The Research about the Technologies of Lowering Noise Signals Applied in Seismic Station

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Abstract. Earthquakes are among the most devastating natural disasters, causing significant loss of life and property. The development of precise seismic monitoring instruments, such as seismic collection stations, is crucial for early earthquake detection and warning systems. These stations, based on IoT technology, collect seismic wave and location data, playing a vital role not only in earthquake forecasting but also in oil and gas exploration. However, the presence of strong background noise often obscures useful seismic signals, complicating data analysis and interpretation. To address this challenge, this paper explores advanced noise reduction technologies, including noise cancellation, adaptive noise cancellation, and filter-based noise cancellation techniques. These methods aim to separate useful seismic signals from noise, enhancing the accuracy and reliability of seismic data. Additionally, the paper discusses noise coupling and filtering technologies, which transfer noise to non-interfering paths and apply filtering techniques to suppress it. By integrating these low-noise technologies, seismic detectors can achieve higher sensitivity and precision, ultimately improving earthquake monitoring, early warning systems, and resource exploration efficiency. This research underscores the importance of low-noise technologies in advancing seismic detection and mitigating the impact of natural disasters.

Keywords: Low Noise Signal, Seismic Station, Noise Cancellation, Noise Coupling, Filter Technology

1 Introduction

1.1 The Signifiance of the Research

Studying the application of low-noise technology in seismic detectors is of great significance. By reducing the instrument's own noise, the signal-to-noise ratio of seismic signals can be significantly improved, enhancing the ability to capture weak seismic signals, thereby improving the accuracy and sensitivity of earthquake monitoring. This not only helps with early earthquake warning and disaster prevention and reduction, but also provides higher quality data support for the study of the Earth's internal structure. In addition, breakthroughs in low-noise technology can also promote

J. Iqbal (ed.), *Proceedings of the 2025 2nd International Conference on Mechanics, Electronics Engineering and Automation (ICMEEA 2025)*, Advances in Engineering Research 272,
https://doi.org/10.2991/978-94-6463-821-9_98

the widespread application of high-precision sensors in resource exploration, medical equipment, and other fields, which have important scientific value and social benefits.

1.2 The Content of the Research

This article mainly collects two methods for reducing noise: noise cancellation technology and noise coupling and filtering technology, and explains their working principles and specific processes accordingly. By collecting and analyzing information on two technologies, readers can have a preliminary understanding of common noise reduction techniques and deepen their understanding of the significance of researching low-noise technologies in seismic detectors.

1.3 The Structure of the Paper

The first chapter of this article serves as an introduction, highlighting the significance of researching low-noise technologies; Chapter 2 is divided into three parts. The first part introduces the concept of seismic detectors and why low noise should be implemented in them. The second part is noise cancellation technology, which introduces its principle and working process; The third part is about noise coupling and filtering technology, introducing its working principle and the characteristics and principles of various basic filters; Chapter 3 serves as the conclusion, concluding the entire text.

2 The Result of the Research

2.1 Seismic Collection Station

Throughout human history, people have been suffering from natural disasters such as earthquake, and numbers of residents lost their lives due to the terrible disasters. Earthquake is one of the most destructive disasters among all of them. For example, the earthquake that occurred in Wenchuan. the worst earthquake during the 21th century in China, led to 69181 people losing their lives and countless people suffering from varying severity of injuries. As a results, it is not difficult to understand how significant building a precision instrument to monitor the seismic signals, and make an early warning for earthquake. Under such a situation, the seismic collection station was invented, and the way to deal with the earthquake signals is the key to solving earthquake monitoring problems.

The seismic collection station is not only applied in the earthquake forecast, but also plays an important role in the oil and gas seismic exploration engineering, in which the seismic collection is the first, as well as the most significant step of its production processes.

The seismic signals collection station, one of the most important parts of seismic monitoring, is a kind of portable device based on the IoT technology, whose main function is to collect seismic wave data and location data at the location of the exploration point [1]. During the seismic exploration, regularly, due to the powerful noise background, the useful part of earthquake signals are usually submerged with it , which will definitely influence the process of the exploration such as the speed calculation, the static correction calculation, the seismic modeling and offset imaging. To improve the efficiency of the relative works, it is of importance to separate the useful signals from others. To put it simply, low noise signals are required. After author's extensive research, several of the latest lowering noise signals technologies are found.

2.2 Noise Cancellation Technology

Noise cancellation technology [2] is one of the methods that can particularly avoid the impact of some specific sources of noise. It makes sense by using negative feedback to cancel out the thermal noise and nonlinear harmonic distortion components of the first stage transistor. To put it simply, it produces a special signal which has the opposite phase and the same amplitude to the original one. In the design of LNA, noise cancellation can be applied interiorly in a chip in order to avoid the influences from interior circuits. At the same time, the exterior impacts can be reduced by improving the design of exterior circuits. Through the way shown in Fig.1, the aim of lowering the noise makes sense.

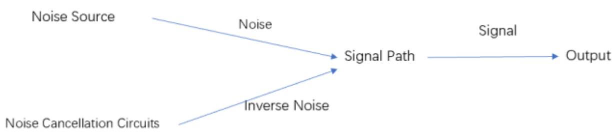

Fig. 1. The process of noise cancellation technology

The common noise cancellation technology includes adaptive noise cancellation technology and the noise cancellation technology based on filters.

2.2.1 Adaptive Noise Cancellation Technology.

2.2.1.1 BASIC PRINCIPLE: the core of adaptive noise cancellation technology[3] is to utilize the relationship between the reference input signal and the main input signal, continuously adjust the parameters of the filter through adaptive algorithms, so that the estimated noise signal output by the filter approximates the noise component in the main input signal as much as possible, and then subtract the estimated noise signal from the main input signal to obtain a useful signal that eliminates noise interference.

2.2.1.2 WORK PROCESS: as what is shown in Fig.2， the first step is signal acquisition, which is to obtain the main input signal x (n) and the reference input signal d (n) separately through sensors or other signal acquisition devices.. After that, the paper inputs the reference input signal d (n) into an adaptive filter, which processes the reference signal based on the current weight coefficients and outputs an estimated noise signal y (n). Getting the output, the paper puts it into error calculation, which means subtracting the output y (n) of the adaptive filter from the main input signal x (n) to obtain the error signal e (n). The next step is weight update. Based on the relevant information (such as delay components) of the error signal e (n) and the reference input signal d (n), use an adaptive algorithm (such as LMS or RLS algorithm) to update the weight coefficients of the adaptive filter. At last, repeat iteration is required, which is repeating steps 2-4 continuously until the adaptive filter converges to the optimal state, at which point the error signal e (n) is the useful signal after noise elimination.

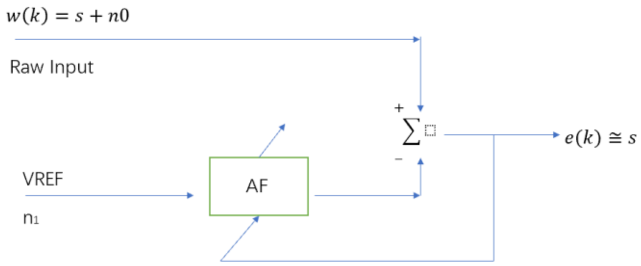

Fig. 2. Principle diagram of adaptive noise cancellation technology [4]

2.2.2 Noise Cancellation Technology Based on Filters.

The basic principles of it is noise signals can usually be seen as the superposition of useful signals and noisy signals. The noise cancellation technique based on filters assumes that noise has certain statistical or spectral characteristics. By designing filters, useful signals can pass through as undistorted as possible, while attenuating the noise signal to achieve noise cancellation. The work process is introduced below. The first step of it is the signal collection, the paper uses sensors and other devices to collect raw signals containing noise, denoted as x (n). This signal is the superposition of the useful signal s (n) and the noise signal v (n), that is, x (n)=s (n)+v (n). After that, the paper obtains a reference signal d (n) that only contains noise or its related information.

Then the paper turns to filtering process， which is described by Fig.3. The paper chooses the appropriate filter type based on the characteristics of the noise (such as frequency distribution range, etc.). Common types include low-pass filter, high-pass filter, band-pass filter, and band-stop filter. Then the main input signal x (n) and the reference input signal d (n) are separately fed into selected filters for processing. For digital filters, the filtering function is usually achieved through a series of mathematical operations such as convolution; For analog filters, it is based on a filtering circuit composed of circuit components such as resistors, capacitors, inductors, etc.

After the above processing, the obtained signal is the useful signal with noise interference eliminated, which is output for subsequent system use. In some simple fixed filter systems, the main input signal directly processed by the filter may be the final denoised output signal; In adaptive systems, filter parameters may be further adjusted based on error signals to optimize denoising effects, ultimately outputting purer useful signals. An example of a filter based on DSP is shown below.

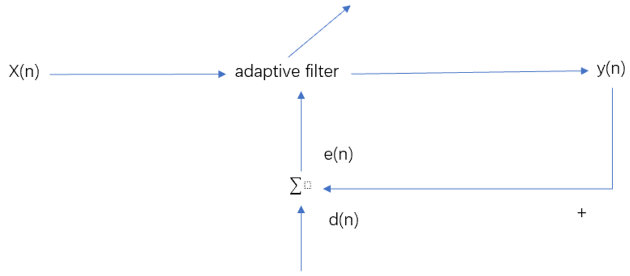

Fig. 3. Schematic of Adaptive Filter

2.3 Noise Coupling And Filtering Technology

Through noise coupling[5] technology, noise can be transferred to a path that does not affect the signal, and filtered through filtering techniques[6] on that path. This requires designers to be able to precisely control the signal path and noise path, while designing filters that match them.

2.3.1 Common Coupling Methods.

The methods consist of three various kinds.

The first one is conduction coupling: Transmitting noise from one circuit to another through conductors such as wires, cables, etc. When two or more circuits share the same conductor, noise current may flow on these conductors and enter other circuits.

The second one is radiation Coupling: The electromagnetic field generated by the noise source radiates outward in the form of electromagnetic waves[7]. If nearby circuits or equipment are within the range of this electromagnetic field, they will induce corresponding voltage or current, thereby introducing noise.

The third one is capacitive coupling: Due to the capacitive effect between two conductors, even if they are not directly electrically connected, an electric field coupling will form between them[8]. When the voltage on one conductor changes, a corresponding charge change is induced on another conductor, resulting in noise voltage.

2.3.2 Filtering Technology.

Filtering technology is an important means for suppressing noise and extracting useful signals. It processes signals by designing specific filters, allowing signals within a specific frequency range to pass through while preventing signals of other frequencies (mainly noise signals) from passing through, thus achieving the goal of improving signal quality.

2.3.2.1 PASSIVE FILTER: based on the frequency characteristics of passive components such as resistors, capacitors, and inductors, the selection of different frequency signals can be achieved[9]. For example, in a low-pass filter, the capacitance reactance of the capacitor decreases with increasing frequency, while the inductance reactance of the inductor increases with increasing frequency. In the low frequency range, capacitors have a larger capacitance impedance and inductors have a smaller inductance impedance, making it easier for signals to pass through; In the high-frequency range, the situation is the opposite, thus achieving suppression of high-frequency noise. The filters can be divided into four different types.

The first one is Low-Pass Filter: At the front end of the audio power amplifier, a low-pass filter is used to filter out high-frequency noise in the power supply, allowing only signals within the audio frequency band to pass through, ensuring high purity of the signal entering the amplifier and reducing the impact of high-frequency noise on audio quality.

The second one is High-Pass Filter: In some sensor signal acquisition systems, if there is low-frequency 50Hz power frequency interference, a high pass filter can be used to filter it out, allowing the weak useful signals output by the sensor (usually in the higher frequency range) to be processed smoothly through subsequent circuits.

The third one is Band-pass filter: In wireless communication receivers, bandpass filters are used to only allow carrier signals within a specific frequency band to pass through, filtering out interference noise from other frequency bands and improving the quality of received signals and the accuracy of demodulation.

The last one is Band-stop filter: For specific frequency interference, such as in power systems, in order to suppress the impact of 50Hz or 60Hz power frequency interference on precision electronic measurements, the use of band stop filters can effectively remove these interfering frequency components.

2.3.2.2 ACTIVE FILTER: in the field of instrumentation, for signals that require high-precision measurement, active filters[10] can accurately design the parameters of the filter, perform more refined filtering processing on the signal, effectively suppress noise, and ensure the integrity of the useful signal. For example, in the signal processing circuit of an electronic balance, active filters are used to remove the influence of environmental noise on the measurement results.

2.3.2.3 DIGITAL FILTER: In modern communication and digital signal processing systems, facing complex signal and noise environments, digital filters[11] can flexibly adjust filtering algorithms and parameters through software programming. For example, in digital audio processing software, FIR or IIR digital filters are used to denoise audio signals, and filtering schemes are customized according to different audio content and noise characteristics to achieve low-noise audio output. In addition, in real-time video surveillance systems, digital filters can quickly process video signals, remove noise interference from images, ensure the clarity and stability of video frames, and meet the needs of real-time monitoring.

3 Conclusion

In conclusion, the application of low-noise technology in seismic detectors represents a significant advancement in the field of earthquake monitoring and seismic exploration. By reducing the inherent noise in seismic collection stations, this technology enhances the ability to detect and analyze weak seismic signals, which are often obscured by environmental noise. This improvement in signal clarity is crucial for accurate earthquake forecasting, early warning systems, and the detailed study of the Earth's internal structure.

The exploration of various noise cancellation techniques, including adaptive noise cancellation and filter-based methods, has demonstrated their effectiveness in isolating useful seismic signals from background noise. These technologies not only improve the precision of seismic data but also contribute to the efficiency of oil and gas exploration by providing clearer subsurface images.

Furthermore, the integration of noise coupling and filtering technologies offers additional pathways for noise reduction, ensuring that seismic detectors can operate effectively even in challenging environments. The development of passive, active, and digital filters provides versatile tools for addressing different types of noise, thereby enhancing the overall performance of seismic monitoring systems.

Overall, the research and implementation of low-noise technologies in seismic detectors have far-reaching implications. They not only advance our understanding of seismic activities but also play a critical role in disaster preparedness and resource exploration. As these technologies continue to evolve, they promise to deliver even greater improvements in the accuracy and reliability of seismic data, ultimately contributing to safer and more informed decision-making in the face of natural disasters.

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