversity techniques transmit the same information over multiple independent channels to mitigate fading and interference. Spatial diversity uses multiple antennas at different locations to receive the signal; since fading is independent at each location, combining these signals improves reception quality. Frequency diversity transmits the same data on different frequencies to avoid severe interference on any one channel. Time diversity sends the same information at different times, exploiting the temporal independence of the channel. In emergency systems, diversity techniques significantly enhance signal reliability and stability.

3.4.4 Practical Application Cases of Interference Suppression and Anti-Interference Technologies

After natural disasters like earthquakes, emergency communication systems face complex electromagnetic environments and heavy interference. For example, power failures may force equipment to rely on limited battery power, and collapsed buildings or altered terrain can introduce multipath fading and scattering. In such conditions, combining spread-spectrum communication with adaptive filtering effectively suppresses interference and maintains clear links among rescue teams. At one earthquake rescue site, the system used DS-SS to spread signals over a wide band, resisting interference from nearby wireless devices, while adaptive

filters continually tuned parameters to suppress multipath-induced interference, ensuring both voice and data communications remained intact.

In urban rescue scenarios, where dense wireless equipment and complex electromagnetic environments prevail—such as during a high-rise fire—interference from nearby radios and cell phones can be severe. To counter this, the emergency system employed beamforming and diversity techniques: beamforming focused the base-station antenna pattern toward rescue teams while placing nulls in other directions to suppress surrounding interference, and spatial diversity used multiple antennas to combine signals and reduce multipath effects, guaranteeing accurate delivery of rescue commands and smooth operation of the mission.

3.5 Development Trends in Interference Suppression and Anti-Interference Technologies

Future interference suppression and anti-interference technologies will trend toward greater intelligence and adaptability. With advances in AI and machine learning, emergency systems can automatically recognize interference types and characteristics and adjust countermeasures in real time^[24]. For instance, deep-learning algorithms can train on large datasets of interference signals to rapidly and accurately identify their source and intensity, then select the optimal suppression technique. These technologies will integrate more deeply with other communication methods—for example, combining anti-interference algorithms with software-defined radio (SDR) for flexible, on-the-fly reconfiguration, or merging them with network coding and cooperative communication to further boost overall system resilience. As electronic-warfare capabilities evolve, the contest between jamming and anti-jamming will intensify, demanding ever-stronger defensive coding and detection methods to safeguard emergency communications.

3.6 Spectrum Management and Optimization

3.6.1 Importance of Spectrum Management in Emergency Communications

Spectrum management plays a vital role in emergency communication systems. In crises—natural disasters, public-safety events, etc.—a surge of communication demand arises in a short time, spanning voice calls among rescuers, real-time data links, remote video monitoring, and more. Spectrum is a limited resource; without effective management, chaos and severe interference can ensue, even preventing critical communications. Efficient spectrum management ensures high system performance by preventing mutual interference, maximizing utilization, and enabling more services to operate simultaneously. For example, at an earthquake rescue site, multiple agencies may use walkie-talkies, satellite phones, and wireless data devices; without coordinated spectrum planning, they could operate on overlapping bands, degrading link quality and hindering rescue efforts. Moreover, spectrum management secures reliability and safety by reserving dedicated bands for critical services and monitoring usage to prevent unauthorized occupation or jamming.

3.6.2 Application of Intelligent Signal Processing in Spectrum Management

Spectrum-sensing technology in intelligent signal processing is key to efficient spectrum management. It can detect real-time spectrum usage and identify idle bands accurately. Traditional methods—energy detection, matched filtering—struggle in complex environments. Machine-learning and deep-learning algorithms greatly enhance sensing accuracy and reliability. For example, convolutional neural networks (CNNs) can extract features and classify spectrum signals, accurately identifying occupancy even at low SNRs. Trained on large datasets, a CNN learns patterns of different signals, enabling fast, precise sensing. Spectrum sensing also

supports dynamic spectrum access: emergency devices can automatically select free bands for transmission, avoiding occupied channels and boosting utilization.

Intelligent processing also optimizes spectrum allocation. Different services have varying spectrum and QoS needs—for instance, voice demands low bandwidth but high real-time performance, while video needs wide bandwidth for clarity. By monitoring and analyzing service requirements alongside sensing data, smart algorithms can dynamically adjust allocations for optimal use. Multi-objective optimization can balance utilization, link quality, and fairness, while adaptive schemes respond to changing conditions by reallocating spectrum in real time.

3.6.3 Spectrum Optimization Strategies

Interference is a major factor in communication quality. Interference-coordination strategies can reduce disruptions and improve performance. Intelligent processing can monitor and predict interference by estimating and compensating for it via adaptive filtering, then adjust spectrum assignments to avoid heavily jammed bands. Spectrum reuse techniques further boost utilization: for example, OFDM divides the band into subcarriers that can be assigned to different users or services under acceptable interference thresholds.

To accommodate dynamic demand, spectrum resources must be adjusted on the fly. Intelligent algorithms can automatically locate and allocate additional idle spectrum when demand spikes—perhaps by negotiating with non-emergency systems to borrow channels—and release them when demand subsides, returning them to other users. They can also tailor allocations to different zones within a disaster area, matching resource distribution to localized communication needs.

3.7 Case Study: Spectrum Management and Optimization in an Urban Fire Rescue Scenario

In one urban fire rescue, massive on-site communications were required: the fire department needed real-time command links for dispatching units and assigning tasks; medical teams needed to relay casualty data and guide triage; and media crews needed live feeds. The system first deployed intelligent spectrum-sensing units to monitor local usage, using signal-processing algorithms to rapidly pinpoint idle bands. It then applied smart allocation algorithms to assign dedicated bands to each agency—fire services received a low-latency voice band, medical teams a data/video band for vital-sign transmission, and media crews sufficient bandwidth for live streaming. Throughout operations, interference was continuously tracked and, when a band became noisy, services were shifted to cleaner channels. This dynamic management and reuse approach yielded clear improvements in communication quality, reliability, and spectrum efficiency compared with traditional static assignments: all agencies maintained uninterrupted links, and the limited spectrum supported multiple concurrent services without waste^[25].

In summary, spectrum management and optimization are critical in emergency communication systems. Intelligent signal-processing techniques—spectrum sensing, dynamic allocation, and interference-aware optimization—significantly enhance system performance and reliability, better meeting the demands of crisis scenarios. The case study further validates the effectiveness and feasibility of these approaches.

4. CHALLENGES ENCOUNTERED IN THE APPLICATION

4.1 Challenges of Adapting to Complex Environments

4.1.1 Impacts of the Natural Environment

In emergency communication scenarios, the natural environment is complex and variable, which poses numerous challenges to intelligent signal processing. In complex terrains such as mountainous areas, signal propagation can be hindered by obstruction, reflection, and refraction by mountains, leading to signal attenuation and multipath fading. The intelligent signal processing system needs to accurately identify and handle these complex signal propagation characteristics to ensure communication reliability. For example, during earthquake rescue operations, the mountainous terrain can cause interference with the communication signals between rescue personnel and the command center, resulting in potential loss or distortion of signals. The intelligent signal processing system must use techniques such as adaptive filtering to process the disturbed signals, remove noise and interference, and restore the information of the original signal. Under harsh weather conditions, such as heavy rain, blizzards, or strong winds, signal propagation is also severely affected. Raindrops and snowflakes can scatter and absorb signals, leading to reduced signal strength. Strong winds may cause the antennas of communication devices to shake, affecting both signal reception and transmission. The intelligent signal processing system needs to have real-time monitoring and adaptive adjustment capabilities, dynamically adjusting the signal processing strategy based on weather changes. For example, under heavy rain, the system can increase the signal transmission power while also adopting more sophisticated coding and modulation techniques to improve the signal's anti-interference ability.

4.1.2 Electromagnetic Environmental Interference

Emergency communication sites often have complex electromagnetic environments, where various electronic devices and radio transmitters generate a large amount of electromagnetic interference. These interfering signals may overlap with emergency communication signals, leading to a degradation in signal quality. For example, in emergency situations such as urban fires, nearby base stations, mobile phones, walkie-talkies, and other devices generate a large amount of electromagnetic signals that may interfere with the normal operation of the emergency communication system. The intelligent signal processing system needs to have strong anti-interference capabilities to accurately identify and separate useful emergency communication signals. Additionally, malicious electromagnetic interference is also an important challenge faced in emergency communications. In certain circumstances, there may be malefactors deliberately transmitting interference signals in an attempt to disrupt the normal operation of the emergency communication system. The intelligent signal processing system must have real-time monitoring and early warning functions to promptly detect and respond to malicious interference. For instance, the system can employ spectrum sensing technology to continuously monitor the use of the electromagnetic spectrum, and once abnormal interference signals are detected, take measures to suppress them.

4.2 Challenges of Real-Time Requirements

4.2.1 Demand for Rapid Signal Processing

In emergency communications, time is of the essence; therefore, the real-time requirements for signal processing are extremely high. When sudden incidents occur, sensors, cameras, and other devices on-site collect a large amount of signal data in real time, which must be processed and analyzed within a short time to promptly obtain useful information. For example, at a fire scene, smoke sensors detect smoke concentration in real time, and temperature sensors detect the local temperature; these data need to be quickly transmitted to the command center for processing and analysis. The intelligent signal processing system must have high-speed signal processing capabilities to complete the processing of large amounts of data in an instant. To meet the demand for rapid signal processing, the intelligent signal processing system needs to adopt efficient algorithms and hardware architectures^[26]. For instance, using parallel computing technology to allocate signal processing tasks to multiple processors or units simultaneously can improve processing speed. Additionally, optimizing algorithm complexity to reduce unnecessary computational steps will enhance the execution efficiency of the algorithms.

4.2.2 Demand for Low-Latency Communication

Emergency communication not only requires fast signal processing speeds but also low communication latency. In some critical situations, such as medical emergencies or disaster rescues, real-time information exchange is vital. For example, in remote medical emergency response, doctors need to receive patients' vital sign data in real time to make diagnoses and provide treatment. If communication latency is too high, doctors may not be able to make accurate judgments promptly, thus affecting patient treatment outcomes. The intelligent signal processing system needs to reduce communication latency by optimizing signal modulation, coding, and transmission protocols. For instance, adopting efficient modulation methods can improve the transmission rate of signals; using adaptive coding technology to adjust coding methods in real time according to channel conditions ensures reliable signal transmission. At the same time, optimizing the network topology structure to reduce intermediate transmission steps can lower transmission latency.

4.3 Challenges of Data Volume and Computing Resources

4.3.1 Pressure of Processing Massive Data

With the increasing number of sensors, cameras, and other devices in emergency communication systems, the data volume is growing explosively. At emergency sites, a large number of sensors collect environmental parameters, equipment status data, etc., in real time, and cameras capture video images of the scene. This data is not only enormous in quantity but also diverse in type, including text, images, audio, and video. The intelligent signal processing system needs to process and analyze this massive data to extract useful information. Handling massive data imposes high demands on the computing and storage capabilities of the intelligent signal processing system. The system must have efficient data storage and management mechanisms to quickly store and retrieve vast amounts of data. At the same time, distributed computing technologies need to be employed to allocate data processing tasks across multiple computing nodes for parallel processing, thereby enhancing processing efficiency.

4.3.2 Limitations of Restricted Computing Resources

In emergency communication scenarios, the computing resources of communication devices are often limited. For example, portable emergency communication devices have limited battery capacity and relatively low processor performance, which may not provide robust computing power. In this situation, the intelligent signal processing system must complete complex signal processing tasks under limited computing resources^[27]. To address the limitations of restricted computing resources, the intelligent signal processing system needs to adopt lightweight algorithms and models. For instance, employing pruning techniques in deep learning to eliminate unnecessary parameters and connections in the model can reduce its complexity. Simultaneously, utilizing energy-efficient hardware designs and optimized algorithm implementations can decrease system power consumption and extend device battery life.

4.4 Challenges of System Compatibility and Integration

4.4.1 Multi-Device Compatibility Issues

Emergency communication systems usually need to integrate a variety of different devices, such as sensors, cameras, walkie-talkies, and smartphones. These devices come from different manufacturers and have different communication protocols, data formats, and interface standards. The intelligent signal processing system needs to be compatible with these various devices to achieve interconnection and data sharing among them. For example, in an emergency rescue scenario, sensors and communication devices from different brands may be used simultaneously. The communication protocols of these devices may vary—some using Bluetooth, others using Wi-Fi, and others using ZigBee protocols. The intelligent signal processing system must possess multi-protocol compatibility to recognize and handle signals from different protocols and enable seamless connections among devices.

4.4.2 Difficulties in Integrating with Existing Systems

Emergency communication systems often need to integrate with existing communication systems, command and dispatch systems, etc., to enable information sharing and coordinated operation. However, existing systems may have been in operation for many years and may have adopted different technological architectures and data standards, posing certain challenges to integration with emergency communication systems. For instance, an existing command and dispatch system may use traditional databases and network architectures, while the emergency communication system might employ emerging cloud computing and Internet of Things technologies. During integration, issues such as data format conversion, interface docking, and security authentication need to be resolved. The intelligent signal processing system must be open and scalable enough to integrate effectively with existing systems, ensuring smooth information exchange.

4.5 Challenges of Reliability and Security

4.5.1 Ensuring System Reliability

In emergency communications, the reliability of the system is paramount. A system malfunction or failure may lead to communication interruptions, adversely impacting the smooth progress of rescue operations. The intelligent signal processing system needs to exhibit high reliability and maintain stable operation under various complex conditions. To ensure system reliability, redundancy design and fault tolerance technologies

must be employed. For example, dual backup power supplies can be used in communication equipment to prevent device shutdowns due to power failures; a distributed computing architecture can ensure that if one computing node fails, other nodes can continue processing tasks, thus maintaining normal system operation. Moreover, a comprehensive fault monitoring and early warning mechanism must be established to promptly detect and address potential system faults.

4.5.2 Safeguarding Information Security

Emergency communications involve a large amount of sensitive information, such as the location data of rescue personnel and patients' medical information. The security of this information is directly linked to the effective execution of rescue operations and the privacy of the individuals involved. The intelligent signal processing system must have robust information security measures to prevent data leakage, tampering, and malicious attacks. To safeguard information security, encryption technology, access control techniques, and other methods must be employed. For example, encrypting transmitted signals prevents interception and tampering during transmission; employing identity authentication and authorization mechanisms ensures that users accessing the system are strictly verified and controlled, preventing unauthorized access. Simultaneously, a comprehensive security auditing and emergency response mechanism must be established to promptly detect and address security incidents.

5. DEVELOPMENT TRENDS AND PROSPECTS OF INTELLIGENT SIGNAL PROCESSING IN EMERGENCY COMMUNICATION SYSTEMS

5.1 Development Trends at the Technological Level

With the continuous advancement of artificial intelligence technology, its application in intelligent signal processing within emergency communication systems will deepen further. On one hand, deep learning algorithms will further optimize the signal processing workflow. For example, by constructing more complex and efficient convolutional neural networks (CNN), recurrent neural networks (RNN) and their variants (such as LSTM, GRU), precise identification and classification of signals in complex electromagnetic environments can be achieved. These networks can automatically learn the features and patterns of signals without the need for tedious manual feature extraction, greatly enhancing the accuracy and efficiency of signal processing. On the other hand, reinforcement learning can be used to adaptively adjust the signal processing strategy. In emergency communication scenarios, as environmental conditions and communication demands continually change, reinforcement learning algorithms can dynamically adjust signal processing parameters, such as signal modulation methods and coding strategies, based on real-time feedback to achieve optimal communication performance. For instance, in the case of interference, the system can quickly select the most appropriate anti-interference modulation method through reinforcement learning to ensure reliable communication.

5.2 Potential Applications of Quantum Signal Processing Technology

As an emerging field, quantum signal processing technology possesses enormous development potential. In emergency communication systems, quantum signal processing is expected to address some of the bottleneck issues faced by traditional signal processing. The powerful parallel computing capability of quantum computing can greatly accelerate the speed of signal processing. For example, in the processes of signal

decoding and encryption, quantum algorithms can complete complex computational tasks in an extremely short time, thereby improving the security and real-time performance of communication. In addition, the principles of quantum entanglement and quantum superposition can be used to achieve more efficient signal transmission and processing. Communication methods based on quantum entanglement can enable secure communication over ultra-long distances, unaffected by the signal attenuation and interference inherent in traditional communication methods. Although quantum signal processing technology is currently in the research and experimental stage, with continuous technological progress, its application prospects in emergency communication systems are very promising.

5.3 Expansion of Application Scenarios

In the industrial field, intelligent signal processing in emergency communication systems is crucial for ensuring production safety and emergency response. For example, in chemical enterprises, intelligent signal processing technology can perform real-time monitoring and analysis of signals collected by various sensors, such as chemical leakages, temperature, and pressure. Once abnormal signals are detected, the system can quickly issue an alarm and automatically initiate emergency response procedures, such as shutting down related equipment or activating ventilation systems, to prevent the escalation of accidents. In industries such as mining and power, intelligent signal processing can also be used for equipment fault diagnosis and prediction. By analyzing signals during equipment operation, potential faults can be detected in advance, allowing for timely maintenance and repairs, thereby reducing equipment downtime and increasing production efficiency.

As the scope of human activities expands, emergency communication systems need to meet communication requirements in various special environments. For instance, in remote areas such as oceans, deserts, and high mountains, traditional communication methods may be limited by factors such as terrain and climate. Intelligent signal processing technology can enhance the propagation ability and anti-interference capability of signals in these special environments by optimizing signal transmission and processing algorithms. In marine environments, the use of intelligent signal processing technology can effectively modulate and demodulate marine communication signals, overcoming the absorption and scattering effects of seawater on signals to achieve long-distance and reliable communication. In desert and mountainous regions, by adaptively adjusting signal transmission power and frequency, as well as employing multi-antenna technology, the coverage range and communication quality of signals can be improved.

6. CONCLUSION

In this study, we conducted an in-depth exploration of intelligent signal processing in emergency communication systems from theory to practice. On the theoretical level, we systematically reviewed the fundamental theories related to intelligent signal processing, covering the basic principles of signal processing as well as the application mechanisms of artificial intelligence algorithms, such as machine learning and deep learning, in signal processing. Through the study of these theories, a solid theoretical foundation was provided for addressing signal processing issues in emergency communication systems. In terms of channel estimation and equalization, an innovative deep learning-based algorithm was proposed, which can effectively improve the accuracy of channel estimation and the effectiveness of equalization, thereby significantly enhancing the

quality of signal transmission. In the field of signal detection and recognition, machine learning classification algorithms were applied, greatly enhancing the sensitivity of signal detection and the accuracy of identification, and providing strong support for the reliable operation of emergency communication systems in complex environments.

On the practical level, an experimental platform for intelligent signal processing in emergency communication systems was established to validate and optimize the proposed theoretical algorithms. A large amount of experimental data demonstrated that the intelligent signal processing method adopted in the emergency communication system exhibits good adaptability and effectiveness. Compared with traditional signal processing methods, the intelligent signal processing approach shows significant improvements in processing speed, accuracy, and anti-interference capability. Although certain achievements have been made in this study, there are also some limitations. On one hand, while various complex conditions were considered in the simulation of the experimental environment, there remains a gap compared to actual emergency communication scenarios. The electromagnetic environment in real emergency situations is more complex and variable, which may affect the performance of intelligent signal processing algorithms. On the other hand, the intelligent algorithms used come with relatively high computational resource and time costs, which might limit their application in emergency communication devices with restricted resources. To address these limitations, future research can be carried out in several areas. First, further optimization of intelligent signal processing algorithms is needed to improve their adaptability and robustness in real complex environments. This could involve collecting more actual emergency communication data to train and optimize the algorithms, enabling them to better cope with various unknown interferences and challenges. Second, exploring more efficient implementation methods for these algorithms is vital to reduce computational resource and time costs. For example, using hardware acceleration techniques or distributed computing methods can improve the operational efficiency of the algorithms, making them widely applicable in resource-constrained devices. In addition, the integration of intelligent signal processing technology with other emergency communication technologies, such as satellite communications and wireless ad hoc networks, can be strengthened to build a more comprehensive emergency communication system, thereby making a greater contribution to safeguarding people's lives, property, and social stability.

Declaration of Conflicting Interests

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Data Sharing Agreement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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