

Integrating Intelligent Audio Technology and Hardware Design in Modern Security Systems

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Abstract

With the acceleration of urbanization and the increasing demand for public safety, modern security systems are facing unprecedented challenges. Audio technology, as an integral part of security systems, plays a key role in surveillance, early warning, and emergency response. This paper aims to explore how the integration of intelligent audio technology and hardware design can enhance the performance of modern security systems. By applying artificial intelligence technologies such as deep learning and machine learning, this paper analyzes the latest advancements in intelligent audio technology in sound recognition, anomaly detection, and data fusion, and discusses the key role of hardware design in supporting these intelligent audio applications. The paper also proposes a security system framework that integrates intelligent audio technology and hardware design and evaluates the effectiveness and potential value of this framework through the analysis of practical application cases. Finally, the paper discusses the current challenges and future development trends, providing new perspectives and solutions for technological progress in the security field.

Keywords: intelligent audio technology, hardware design, security systems, artificial intelligence, sound recognition, sound source localization, audio anomaly detection, Internet of Things (IoT), edge computing

1. Introduction

1.1 Research Background and Significance

In the context of globalization and informatization, security systems have become an important tool for maintaining social stability and public safety. Audio technology, as a key component of security systems, is increasingly highlighted in its role in surveillance, early warning, and emergency response. With the rapid development of intelligent technology, especially the application of artificial intelligence technology, the application prospects of audio technology in the security field have become broader. Intelligent audio technology can provide more accurate sound recognition, abnormal sound detection, and environmental sound analysis, thereby improving the response speed and accuracy of security systems. Therefore, studying the integration of intelligent audio technology and hardware design is of great practical significance for enhancing the performance of modern security systems.

1.2 Research Objective

The objective of this paper is to explore how to combine intelligent audio technology with hardware design to enhance the performance of modern security systems. Specifically, this paper will analyze the application of intelligent audio technology in security systems, including sound recognition, abnormal sound detection, and audio data fusion, and discuss how hardware design supports these intelligent audio applications. In addition, this paper will propose a security system framework that integrates intelligent audio technology and hardware design and evaluate the effectiveness and potential value of this framework through the analysis of practical application cases.

2. Overview of Modern Security Systems

2.1 Definition and Classification of Security Systems

Security systems, also known as security and protection systems, are comprehensive technical systems used to protect people's life and property safety, prevent and reduce crimes and accidents. They achieve surveillance, early warning, and emergency response in specific areas through technical means. Security systems can be classified into the following main types based on their functions and application scenarios:

- 1) **Surveillance systems:** Including video surveillance, audio surveillance, and environmental monitoring, used for real-time monitoring of the security status of specific areas.
- 2) **Alarm systems:** Systems that trigger alarms when abnormal situations are detected, such as intrusion alarm systems and fire alarm systems.
- 3) **Access control systems:** Systems for controlling and managing the entry and exit of personnel, such as access control systems and electronic locks.
- 4) **Emergency response systems:** Systems that provide rapid response in emergency situations, such as emergency broadcasting and one-button alarm systems.

Each type of security system has its unique technical requirements and application scenarios. They work together to form a complete security protection network.

2.2 Development History of Security Systems

The development of security systems has gone through a transformation from simple physical protection to modernization and intelligentization. Initially, security mainly relied on physical barriers, such as walls and locks. With the development of electronic technology, electronic locks and simple alarm systems emerged. Entering the 21st century, with the progress of computer and network technology, security systems began to develop towards digitalization and networking, with the emergence of integrated monitoring centers and remote monitoring systems. In recent years, the application of artificial intelligence technology has led security systems towards intelligent development, achieving more accurate threat identification and response. (Wang, D., & Brown, G. J., 2006)

2.3 Challenges Faced by Modern Security Systems

With the development of technology and changes in the social environment, modern security systems face the following challenges:

- 1) **Technological integration:** How to effectively integrate traditional security technology with emerging information technology and artificial intelligence technology to enhance the system's intelligent level.
- 2) **Data security:** With the increasing dependence of security systems on data, the secure storage and processing of data have become a major challenge.
- 3) **Privacy protection:** While enhancing public safety, how to protect personal privacy and prevent the misuse of surveillance data.
- 4) **Environmental adaptability:** Security systems need to work stably in various complex environments, including extreme weather and electromagnetic interference.
- 5) **Cost and benefits:** With the development of technology, the construction and maintenance costs of security systems are constantly rising. How to balance cost and benefits has become a problem.

2.4 Current Application Status of Intelligent Technology in Security Systems

The application of intelligent technology, especially artificial intelligence technology, in security systems is becoming more and more extensive. The following are some key applications:

- 1) **Intelligent video analysis:** Using computer vision technology to intelligently analyze video content, such as behavior recognition and crowd counting.
- 2) **Voice recognition and analysis:** Automatically recognizing and analyzing sounds through audio monitoring for early warning and emergency response.
- 3) **Big data analysis:** Collecting and analyzing a large amount of security data to identify potential security threats and optimize resource allocation.
- 4) **Machine learning:** Improving the adaptability and predictive capabilities of security systems through machine learning algorithms.
- 5) **Internet of Things (IoT):** Interconnecting security devices through IoT technology to enhance the

system's response speed and coverage.

The application of intelligent technology not only improves the efficiency and accuracy of security systems but also provides new possibilities for the future development of security systems. However, the application of these technologies also brings new challenges, such as technological integration, data security, and privacy protection, which require joint efforts from the industry and beyond to address. (Wang, D., & Brown, G. J., 2006)

By deeply analyzing the definition, classification, development history, and challenges faced by modern security systems, this chapter lays the foundation for in-depth research in subsequent chapters and provides a background for discussing the application of intelligent audio technology and hardware design in security systems.

3. Fundamentals of Intelligent Audio Technology

3.1 Basic Principles of Audio Signal Processing

Audio signal processing is the technology of converting analog sound signals into digital signals and analyzing and processing them through algorithms. This process includes the following basic steps: (Sohn, J., Kim, W., & Sung, W., 2001)

- 1) **Sound collection:** Using microphones to convert pressure waves in the air into electrical signals. The key to this step is to choose the right microphone to ensure that the signal's sensitivity and frequency response meet the needs of specific applications.
- 2) **Analog-to-Digital Conversion (ADC):** Converting analog electrical signals into digital signals for computer processing. The sampling rate and quantization bits in the ADC process directly affect the quality of the audio signal.
- 3) **Preprocessing:** Including noise reduction, gain control, and normalization to improve signal quality. Noise reduction techniques such as wavelet transform and spectral subtraction are used to reduce background noise, while gain control is used to adjust the signal's dynamic range.
- 4) **Feature extraction:** Extracting key features from audio signals, such as Mel Frequency Cepstral Coefficients (MFCC). These features are crucial for subsequent sound recognition and classification.
- 5) **Signal analysis:** Analyzing the extracted features to identify the type, source, and content of the sound. This usually involves statistical analysis and pattern recognition techniques.

3.2 Development of Intelligent Audio Technology

The development of intelligent audio technology has benefited from the progress of machine learning and deep learning, enabling audio systems to automatically recognize and respond to sound events.

3.2.1 Sound Recognition Technology

Sound recognition technology involves the recognition of specific sound patterns, such as speech, vehicle types, or animal calls. This technology is usually based on the following steps: (Sohn, J., Kim, W., & Sung, W., 2001)

- 1) **Feature extraction:** Extracting features of the sound, such as frequency, rhythm, and timbre. These features can represent the essential attributes of the sound.
- 2) **Model training:** Training classifiers with a large amount of labeled data, such as Support Vector Machines (SVM) or neural networks. Deep learning models, especially Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), have shown excellent performance in sound recognition.
- 3) **Recognition and application:** Applying the trained model to new sound samples to identify the type of sound. This involves real-time processing and low-latency response.

3.2.2 Sound Source Localization Technology

Sound source localization technology aims to determine the source of sound in space. This is usually achieved through microphone arrays:

Direction of Arrival (DOA) estimation: Using algorithms such as beamforming or Time Difference of Arrival (TDOA) to estimate the direction of the sound source. These algorithms require precise timing information and array geometry configuration. (Sohn, J., Kim, W., & Sung, W., 2001)

Environmental modeling: Considering environmental factors, such as reflection and reverberation, to improve localization accuracy. This may involve complex acoustic models and environmental perception techniques.

Real-time localization: Tracking the position of the sound source in real-time in dynamic environments. This requires the system to quickly adapt to environmental changes and sound source movement.

3.2.3 Audio Anomaly Detection Technology

Audio anomaly detection technology is used to identify abnormal sounds in the environment, such as glass breaking or gunshots:

- 1) **Abnormal sound database:** Building a database that includes various abnormal sounds. This database needs to be regularly updated and maintained to ensure the accuracy of identification.
- 2) **Deep learning models:** Using Convolutional Neural Networks (CNN) or Recurrent Neural Networks (RNN) to recognize abnormal sounds. These models can learn complex patterns of sounds from a large amount of data.
- 3) **Real-time monitoring:** Detecting abnormal events in real-time audio streams and triggering alarms. This requires the system to have high processing speed and high accuracy.

3.3 Potential Applications of Intelligent Audio Technology in Security

The application prospects of intelligent audio technology in the security field are broad, and the following are some potential application scenarios:

- 1) **Intrusion detection:** Detecting illegal intrusion activities through sound recognition technology, such as the sound of breaking windows or door locks being pried open. This requires the system to accurately recognize specific sounds in complex environments.
- 2) **Emergency response:** Quickly responding to emergencies using audio anomaly detection technology, such as fire alarms or screams. This involves real-time monitoring and rapid response mechanisms.
- 3) **Traffic monitoring:** Monitoring traffic flow and identifying abnormal vehicle sounds through sound source localization technology. This can help traffic management departments optimize traffic flow and prevent accidents.
- 4) **Public safety:** Using audio monitoring technology in public places for crowd behavior analysis and violence prevention. This requires the system to process a large amount of audio data and identify potential threats.
- 5) **Border security:** Using audio technology to monitor illegal border crossings. This involves long-distance sound monitoring and recognition.

The application of intelligent audio technology in security systems can not only improve safety but also increase efficiency by reducing false alarms and improving response speed. With the continuous development of technology, it is expected that intelligent audio technology will play an increasingly important role in the security field.

4. Application of Hardware Design in Security Audio Systems

4.1 Hardware Composition of Audio Surveillance Equipment

Audio surveillance equipment is a key component of security systems for capturing and analyzing sound signals. Its hardware composition typically includes the following parts: (IEEE Standards Association, 2019)

- **Microphone arrays:** Arrays of multiple microphones used to capture sound signals and provide spatial sound information, such as sound source localization and beamforming.
- **Signal preprocessors:** Including amplifiers and filters, used to enhance signals and filter out noise.
- **Analog-to-Digital Converters (ADC):** Converting analog signals into digital signals for digital signal processing.
- **Digital Signal Processors (DSP):** Used to perform complex audio processing algorithms, such as feature extraction and pattern recognition.
- **Storage units:** Used to store collected audio data and processing results for subsequent analysis.
- **Communication interfaces:** Including wireless and wired interfaces, used to transmit audio data to monitoring centers or other devices.

4.2 Impact of Hardware Design on Audio Performance

Hardware design has a direct impact on the performance of audio surveillance equipment, and the following are several key aspects:

4.2.1 Sensor and Microphone Array Design

The design of microphone arrays is crucial for the quality and accuracy of sound capture. Considerations during design include:

Array configuration: The geometric layout of microphones affects the accuracy of sound source localization and the directionality of sound capture.

Sensitivity and dynamic range: The sensitivity of microphones determines the strength of the signal, and the dynamic range affects the maximum and minimum detectable levels of the signal.

Frequency response: The microphone's response to different frequency sounds affects the fidelity of the sound.

4.2.2 Signal Amplification and Filtering Circuits

Signal amplification and filtering circuits play a key role in improving audio signal quality:

Amplifiers: Used to enhance weak sound signals so that they can be converted by ADC. The design of amplifiers needs to consider noise gain and linearity.

Filters: Used to remove unwanted frequency components, such as low-frequency noise or high-frequency interference. Filter design needs to consider cutoff frequency and bandwidth.

4.2.3 Data Acquisition and Processing Units

Data acquisition and processing units are the brains of audio surveillance equipment:

ADC: Choosing high-resolution and high-sampling-rate ADCs can improve signal fidelity and dynamic range.

DSP: High-performance DSPs can process complex audio algorithms in real-time, improving the system's response speed and accuracy.

4.3 Challenges and Optimization Strategies in Hardware Design

Hardware design needs to face various challenges and adopt corresponding optimization strategies:

4.3.1 Anti-Interference Design

Anti-interference design is key to ensuring the stable operation of audio surveillance equipment in complex electromagnetic environments:

Shielding and grounding: Using shielding materials and proper grounding techniques to reduce electromagnetic interference.

Signal isolation: Using isolation techniques between sensitive circuits and noise sources, such as optocouplers and transformers.

4.3.2 Low-Power Design

Low-power design is crucial for extending battery life and reducing energy consumption:

Power management: Using low-power modes and sleep modes to reduce energy consumption.

Efficient circuit design: Optimizing circuit design to reduce static and dynamic power consumption.

4.3.3 Environmental Adaptability Design

Environmental adaptability design ensures that equipment can work stably under various environmental conditions:

Waterproof and dustproof: Using sealing and protection measures to prevent water and dust from entering the equipment.

Temperature management: Designing heat dissipation and insulation measures to adapt to extreme temperature changes.

By deeply discussing various aspects of hardware design, this chapter provides a solid foundation for understanding the physical basis of security audio systems and provides a background for the application of intelligent audio technology in subsequent chapters. These details of hardware design are crucial for achieving efficient and reliable security audio surveillance systems.

5. Integration of Intelligent Audio Technology and Hardware Design

5.1 Integration Framework Design

In the integration of intelligent audio technology and hardware design, framework design is key to achieving an efficient and stable system. The following are two core elements for building this integration framework:

5.1.1 System Architecture

System architecture is the blueprint for integration framework design, defining the components of the system, their relationships, and how data flows between them. A typical intelligent audio surveillance system architecture includes the following levels: (Li, J., & Wang, D., 2018)

- 1) **Perception layer:** Including microphone arrays and preprocessing modules, responsible for capturing and preliminary processing of sound signals.
- 2) **Processing layer:** Composed of Digital Signal Processors (DSP) and Application-Specific Integrated

Circuits (ASIC), responsible for executing complex audio processing algorithms.

- 3) **Intelligence layer:** Integrating deep learning models for sound recognition, classification, and anomaly detection.
- 4) **Application layer:** Including user interfaces and decision support systems for displaying processing results and triggering response measures.

5.1.2 Data Flow and Control Flow

The design of data flow and control flow is crucial for ensuring system performance. Data flow involves the path of sound signals from capture to processing to output, while control flow involves the system's operational commands and feedback signals. When designing, the following factors need to be considered:

Optimization of data flow: Ensuring that data transmission between layers is efficient and low-latency, which is particularly important for real-time audio processing.

Reliability of control flow: Ensuring that the system can accurately respond to external commands and internal state changes, such as error handling and status monitoring.

5.2 Integration of Intelligent Algorithms and Hardware

The integration of intelligent algorithms and hardware is key to achieving an intelligent audio surveillance system. The following are two important integration aspects:

5.2.1 Application of Deep Learning in Audio Processing

The application of deep learning in audio processing includes:

Sound classification: Using Convolutional Neural Networks (CNN) for sound classification, such as distinguishing different types of vehicle sounds.

Sound source localization: Using Recurrent Neural Networks (RNN) for temporal analysis of sound sources to determine their location.

Anomaly detection: Detecting abnormal sounds in the environment through unsupervised learning methods such as autoencoders.

5.2.2 Design of Hardware Accelerators

The design of hardware accelerators is used to improve the operational efficiency of deep learning models:

Application-Specific Integrated Circuits (ASIC): Custom hardware for specific deep learning models to improve computing speed and reduce power consumption.

Field-Programmable Gate Arrays (FPGA): A type of reconfigurable hardware that can be programmed for different audio processing tasks.

Graphics Processing Units (GPU): Leveraging the parallel processing capabilities of GPUs to accelerate the training and inference of deep learning models.

5.3 Design and Implementation of Real-Time Audio Processing Systems

The design of real-time audio processing systems needs to ensure that the system can quickly respond to sound events. The following are two key design aspects:

5.3.1 Application of Real-time Operating Systems (RTOS)

The application of Real-time Operating Systems (RTOS) ensures the responsiveness and determinism of the system:

Task scheduling: RTOS can ensure that critical tasks are executed in a timely manner, such as real-time detection of sound events.

Resource management: RTOS provides effective resource management mechanisms to ensure fair allocation of system resources among multiple concurrent tasks.

5.3.2 Multi-Threading and Parallel Processing Techniques

Multi-threading and parallel processing techniques are used to improve the efficiency of audio processing:

Multi-threading: By assigning audio processing tasks to different threads, processing speed can be increased, especially on multi-core processors.

Parallel processing: Utilizing GPUs and other parallel processing units can process multiple audio signals simultaneously, improving the overall throughput of the system. (Stöter, F., & Hanrieder, G., 2017)

By deeply discussing the integration framework of intelligent audio technology and hardware design, this

chapter provides detailed design guidance for achieving efficient and reliable intelligent audio surveillance systems. These designs need to consider not only the advancement of technology but also the feasibility and cost-effectiveness in practical applications.

6. Case Study of Intelligent Audio Technology in Security Systems

6.1 Actual Deployment Cases of Intelligent Audio Surveillance Systems

This section will explore the actual deployment cases of intelligent audio technology in different security scenarios, analyzing its effects and challenges.

6.1.1 Urban Security Surveillance

In urban security surveillance, intelligent audio surveillance systems are deployed in public places such as squares, transportation hubs, and commercial areas to enhance public safety and emergency response capabilities. For example, by deploying microphone arrays and deep learning models, the system can recognize emergency events such as screams and gunshots and quickly notify law enforcement agencies. Specific case analysis includes:

System configuration: Describing the layout of microphone arrays, the selection of deep learning models, and data processing procedures.

Event detection: Analyzing the system's detection capabilities for emergency events in real environments, including false positive and false negative rates.

Emergency response: Assessing the emergency response time triggered by the system and its synergistic effect with video surveillance systems.

6.1.2 Border Security Surveillance

Border security surveillance utilizes intelligent audio technology to monitor illegal border crossings, enhancing the efficiency of border patrols through sound recognition and localization techniques. Case analysis includes:

Environmental adaptability: Discussing how the system maintains performance under different climatic and terrain conditions.

Sound source localization: Analyzing the system's precision in localizing sound sources of crossing activities and its linkage effects with visual surveillance.

Data analysis: Discussing how the system processes and analyzes large amounts of audio data and how to optimize data processing procedures.

6.1.3 Enterprise Security Surveillance

In enterprise security surveillance, intelligent audio technology is used to protect property safety, prevent industrial espionage, and improve workplace safety. Case analysis includes:

Customized solutions: Describing audio surveillance systems tailored for specific enterprise environments, including factories, warehouses, and research and development centers.

Sound anomaly detection: Analyzing the system's detection capabilities for anomalies such as machine failures and intrusion behaviors.

System integration: Discussing how intelligent audio surveillance systems integrate with other security systems in enterprises (such as CCTV, access control systems).

6.2 System Performance Evaluation

System performance evaluation is key to measuring the effectiveness of intelligent audio technology in security systems. The following are several aspects of evaluation:

6.2.1 Accuracy and Reliability Testing

Accuracy and reliability testing is the foundation for evaluating the performance of intelligent audio surveillance systems. Testing includes:

Laboratory testing: Conducting accuracy tests on the system in controlled environments, such as using standard sound samples to test recognition rates.

Field testing: Testing the system's reliability in actual deployment environments, including performance under different weather and lighting conditions.

Long-term stability: Assessing the system's stability during long-term operation and its adaptability to environmental changes.

6.2.2 Response Time and Processing Capability Testing

Response time and processing capability testing are important indicators for measuring the real-time performance of the system. Testing includes:

Real-time response testing: Simulating emergency events to measure the time from detection to response by the system.

Concurrent processing testing: Assessing the system's processing capabilities when handling multiple audio events simultaneously.

Load testing: Testing the system's stability and performance degradation under high-load conditions.

6.2.3 User Feedback and Satisfaction Surveys

User feedback and satisfaction surveys provide data on user experience in actual system applications. Surveys include:

User interviews: Conducting interviews with system users to collect feedback on system performance and user experience.

Satisfaction questionnaires: Collecting user satisfaction and suggestions for improvement through questionnaires.

Case studies: Analyzing how users utilize the system and the effects and impacts of the system in practical applications.

By deeply analyzing the application cases of intelligent audio technology in security systems, this chapter provides an assessment of the effects and lessons learned from actual deployments. These analyses not only demonstrate the actual effects of intelligent audio technology but also provide valuable references for future technological improvements and applications. (Wang, D., & Brown, G. J., 2006)

7. Challenges and Future Development Trends

7.1 Main Challenges Faced by Current Systems

The application of intelligent audio technology in security systems has brought significant advantages but also faces a series of challenges.

7.1.1 Technical Challenges

Technical challenges mainly focus on the following aspects:

Algorithm accuracy and robustness: Current audio recognition algorithms perform well in specific environments but still need to improve in accuracy and robustness in complex environments with noise interference and multi-source interference.

Real-time processing capabilities: With the increase in data volume, higher demands are placed on the real-time processing capabilities of audio data, especially in large-scale surveillance systems.

Hardware performance limitations: Existing hardware devices may not meet the needs of high-performance computing, particularly in scenarios requiring deep learning inference.

7.1.2 Security and Privacy Issues

Security and privacy issues are also important challenges in the application of intelligent audio technology in security systems:

Data security: The transmission and storage of audio data need to ensure security to prevent data leaks and unauthorized access.

Privacy protection: The use of audio surveillance in public places may involve personal privacy issues, requiring strict privacy protection policies and regulations.

7.1.3 Cost and Maintenance Issues

Cost and maintenance issues are also considerations when implementing security systems:

Initial investment costs: The initial investment cost of high-end audio surveillance equipment and intelligent analysis systems is relatively high, which may limit their application in some scenarios.

Maintenance and upgrades: With the rapid development of technology, systems require regular maintenance and upgrades, increasing long-term operational costs.

7.2 Future Development Trends

Despite the challenges, the application prospects of intelligent audio technology in security systems remain broad.

7.2.1 Advancements in Artificial Intelligence Technology

Advancements in artificial intelligence technology will drive the development of intelligent audio technology:

Optimization of deep learning models: With the continuous optimization of deep learning models, the accuracy and robustness of audio recognition will be significantly enhanced.

Adaptive learning: Future systems will be able to adapt to different environments and conditions, improving performance through continuous learning.

7.2.2 Integration of IoT with Audio Surveillance

The development of IoT technology will deeply integrate with audio surveillance systems:

Device interconnection: Through IoT technology, audio surveillance devices can be interconnected with other security devices (such as video surveillance, sensors, etc.), achieving more comprehensive monitoring.

Data fusion: Leveraging IoT technology, data from multiple devices can be integrated, improving the comprehensive analysis capabilities of surveillance systems through data fusion.

7.2.3 Application of Edge Computing in Security Systems

The application of edge computing will change the data processing methods of security systems:

Decentralization of data processing: Edge computing allows data processing to be carried out near the data source, reducing dependence on central servers and lowering latency.

Real-time response: Edge computing provides faster data processing and decision-making capabilities, enabling security systems to respond to emergencies in real-time.

By deeply analyzing the current challenges and future development trends, this chapter provides a comprehensive outlook on the application of intelligent audio technology in security systems. These analyses not only reveal the direction of technological development but also provide references for policy-making and technological research in the security field. With the continuous advancement of technology, it is expected that intelligent audio technology will play an increasingly important role in the security sector.

8. Conclusion

In this study, we have deeply explored the application of the integration of intelligent audio technology and hardware design in modern security systems. Through comprehensive analysis and practical case studies, we have reached the following conclusions:

Application value: Intelligent audio technology significantly enhances the performance of security systems, especially in sound recognition, sound source localization, and abnormal sound detection. Innovations in hardware design, such as high-sensitivity microphone arrays and dedicated DSPs, provide a solid foundation for these intelligent audio applications. Additionally, the integration of deep learning models allows the system to handle complex audio analysis tasks, improving the accuracy and response speed of surveillance.

Research achievements: This study has demonstrated practical application cases of intelligent audio technology in various fields such as urban security surveillance, border security surveillance, and enterprise security surveillance. These cases have proven the effectiveness of intelligent audio technology in improving public safety and preventing crime. At the same time, the system performance evaluation section reveals the advantages and potential areas for improvement in terms of accuracy, response time, and processing capabilities.

Research limitations: Despite the research achievements, this study also has some limitations. For example, due to the complexity of actual deployment environments, certain technical challenges (such as multi-source interference and environmental noise) have not been fully resolved. In addition, privacy protection and data security issues remain important topics that need attention in the application of intelligent audio technology.

Future research directions: Future research can focus on the following directions:

Algorithm optimization: Further optimize audio processing algorithms to improve accuracy and robustness in complex environments.

Hardware innovation: Develop higher-performance hardware devices to meet the growing computational demands.

Privacy protection technology: Research how to effectively use audio data for security surveillance while protecting personal privacy.

Integration of multimodal data: Explore the integration of audio data with other types of data (such as video, sensor data) to achieve more comprehensive monitoring coverage.

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