Comparative Analysis of the Effectiveness of Spectral Gating and Wiener Filtering for Noise Reduction in Enhancing the Quality of Lampung Language Audio Recordings

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Abstract. Lampung language, as one of the regional languages in Indonesia, has cultural and linguistic richness that is important to document and preserve, especially through quality audio documentation. One of the main problems in Lampung language audio recordings is background noise, which can reduce the clarity and quality of the recording. This research aims to analyze and compare the effectiveness of two noise reduction methods, which are Spectral Gating and Wiener Filtering, in improving the quality of Lampung language audio recordings. These methods use different approaches to handle noise. Spectral Gating focuses on removing dominant noise frequencies, while Wiener Filtering uses a statistical approach to minimize overall noise. This study used voice recordings of six respondents from different locations, ages, and genders, resulting in varied background noise levels. Audio quality was evaluated using the signal-to-noise ratio (SNR), which is usually expressed in decibels (dB). The higher the SNR value, the better the signal quality, as the signal is more dominant over the noise. Conversely, a lower SNR value indicates that the noise is more dominant over the signal. This research shows that Spectral Gating is more effective than Wiener Filtering in improving audio quality. These results provide valuable insight into the most effective noise reduction method for preserving recordings of local languages, particularly the Lampung language.

Keywords: Noise Reduction, Spectral Gating, Wiener Filtering, Audio Recording, Lampung Language.

1 Introduction

In the current digital era, the quality of audio recordings is crucial, especially in the context of preserving regional languages that are increasingly endangered. Lampung

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language, one of the regional languages in Indonesia, possesses cultural and linguistic richness that is important to document and preserve. However, one of the main challenges in audio documentation is background noise, which reduces the clarity and quality of the recordings. This noise may come from various sources, such as the surrounding environment, recording equipment, or audio transmission processes, significantly interfering with the main signal in the recordings [1]. To address this issue, various noise reduction methods have been developed. Spectral Gating and Wiener Filtering are two commonly used techniques in audio signal processing to reduce noise without distorting the desired original signal [2] [3].

Spectral Gating works by dividing the audio signal based on frequency and reducing the amplitude of signal portions below a certain threshold, effectively eliminating background noise [4]. On the other hand, Wiener Filtering uses a statistical approach to separate the desired signal from noise, minimizing the mean square error between the original signal and the noise-mixed signal [5] [6]. Noise reduction plays a crucial role in improving audio recording quality, evaluated using the signal-to-noise ratio (SNR). SNR is an important metric that compares the strength of the desired signal to the noise contained within, expressed in decibels (dB). A higher SNR indicates better signal quality, as the desired signal is more dominant over noise [7].

Previous studies have shown that noise reduction methods like Wiener Filtering can significantly improve audio quality by minimizing noise interference in various environments [5]. For example, Butarbutar et al. (2023) explored the efficacy of adaptive Wiener Filtering in various environmental conditions, demonstrating good results in reducing background noise [6]. Additionally, Agrawal, Gupta, and Garg (2023) showed that combining Spectral Gating with U-Net neural networks significantly improved speech processing performance, tested on LibriSpeech and NOIZEUS datasets [4] [8]. This Spectral Gating algorithm proved effective in reducing low-frequency noise, which is often encountered in audio recordings [4].

However, studies comparing the effectiveness of these two methods, particularly in the context of preserving regional languages like Lampung, remain limited. Therefore, this research aims to analyze and compare the effectiveness of the two noise reduction methods, Spectral Gating and Wiener Filtering, in improving the quality of Lampung language audio recordings. This evaluation will provide further insights into which method is more effective in enhancing audio quality, especially in dealing with background noise in different environments.

2 Research Methodology

This study was conducted through several stages to test two noise reduction methods, i.e., Spectral Gating and Wiener Filtering. The research methodology used in this study is explained through the following steps. Figure 1 presents the detailed research methodology steps applied in this study to evaluate the effectiveness of Spectral Gating and Wiener Filtering in noise reduction for Speech-to-Text.

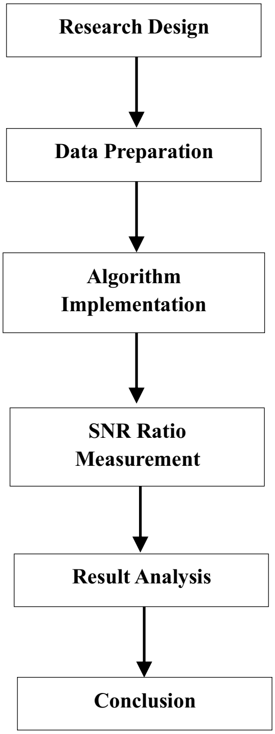


Fig. 1. Research Methodology

2.1 Research Design

This research aims to evaluate and compare two noise reduction methods, Spectral Gating and Wiener Filtering, in improving the quality of Lampung language audio recordings. Each method was applied to the same audio recordings to ensure accurate comparison. The results of these methods were evaluated and compared to determine which one is more effective in enhancing the quality of the recordings. Audio quality was measured using the Signal-to-Noise Ratio (SNR), which is a primary indicator used to assess the ratio of the desired signal to noise. Previous studies have shown that increasing the SNR is directly related to the improvement of audio quality [7] [8].

2.2 Data Preparation

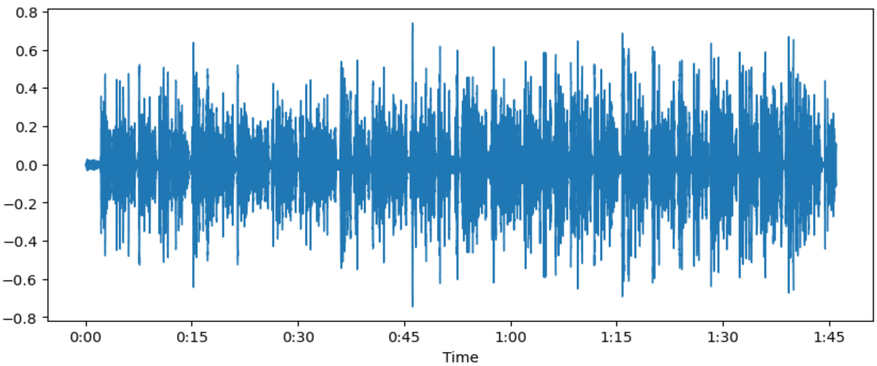
The dataset used in this study consisted of Lampung language audio recordings collected from several respondents. The recordings were made in various locations with different levels of background noise, such as indoor and outdoor environments, to record noise variation. Each recording was processed using both the Spectral Gating and

Wiener Filtering methods. The signal processing was carried out in the .wav format, which maintains the original audio quality and facilitates analysis [4] [6].

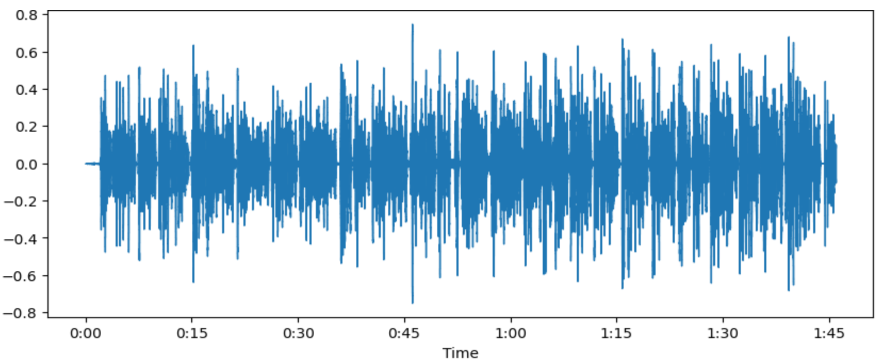
3 Results

3.1 Algorithm Implementation

- **Spectral Gating** is a noise reduction method that operates in the frequency domain. The process involves transforming the audio signal from the time domain to the frequency domain using Fast Fourier Transform (FFT). After the signal is transformed into the frequency domain, the amplitude of the frequencies is analyzed, and frequency components that fall below a certain threshold are identified as noise. The threshold value determines which components are considered noise and can vary based on the application or experiment. Typically, this value is chosen through empirical analysis or preset standards, and it may be applied multiple times during an experiment depending on the processing requirements. The identified noise frequencies are reduced or blocked, while the frequencies considered as the main signal are retained [4] [8]. According to research by Agrawal et al. (2023), Spectral Gating can improve SNR by up to 12 dB in environments with dynamic noise, making it effective in applications such as podcasting and outdoor recording [4] [8].



(a)

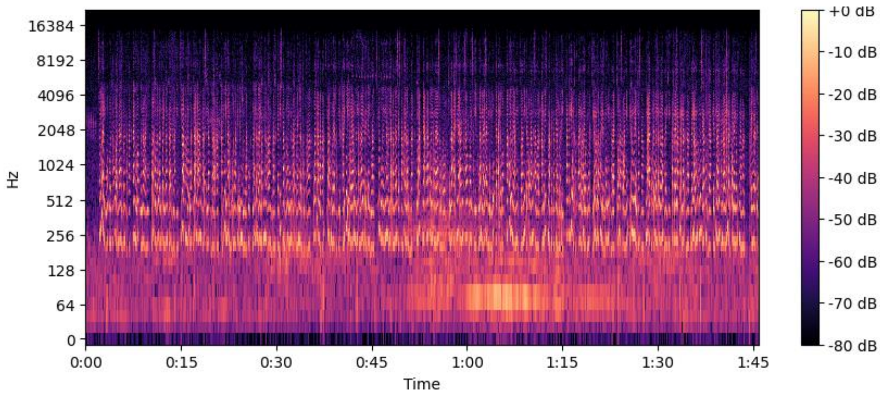


(b)

Fig. 2. Audio Waveform (a) before and (b) After Spectral Gating

Figure 2 shows the difference in audio waveforms before and after applying Spectral Gating. In Figure 2 (a), the original audio waveform shows that the signal has consistently varying amplitudes, indicating the presence of significant background noise throughout the recording duration, including low to mid-range frequencies, which distort parts of the recording that should be silent, leading to poor recording clarity.

In contrast, Figure 2 (b) shows the waveform after applying Spectral Gating, demonstrating a noticeable reduction in noise in lower amplitude sections, especially in areas previously containing background noise, resulting in a more stable amplitude focused on the main signal, with much less interference from background noise. Though some noise reduction artifacts might appear in specific frequencies, the overall process retains the main signal well and significantly improves the recording quality.



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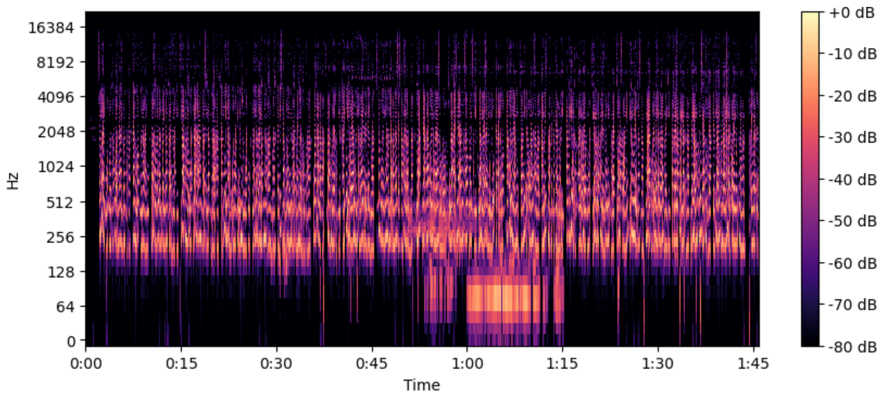


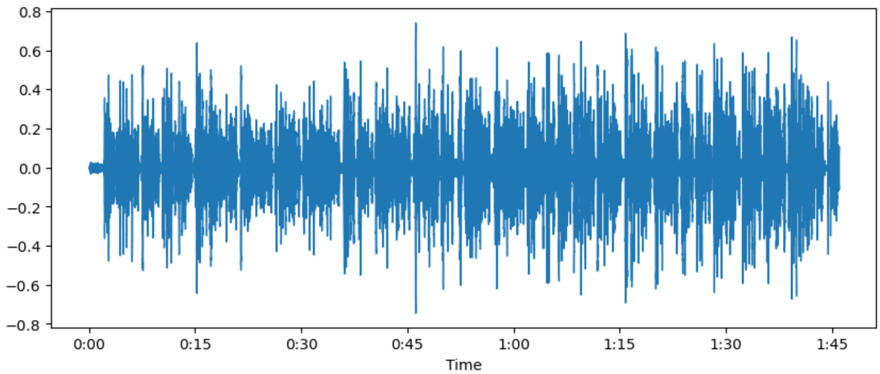
(b)

Fig. 3. Spectrogram (a) before and (b) After Spectral Gating

Figure 3 shows the difference in audio spectrograms before and after applying Spectral Gating. In Figure 3 (a), the original audio spectrogram shows significant noise across a wide range of frequencies, particularly in the low-frequency range (64 Hz to 256 Hz), as seen in the bright orange and yellow areas dominating the spectrum throughout the recording. Noise is also present in mid-to-high frequencies, indicated by the even distribution of intensity across the frequency spectrum, reflecting persistent background noise interference.

In contrast, Figure 3 (b) shows the spectrogram after applying Spectral Gating, where significant noise reduction is observed in the low-to-mid frequency range, represented by much darker colors (mainly purple and black) in the spectrogram, especially at the lower end of the spectrum, indicating that background noise in these frequencies has been substantially minimized. The main signal in the higher frequencies is well-preserved, as seen by the bright intensity still visible in those areas, demonstrating that Spectral Gating effectively reduces noise without compromising the quality of the main signal, thus enhancing overall audio clarity by focusing on important signal parts.

- **Wiener Filtering** uses a statistical approach to separate the main signal from noise by minimizing the mean square error (MSE) between the desired signal and the noise. This filter uses a probabilistic model to estimate noise and adaptively adjust the frequencies containing noise. Wiener Filtering is more suitable for environments with stable noise, such as noise in hearing aids [5] [6]. Research by Kumar and Chari (2020) shows that Wiener Filtering can improve SNR, although it is less effective in environments with more dynamic noise [6] [7].



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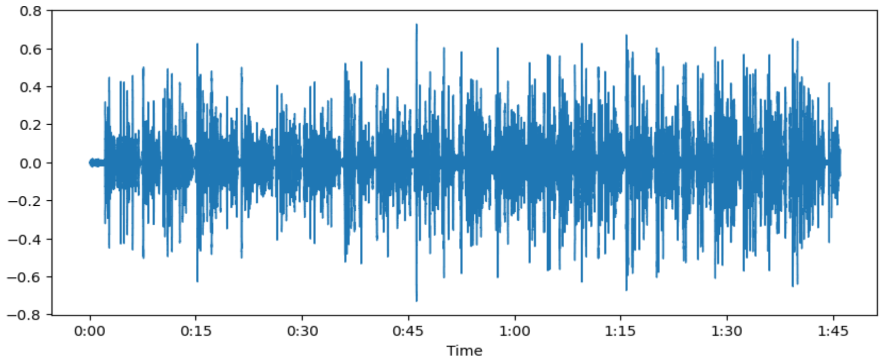
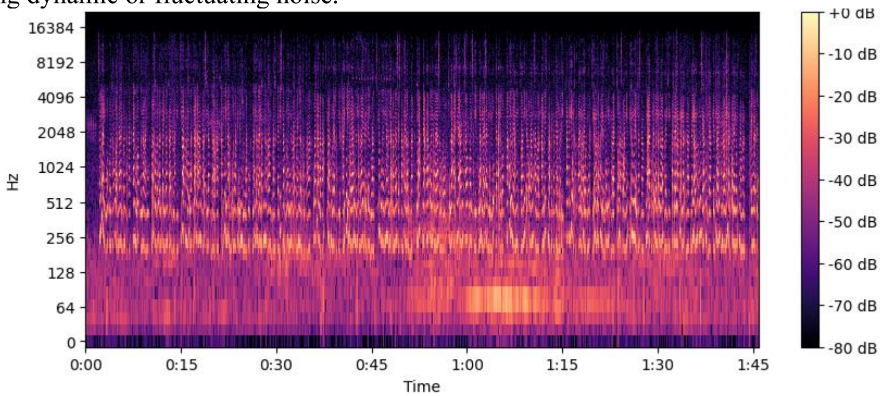


(b)

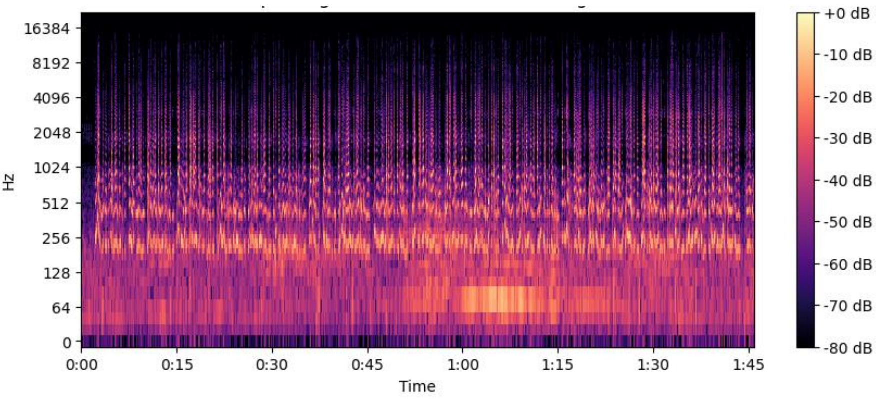
Fig. 4. Audio Waveform (a) before and (b) After Wiener Filtering

Figure 4 shows the audio waveform before and after applying Wiener Filtering. In Figure 4 (a), the original audio waveform shows significant amplitude variations throughout the recording, indicating noise interference in both low and high frequencies, causing substantial distortion to the main signal and making it appear dense with background noise.

In contrast, Figure 4 (b) shows that after applying Wiener Filtering, the overall amplitude demonstrates a smoother and more controlled reduction, particularly in quieter sections where the background noise is significantly reduced. Wiener Filtering successfully maintains the integrity of the main signal without diminishing important components, producing a clearer and more controlled waveform. However, some residual noise remains in certain areas, especially those with higher amplitude, indicating that while this filter is effective in environments with stable noise, it is less ideal for handling dynamic or fluctuating noise.



(a)



(b)

Fig. 5. Spectrogram (a) before and (b) After Wiener Filtering

Figure 5 shows the audio spectrogram before and after applying Wiener Filtering. In Figure 5 (a), the original audio spectrogram displays significant noise across various frequencies, particularly in the low-to-mid frequency range (around 64 Hz to 512 Hz), with high intensity indicated by the dominant orange and pink colors, especially at the lower end of the spectrum. This suggests strong, consistent background noise throughout the recording. In contrast, Figure 5 (b) shows that after applying Wiener Filtering, although there is some reduction in certain low-frequency areas, especially around 64 Hz, the change in noise intensity is not significant, as the orange and pink colors remain visible and dominate the same spectrum range.

This indicates that Wiener Filtering does not effectively reduce background noise in the low-to-mid frequency range. Similarly, in the high-frequency range (above 512 Hz), the noise does not show a significant change, with the spectrogram colors remaining similar to the original audio, indicating that this filter provides only minimal noise reduction and tends to be less effective in handling dynamic or complex noise, resulting in little difference between the original and Wiener Filtered audio.

3.2 Signal-to-Noise Ratio (SNR) Measurement

Signal-to-Noise Ratio (SNR) is one of the key metrics used in this research to evaluate the success of noise reduction. SNR measures the comparison between the strength of the main signal and the noise, expressed in decibels (dB). The higher the SNR value, the better the audio quality, as the main signal becomes more dominant than the background noise. This measurement is important in the context of audio processing, as an increase in SNR is directly related to the improvement in the perceived quality of voice by the end user [7] [8].

In this study, SNR measurements were taken by comparing the energy of the main signal to the energy of the noise remaining after the noise reduction process. The SNR calculation formula is as follows.

$$\mathrm{SNR_{dB}} = 10 \times \log_{10}\left(\frac{Signal\ Enery}{Noise\ Energy}\right) \quad (1)$$

The SNR values of the two noise reduction methods were compared to determine which method is more effective in reducing noise and improving the quality of Lampung language audio recordings.

Table 1. Comparison of SNR After Noise Reduction Methods

Method	SNR (dB)
Spectral Gating	21.31
Wiener Filtering	10.67

As shown in Table 1, the SNR values were calculated for both noise reduction methods, Spectral Gating and Wiener Filtering, to evaluate which method more effectively improves the quality of Lampung language audio recordings.

- **High SNR (>20 dB)**: Spectral Gating produced a significant SNR improvement in dynamic noise conditions, with an SNR value of 21.31 dB. Based on research by Saad Ahmed et al. (2023), this method consistently reduces noise in recordings with unstable background noise, such as outdoor environments, demonstrating its ability to adapt to varying noise throughout the duration of the recording [4] [8].
- **Medium SNR (10–20 dB)**: Wiener Filtering, on the other hand, produced a lower SNR value of 10.67 dB, which falls into the medium SNR category. Although Wiener Filtering is quite effective in reducing noise in environments with more stable noise, such as indoor spaces or consistent low-frequency noise disturbances, these results highlight its limitations in handling more dynamic or fluctuating noise [6] [7].
- **Low SNR (<10 dB)**: In environments with low SNR, the quality of sound is significantly disrupted by noise. In these cases, audio recordings often require further processing to improve sound quality [5] [6].

3.3 Result Analysis

The SNR comparison results show that Spectral Gating provides a greater SNR increase compared to Wiener Filtering. The higher SNR value after Spectral Gating (21.31 dB) indicates that this method is more effective at reducing noise and improving the quality of recordings, especially in environments with dynamic noise. Wiener Filtering, while offering decent noise reduction with an SNR of 10.67 dB, is shown to be more suitable for environments with more stable noise.

3.4 Analysis of Results After Double Noise Reduction Methods

Two consecutive noise reduction processes are necessary to achieve optimal audio clarity, especially in low-quality recordings. The initial Wiener Filtering reduces general noise, but applying Spectral Gating followed by a second pass of Wiener Filtering further enhances the quality by minimizing residual noise and improving the overall intelligibility of the audio. As shown in Table 2, the SNR values were calculated for both consecutive noise reduction methods to compare their effectiveness.

Table 2. Comparison of SNR After Double Noise Reduction Methods

Method	SNR (dB)
Wiener Filtering → Spectral Gating	22.17
Wiener Filtering → Wiener Filtering	14.91

- **Spectral Gating After Wiener Filtering**: Using Spectral Gating after Wiener Filtering resulted in a more significant SNR improvement, with a final SNR value of 22.17 dB. Spectral Gating was able to eliminate the remaining dynamic noise that was not completely removed by Wiener Filtering, especially in the low-to-mid frequency range. This result indicates that the combination of these two methods is more effective in reducing noise and improving the quality of the signal. Listeners reported a cleaner and clearer voice quality, with further minimized background noise.
- **Wiener Filtering After Wiener Filtering**: Applying Wiener Filtering consecutively resulted in a final SNR value of 14.91 dB, showing a relatively insignificant improvement compared to the first application. Although there was some improvement, repeating Wiener Filtering did not provide optimal noise reduction, especially for dynamic noise that remained after the first processing.

4 Conclusion

This study aimed to evaluate the effectiveness of two noise reduction methods, Spectral Gating and Wiener Filtering, in improving the Signal-to-Noise Ratio (SNR) in audio recordings with dynamic noise. SNR measurements were used as a metric to evaluate the quality of noise reduction and to determine the extent to which these methods can reduce noise and improve the quality of audio recordings [9] [10].

The test results show that Spectral Gating consistently produces a more significant SNR improvement compared to Wiener Filtering. Spectral Gating achieved an SNR of 21.31 dB, which increased to 22.17 dB when used after Wiener Filtering. This demonstrates that Spectral Gating is highly effective in reducing dynamic noise, such as those found in real-world recording environments. Its advantage lies in its ability to effectively handle varying noise, especially in the low-to-mid frequency range, resulting in clearer and higher-quality audio.

On the other hand, Wiener Filtering, which resulted in an SNR of 10.67 dB when used once without any reduction processing, performed well in environments with more stable or static noise. When Wiener Filtering was applied twice, the resulting SNR was 14.91 dB, indicating some improvement but not as effective as combining it with Spectral Gating. This shows that repeating the same method does not yield significant noise reduction, especially when dealing with dynamic noise.

From these results, it can be concluded that a combination of noise reduction methods is more effective in improving SNR compared to applying a single method repeatedly. Using Spectral Gating after Wiener Filtering is a superior approach, as each method complements the other in handling different types of noise. Therefore, this combination is recommended for audio processing applications that require high recording quality, especially in environments with unstable noise.

Overall, this study demonstrates that layered or combined noise reduction methods can significantly improve the quality of audio recordings, particularly in dynamic environments.

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