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The Design and Application of a Mobile Sound Source Localization System

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Abstract: The mobile sound source localization system is a technology that can track and locate mobile sound sources in real time and has broad application prospects in many fields. This article first provides an overview of the mobile sound source localization system, introducing its concept and composition, as well as its design and application significance. It elaborates on the importance of the mobile sound source localization system from multiple aspects, such as safety, production, and daily life, and deeply explores its design and application strategies. The problems faced by the mobile sound source localization system and its future development direction were pointed out.

Keywords: Mobile sound source; Localization system; Design application

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1. Introduction

In modern society, sound, as an important carrier of information, contains rich information. Abnormal sounds emitted by equipment in industrial production and the determination of the location of sound sources in public security, such as people's cries for help and explosions, are of vital importance. With the increasing mobility of sound sources, fixed sound source localization systems can no longer meet the actual needs, and thus, mobile sound source localization systems have emerged. The mobile sound source localization system can follow the moving sound source for positioning and is no longer limited to fixed positioning. This paper mainly focuses on the research of mobile sound source localization systems. Through the analysis and study of various aspects of mobile sound source localization systems, it provides references for related research and applications.

2. The current design status of the mobile sound source localization system

2.1. The development of localization algorithms

Localization algorithm is the main theoretical basis of the mobile sound source localization system. The

development of a localization algorithm directly affects the positioning accuracy and efficiency of the system. Most early localization algorithms relied on a single parameter for positioning. The Time of Arrival (TOA) algorithm determines the position of the sound source by measuring the absolute time it takes for the sound source signal to reach the sensor. This algorithm has a high requirement for time synchronization and is easily affected by clock errors in actual mobile environments, which limits its application. With the deepening of research, the Time Difference of Arrival (TDOA) algorithm has gradually become mainstream. The TDOA algorithm determines the position of the sound source by using the time difference of the sound source signal reaching different sensors, reducing the requirement for absolute time synchronization and demonstrating better stability in mobile environments. However, when the sound source moves rapidly, the positioning error of the TDOA algorithm will increase due to the dynamic changes in signal propagation time. Therefore, researchers have proposed a dynamic TDOA correction model. By introducing the parameter of the sound source's movement speed, the time difference is compensated in real time, thereby improving the positioning accuracy of high-speed moving sound sources [1].

2.2. Theoretical research on noise and multipath interference processing

In the localization of mobile sound sources, noise and multipath interference are the main factors affecting positioning accuracy. Relevant theoretical research has always been a focus. Regarding environmental noise, in the early days, filtering algorithms were mainly used for suppression. Adaptive filtering algorithms can dynamically adjust filtering parameters based on noise characteristics, thereby removing stationary noise. However, in mobile scenes, noise often has non-stationary characteristics. The effect of traditional filtering algorithms is poor. To overcome the above problems, the noise suppression theory based on wavelet transform emerged. It uses multi-scale analysis to concentrate noise in the high-frequency band for suppression, while the sound source signal is concentrated in the low-frequency band. In this way, noise is effectively removed while maintaining the important components of the sound signal, and it performs well when dealing with impulse noise and burst noise. In addition, noise suppression methods based on sparse representation have emerged. This method regards the sound source signal as a sparse signal and then uses a sparse reconstruction algorithm to recover a clean signal from the noisy signal. This not only improves the accuracy of noise suppression but is also suitable for the localization of mobile sound sources with relatively low signal-to-noise ratios. Multipath interference occurs when the sound source signal, after being reflected and refracted by obstacles during its propagation, reaches the sensor, causing multiple path signals to superimpose and resulting in distortion in the measurement of positioning parameters. The multipath compensation theory based on the propagation model has also been developed. By establishing the propagation model of sound in complex environments, the propagation path and attenuation of multipath signals are predicted, and the measured positioning parameters are compensated and corrected to improve the positioning accuracy. However, this theory has relatively high requirements for environmental modeling. When the environment where the moving sound source is located is constantly changing, the applicability of the model needs to be improved.

2.3. Theoretical research on cooperative localization of mobile platforms

Mobile sound source localization systems generally require installation on mobile platforms, such as robots and unmanned aerial vehicles, and the mobility of mobile platforms also poses new requirements for positioning theory. The motion error of the mobile platform can lead to inaccurate sensor position, thereby causing positioning error. Therefore, the theory of platform motion state estimation and compensation has become the focus of research. The platform positioning theory, based on the inertial Navigation System (INS), measures the

acceleration and angular velocity of the platform to estimate its position and attitude in real time. However, it has cumulative errors, which will increase significantly after long-term operation. Therefore, the integrated navigation theory combining GPS and INS is adopted. The absolute position information of GPS can correct the cumulative errors of INS. INS can make up for the problem of signal loss of GPS in occluded environments, providing stable and reliable location information for mobile platforms, thereby ensuring the positioning reference accuracy of the sensor array [2]. In terms of multi-platform collaborative localization, the distributed positioning theory has become relatively mature. Multiple mobile platforms share the sound source information they measure through wireless communication and jointly solve the sound source localization using distributed estimation algorithms. This not only expands the positioning range but also reduces the uncertainty of single-platform positioning through the data fusion of multiple platforms. However, when the distributed positioning theory encounters data synchronization, how to achieve efficient collaboration while ensuring real-time positioning and avoiding communication delay is also a point that needs to be deeply explored.

3. The design significance of the mobile sound source localization system

3.1. Ensuring public safety

The use of mobile sound source localization systems in public security is of great significance. For example, in the event of natural disasters such as earthquakes and fires, the affected areas are often highly complex environments with limited visibility, so victims' cries for help cannot be heard easily. However, this mobile sound source localization system can promptly locate the sounds made by trapped victims by crossing smoke barriers and other means, and provide centimeter-level position information. It has greatly shortened the rescue time and increased the possibility of a successful rescue. In anti-terrorism and anti-violence, what is encountered are cunning terrorist criminals. Their gunshots, explosion sounds, etc., are all key clues for quickly identifying the criminals. The system can continuously track and locate the sounds, allowing the police to make rapid arrests based on the movement trajectory of the sound source, minimizing the injury and death of innocent people to the greatest extent. It has effectively protected the safety of lives and property. When holding major meetings or other events, we can also promptly hear abnormal sounds from the crowd, such as quarrels and cries for help, and intervene in advance to prevent more serious incidents.

3.2. Improving industrial production efficiency

In the industrial production process, whether the equipment can operate normally is directly related to the level of production efficiency. The mobile sound source localization system can conduct real-time monitoring of mobile production equipment and promptly detect abnormal sounds produced by the equipment, such as high-frequency abnormal sounds caused by bearing wear and periodic noises caused by poor gear meshing. By precisely locating these abnormal sound sources and analyzing their spectra, the specific location and severity of equipment failures can be identified, thereby enabling early prediction of equipment failure conditions. This facilitates targeted maintenance and repair work by maintenance personnel, preventing sudden equipment shutdowns that could lead to production line disruptions. For instance, in an automotive manufacturing workshop, if a robot's mechanical arm joint malfunctions during mobile operations, the system will immediately locate and issue an alarm. Maintenance personnel can handle the issue promptly before it worsens, reducing equipment downtime and enhancing production efficiency. Moreover, this system can also record and analyze the operation of the equipment for a long time, providing data support for the formulation of equipment maintenance plans and improving the

production process [3].

3.3. Improving traffic management

Traffic management is a key part of urban management. The mobile sound source localization system also plays a significant role in traffic management. Taking urban roads as an example, the collision sounds and sudden braking sounds of vehicles produced during traffic accidents are often direct signals of accidents. This system can quickly determine the specific lane and location where the accident occurred. Through the linked monitoring system, the traffic management department can immediately dispatch police forces and rescue resources to the scene, thereby preventing prolonged traffic congestion time due to information lag. The frequent occurrence of illegal honking in cities has a very low manual efficiency in traditional supervision methods. However, this system can accurately determine the location and time of the honking vehicle, and can also be linked with electronic police to record violation information, forming a deterrent, reducing noise pollution, and improving the traffic civilization level of the city. It can also detect abnormal sounds emitted by vehicle malfunctions on highways. For instance, if there are sounds like tire blowouts or abnormal noises from the engine, the system can promptly notify the patrol personnel to handle them and prevent secondary accidents.

3.4. Promoting the development of scientific research

The mobile sound source localization system provides a very powerful tool for related scientific research. In acoustic research, this system can be used to explore the propagation characteristics of sound in various environments, such as reflection and diffraction rules in complex terrains and building complexes, etc., thereby providing a lot of precise experimental data for the development of acoustic theory. Promoting the development of new acoustic materials and sound insulation technologies, in the field of biological research, researchers can use this system to trace the moving sound sources of wild organisms, such as the calls of birds and the sounds of animal activities, thereby understanding their activity range, migration routes, and social behaviors, and providing key information for animal protection and ecological environment research.

4. Design and application strategies of mobile sound source localization systems

4.1. Hardware selection

Hardware is the foundation of a mobile sound source localization system, and the selection of hardware will directly affect the performance of the system. When selecting hardware, the following points should be noted: The microphone array is an important component for collecting sound source signals. Its performance directly affects the quality of the collected signals. Microphones with high sensitivity, low noise, and wide frequency bands should be selected. The size and arrangement of the microphone array should also be determined according to the requirements of the actual application scenario. If a high positioning accuracy is to be achieved, larger-scale uniform linear arrays or circular arrays can be adopted. The signal acquisition card is used to convert the analog signals collected by the microphone array into digital signals. Its sampling rate and resolution must meet the requirements of the system. The higher the sampling rate, the wider the frequency range of the collected signals. The higher the resolution, the higher the quantization accuracy of the signals. The mobile platform is the carrier on which the entire system relies. The mobile platform should be selected based on the application scenarios, such as robots, drones, vehicles, etc. The mobile platform should have good mobility, stability, and battery life to adapt to different terrains and environments. The processor is used to process and analyze the collected signals.

Its computing speed and performance will affect the real-time performance of the system. High-performance embedded processors or digital signal processors should be selected to meet the system's requirements for real-time signal processing.

4.2. Algorithm design

The algorithm is the heart of the mobile sound source localization system. Its quality directly determines the positioning accuracy and reliability of the system. In the design of the algorithm, the following points should be considered: Sound source localization algorithm. Common sound source localization algorithms include the TDOA algorithm, the AOA algorithm, the beamforming algorithm, etc. The TDOA algorithm locates the position of the sound source by measuring the time difference of the sound source signal reaching each microphone, and has a relatively high positioning accuracy. The AOA algorithm determines the position of the sound source by measuring the angle at which the sound source signal reaches the microphone, and is suitable for short-range positioning. The beamforming algorithm forms a beam directed towards the sound source by weighting the output signal of the microphone array, and it has a good anti-interference ability. In practical applications, it is necessary to select the appropriate sound source localization algorithm or combine multiple algorithms based on specific application scenarios and requirements to enhance the system's location performance. Noise suppression algorithms: In actual environments, there are numerous noise interferences, such as environmental noise and equipment noise. These noises can affect the collection and processing of sound source signals, thereby reducing the positioning accuracy of the system. Therefore, it is necessary to design effective noise suppression algorithms, such as adaptive filtering algorithms and wavelet transform algorithms, to remove noise interference and improve the signal-to-noise ratio of the sound source signal. Multipath effect processing algorithm: Multipath effect refers to the situation where the signal emitted by the sound source reaches the microphone array through different paths during transmission, causing reflection, refraction, and other conditions, which in turn affect the accuracy of sound source localization. To address the multipath effect, one can adopt a multipath suppression algorithm relying on the signal model.

4.3. Software development

Software is an important component of the mobile sound source localization system, mainly used to control the entire system, process data, display information, etc. When writing software, the following points should be considered: Operating system. An operating system suitable for the mobile platform should be selected, such as Linux or Android. These systems are stable and expandable, meeting the real-time requirements of the system. The data processing module is used to process and analyze the collected signals, involving functions such as signal preprocessing, feature extraction, and sound source localization. It is necessary to adopt efficient data processing algorithms and programming techniques to accelerate the data processing speed and improve the processing efficiency. The control module is responsible for controlling the mobile platform and hardware devices, enabling the system to move autonomously and switch working modes. A stable and reliable control algorithm needs to be designed to ensure the safety of the system. The display module is used to show the real-time location information of the sound source, signal strength, and other parameters, which is convenient for the operator to understand the working condition of the system. A friendly interface needs to be designed to enhance the usability of the system [4].

4.4. System integration

System integration is the organic combination of various components, such as hardware and software, to form

a complete mobile sound source localization system. When integrating the system, the following points should be taken into consideration: the interface between hardware and software, which should ensure compatibility between the software and hardware interfaces to achieve precise data transmission and effective execution of control commands [5]; the stability and reliability of the system; the system integration needs to be fully tested and debugged to ensure stable and reliable operation in different environments. The power consumption of the system: Mobile sound source localization systems are generally powered by batteries. Therefore, to reduce the power consumption of the system and extend its battery life, the hardware design and software algorithms can be improved to cut down on unnecessary energy consumption.

5. Conclusion

In conclusion, as a new technology, the mobile sound source localization system has a wide range of applications and a promising development prospect. The research on this system is of great significance. The mobile sound source localization system will play a greater role in public safety, industrial production, traffic management, scientific research, and other aspects in the future, making tremendous contributions to the development and progress of society. It will play an increasingly important role in future life. Through the continuous efforts and innovations of scientists, the mobile sound source localization system will be continuously improved and developed. It brings convenience and security to our lives and work.

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Disclosure statement

The authors declare no conflict of interest.

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