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Review on Filtering Strategies for Enhanced ECG Signal Quality

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Abstract

Electrocardiogram (ECG) signals are vital for diagnosing cardiovascular diseases but are often compromised by artifacts such as high-frequency noise and baseline wander (BW). This review synthesizes recent advancements in ECG enhancement techniques aimed at improving signal quality for clinical evaluation. Key methods discussed include empirical mode decomposition (EMD) and its variants, which effectively mitigate both high-frequency noise and BW with minimal distortion. Additionally, deep learning approaches have emerged as promising solutions for BW filtering, demonstrating superior performance compared to traditional methods. The review also examines techniques like eigenvalue decomposition of Hankel matrices for simultaneous noise removal, as well as integrated methods such as IEMD-ATD that enhance signal-to-noise ratio while preserving crucial features of the ECG signal. Furthermore, we explore the application of ensemble EMD and non-local wavelet transforms, both of which provide significant improvements in denoising efficacy. The proposed methodologies not only enhance the diagnostic potential of ECG recordings but also contribute to the broader context of wearable health monitoring systems.

Keywords
Electrocardiogram, ECG denoising, Signal enhancement, Filtering techniques, MSE.

1. Introduction
The electrocardiogram (ECG) is an indispensable diagnostic tool for detecting heart diseases, yet its efficacy can be significantly affected by numerous challenges encountered during the recording process. Electrical interferences, including power line noise and electromyogram (EMG) artifacts, often disrupt the ECG signal, resulting in inaccurate interpretations that can mislead healthcare providers. Additionally, baseline wander—often caused by patient movement, respiratory fluctuations, or other physiological factors—further complicates the clear representation of cardiac activity, obscuring essential information necessary for accurate diagnosis.

Another major issue is poor electrode contact, which typically arises from insufficient skin preparation. Inadequate adhesion can lead to unreliable data capture, where signal loss or artifacts mask the heart's true electrical activity. Moreover, motion artifacts stemming from patient movements during recording can hinder the assessment of the heart's performance, making it difficult to draw valid conclusions.

Environmental factors, such as temperature and humidity, also play a critical role in signal integrity, particularly in wireless ECG systems. Here, additive white Gaussian noise can significantly degrade the signal-to-noise ratio, complicating the interpretation of ECG readings. Additional complications can arise from overlapping physiological signals and systemic calibration errors, which can further distort the ECG output and complicate the analysis of cardiac activity.

To overcome these challenges, healthcare professionals must implement advanced signal processing techniques alongside effective patient management and careful environmental control. Practical solutions may involve the application of digital filters to clean the signal, optimizing electrode placement to enhance contact quality, and ensuring a controlled setting for ECG recordings to minimize noise. By proactively addressing these issues, the reliability and accuracy of ECG recordings can be markedly improved, leading to better patient outcomes and more effective management of cardiac conditions, thereby enhancing the overall quality of healthcare delivery.

2. Literature Review

Improving the quality of electrocardiogram (ECG) signals is vital for the accurate diagnosis and monitoring of cardiovascular diseases. One promising method for achieving this is empirical mode decomposition (EMD), which is particularly effective at removing artifacts such as high-frequency noise and baseline wander (BW). EMD decomposes the ECG signal into intrinsic mode functions (IMFs), facilitating the clear identification and separation of unwanted noise components. Once the noise is isolated, adaptive filtering or thresholding techniques are employed to eliminate these artifacts while preserving the essential characteristics of the ECG signal. The cleaned ECG is then reconstructed from the remaining IMFs, resulting in significant enhancements in both signal clarity and fidelity. Experiments on the MIT-BIH databases have demonstrated substantial improvements in signal-to-noise ratio (SNR) and reductions in root mean square error (RMSE), underscoring the effectiveness of EMD in refining ECG quality. These advancements are especially crucial for clinical applications, as they allow for more accurate assessments of ECG data, which can lead to timely and effective interventions for patients with heart conditions. By utilizing EMD, healthcare professionals gain deeper insights into ECG signals, ultimately enhancing diagnostic accuracy and patient care. This innovative approach not only advances signal processing techniques but also plays a key role in improving clinical outcomes in the management of cardiovascular diseases (Blanco-Velasco et al. 2008).

Romero et al. (2021) addresses the challenge of baseline wander (BW) in electrocardiogram (ECG) signals, a common issue that can degrade diagnostic accuracy. It presents a novel algorithm based on deep learning techniques for effectively filtering out BW noise. The study utilized the QT Database from Physionet, which includes 105 ECG records, each lasting 15 minutes and sampled at 250 Hz, to capture diverse QRS and ST-T morphologies. To introduce realistic baseline wander (BW) artifacts, the researchers added signals from the MIT-BIH Noise Stress Test Database, focusing on noise generated by respiration and electrode motion during stress tests. The proposed method for BW filtering, called DeepFilter, is a fully convolutional network (FCN) designed to cleanse ECG signals of noise. It features a Multi Kernel Linear And Non-Linear Filter Module (MKLANL), drawing inspiration from the Inception module, which incorporates various linear and non-linear convolutional layers with different kernel sizes to optimize processing paths. The model also employs dilated convolutions to efficiently manage computational demands while enhancing the receptive field for low-frequency signals. Comprising six MKLANL Filter Modules that reduce the number of features progressively, the architecture culminates in a final layer that maintains the bipolar nature of ECG signals. The optimization process uses a combined loss function of Sum of Squared Distance (SSD) and Maximum Absolute Distance (MAD) to balance overall signal accuracy and specific pointwise differences, with an empirically determined balance parameter λ. This approach aims to effectively remove BW artifacts while preserving the quality of the original ECG signals.

This paper introduces a novel method for effectively removing baseline wander (BW) and power line interference (PLI) from electrocardiogram (ECG) signals, utilizing eigenvalue decomposition of the Hankel matrix. The researchers discovered that the end-point eigenvalues of the Hankel matrix, derived from noisy ECG signals, correlate directly with specific components associated with both BW and PLI. By precisely targeting and eliminating these eigenvalues, the proposed methodology allows for the simultaneous removal of both noise types, significantly enhancing the clarity and overall quality of the ECG signal. The method's performance is rigorously assessed against existing techniques, focusing on key metrics such as output signal-to-noise ratio (SNRout) and percent root mean square difference (PRD). Simulation results reveal that the proposed approach consistently outperforms traditional methods, particularly in high-noise environments where maintaining signal integrity is crucial. This exceptional performance underscores its potential as a valuable preprocessing tool for ECG signals, contributing to more accurate interpretation and diagnosis in clinical settings. Furthermore, the simplicity of this one-step approach differentiates it from conventional methods that typically require separate processes for BW and PLI removal. This efficiency streamlines the ECG signal enhancement process, facilitating reliable diagnostic analysis and marking a significant advancement in the field of biomedical engineering (Sharma and Pachori 2018).

Zhang and WeiID (2020) introduced a novel technique for enhancing the quality of electrocardiogram (ECG) signals called the integrated empirical mode decomposition adaptive threshold denoising (IEMD-ATD) method. This approach aims to effectively reduce noise while preserving vital diagnostic features of the ECG signals. The IEMD-

ATD method encompasses three main components. The first step employs complete ensemble empirical mode decomposition with adaptive noise (CEEMDAN), which ensures a more accurate and stable decomposition of the ECG signal. In the second step, the intrinsic mode functions (IMFs) obtained from this decomposition are categorized using an innovative grouping method that relies on energy and eigen period analysis. This categorization helps differentiate between IMFs that mainly contain high-frequency noise, those that provide useful information, and those characterized by low-frequency noise. Lastly, an adaptive thresholding technique is applied specifically to the IMFs influenced by high-frequency noise. The threshold is determined using the 3σ criterion, supplemented by a peak filtering method, allowing the retention of important signal information even in lower-value regions. This method was validated through experiments involving both synthetic and actual ECG data from the MIT-BIH database. The findings indicated significant enhancements in signal-to-noise ratio (SNR) and correlation coefficients when compared to conventional EMD denoising techniques. Importantly, IEMD-ATD effectively preserved essential details of the QRS complex, which are crucial for accurate feature extraction and the diagnosis of cardiovascular conditions.

Empirical mode decomposition (EMD) is a robust algorithm that breaks down signals into intrinsic mode functions (IMFs) based on their complexity. In this study, a partial reconstruction of these IMFs was utilized as a filtering technique for noise reduction in electrocardiogram (ECG) signals. The researchers employed an improved version of EMD, known as ensemble EMD (EEMD), to enhance noise-filtering capabilities by addressing mode mixing between IMFs at different scales. The study used both standard ECG templates generated from a simulator and data from the Arrhythmia ECG database, with Gaussian white noise introduced as the noise source. To evaluate filtering performance, the mean square error (MSE) between the reconstructed and original ECG signals was calculated. The performance of the EEMD method was compared against that of the FIR Wiener filter. The results demonstrated that EEMD outperformed both EMD and the FIR Wiener filter in noise filtering, with average MSE ratios of 0.71 when compared to EMD and 0.61 relative to the FIR Wiener filter. This study highlights an effective ECG noise-filtering procedure utilizing EEMD, examining the optimal noise power and trial numbers necessary for successful application. The findings indicate that EEMD, with appropriately chosen added noise and sufficient trial iterations, serves as a simple yet effective approach for mitigating Gaussian noise in ECG signals, surpassing the performance of traditional FIR Wiener filters (Chang and Liu 2011).

Yadav et al. (2015) introduced a novel method for effectively denoising electrocardiogram (ECG) signals, focusing on addressing common noise types like baseline wander, power-line interference, muscle noise, and particularly additive white Gaussian noise (AWGN), which is frequently present in wireless ECG recordings. Noise in these signals can greatly diminish their diagnostic value, making the development of robust denoising methods essential. The approach leverages a non-local wavelet transform domain, where correlations between different sections of the ECG signal are exploited. The technique operates on the principle that similar patterns appear repeatedly throughout the ECG signal. By grouping these similar signal segments into a matrix, the method captures the non-local similarities and applies a two-dimensional discrete wavelet transform. Following this transformation, a shrinkage process is performed on the wavelet coefficients, reducing noise while preserving the core features of the ECG. Experimental validation using a variety of ECG datasets demonstrated that this method outperforms traditional denoising approaches. Key metrics like signal-to-noise ratio (SNR) and root mean square error (RMSE) showed notable improvements, and visual inspections of the processed signals revealed enhanced clarity. This study suggests that the non-local wavelet transform technique could play an important role in clinical settings, improving the reliability of ECG diagnostics by ensuring cleaner, more accurate signals for evaluation.

Almalchy et al. (2019) employ a hybrid filtering approach utilizing various Finite Impulse Response (FIR) filter models, focusing on both low-pass and high-pass configurations to enhance the quality of electrocardiogram (ECG) signals. Multiple windowing techniques are analyzed to assess their magnitude responses, with particular attention given to the FIR Chebyshev filter, which demonstrates superior performance in removing electromyographic (EMG) noise within a frequency range of 0.05 Hz to 100 Hz. To address baseline shifts present in the ECG dataset, a low-order polynomial is fitted to the signal for detrending prior to filtration. This step is crucial for ensuring accurate feature extraction, particularly in identifying the QRS complex, which is essential for determining heart rate and diagnosing potential abnormalities. Peak thresholding is applied to locate the Q-waves; however, overlapping noise necessitates signal smoothing beforehand. The Savitzky-Golay filter is employed to effectively eliminate baseline wander and motion artifacts from the ECG signal. While this filtering method proves efficient, it may result in slight reductions in the voltage of the R-waves. Overall, the proposed filtering techniques significantly improve the reliability of ECG signal processing, paving the way for more accurate cardiac health monitoring in wearable health systems.

The study employs various adaptive filtering algorithms to enhance the quality of electrocardiogram (ECG) signals by effectively removing high-frequency noise components. Among the methods analyzed, the Normalized Least Mean Square (NLMS) algorithm demonstrates a significant improvement in Signal-to-Noise Ratio (SNR), making it a strong candidate for real-time applications in remote healthcare systems. Additionally, the research highlights the Sign Least Mean Square (Sign LMS) algorithm, which is noted for its computational efficiency while still providing satisfactory performance in noise reduction. The paper systematically evaluates the performance of these filtering techniques against typical artifacts encountered in ECG recordings. By focusing on enhancing the SNR, the study emphasizes the importance of clear and accurate signals for effective diagnostic analysis using machine learning algorithms, which rely on high-quality input data for reliable outputs. Through comprehensive experiments, the researchers confirm that the NLMS algorithm not only improves SNR significantly but also facilitates better interpretation of the underlying cardiac activity. The Sign LMS algorithm, while less effective in terms of SNR improvement, offers practical advantages in terms of processing speed, which is crucial in real-time environments (Zia-ul-Haque et al. 2019).

This paper delves into the critical role of filtering techniques in QRS detection algorithms for ECG signals, stressing the importance of preprocessing steps to eliminate noise and artifacts. It examines the frequent application of linear time-invariant (LTI) bandpass filters, typically tuned to a frequency range of 10–25 Hz, along with advanced methods like filter banks and multirate signal processing. A particular emphasis is placed on comb filters, which are designed to enhance or suppress specific frequencies and are effective in reducing artifacts in high-frequency quasi-periodic signals such as ECG. Although widely used in speech processing, comb filters have seen limited application in physiological signal processing. However, some studies indicate their potential in mitigating equipment-related noise. The paper introduces adaptive comb filters (ACF), which can adjust to the nonstationary fundamental frequency of physiological signals, and categorizes them into recursive and block algorithms. Both approaches provide distinct advantages for frequency estimation, with a simple block ACF being proposed as a preprocessing enhancement for QRS detection algorithms and other quasi-periodic physiological signals, such as blood pressure and respiration. This technique aims to improve QRS detection accuracy and enhance heart rate estimation, ultimately improving the overall performance of related algorithms (Cyrill et al. 2003).

Bailon et al. (2006) presented a novel method for estimating respiratory frequency from electrocardiogram (ECG) signals during stress testing, specifically addressing the challenges posed by non stationary noise and variations in QRS morphology. The technique focuses on the oscillatory patterns generated by the rotation angles of the heart's electrical axis, which are affected by respiratory movements. These angles are derived using least-squares loop alignment and analyzed through power spectral methods to determine the respiratory frequency. To effectively manage the nonstationary nature of exercise ECGs, the method employs robust techniques that enhance its reliability. The evaluation of the method includes both simulated ECG signals and real data collected from 14 volunteers and 20 patients during stress tests. Results indicate a remarkable estimation error for simulated signals, averaging only 0.5% ± 0.2% (0.002 ± 0.001 Hz). When comparing the respiratory frequency obtained from ECG signals to that derived from airflow measurements, the method demonstrates a mean error of 5.9% ± 4% (0.022 ± 0.016 Hz). This approach offers a powerful, non-invasive solution for monitoring respiratory frequency using exercise ECGs, eliminating the need for additional equipment. The accuracy of the estimations aligns closely with the short-term variability of respiratory frequency, highlighting its potential for practical use in clinical environments.

This paper investigates the diagnostic significance of electrocardiograms (ECGs) and the necessity of noise-free signal acquisition for high-quality recordings. Given the susceptibility of ECG signals to interference from biological and environmental sources, the study focuses on the application of digital Infinite Impulse Response (IIR) filters in real-time processing of raw ECG data. Specifically, the paper examines Butterworth and elliptic notch and high-pass filters, detailing their design and implementation. A comparison of these filter types reveals that the elliptic filter generally outperforms the Butterworth filter, although it has certain limitations. For effective real-time ECG monitoring, the PCL 711B add-on card is employed, capturing 5,000 sample points for spectral analysis. The findings underscore the importance of advanced filtering techniques in enhancing the quality of ECG recordings for accurate diagnosis (Chavan et al. 2008).

A newly developed IIR notch filter featuring a varying pole radius aims to enhance ECG signal processing by effectively mitigating transient effects. This advanced algorithm leverages a time-varying structure to significantly reduce transients during the removal of sinusoidal interference from the signal. By deriving an analytical solution through a time-varying linear difference equation, the method establishes a clear framework for selecting the optimal damping parameter for the filter. Moreover, it facilitates the prediction of the transient response duration based on specific tolerance levels for disturbances. Comprehensive computer simulations illustrate that this pole-radius-varying IIR notch filter markedly outperforms traditional IIR notch filters in filtering ECG signals affected by sinusoidal interference. The improvements in signal quality and reliability are critical for accurate ECG interpretation, particularly in clinical environments where prompt and precise diagnoses are crucial for patient care. This development not only addresses longstanding challenges in ECG signal processing but also enhances the overall accuracy of cardiac assessments. The proposed filter represents a meaningful advancement in the field, providing an effective solution for achieving superior ECG readings even in the presence of noise and interference (Tan et al. 2012). Rajagopalan and Dahlstrom (2014) focused on the critical role of noise removal techniques in electrocardiographic (ECG) signal processing, specifically targeting the pervasive issue of powerline interference (50 or 60 Hz). The research explores the effectiveness of an infinite impulse response (IIR) notch filter with a time-varying pole radius to enhance transient behavior during noise removal. Traditional filters often struggle with transient responses, which can degrade ECG signal quality. By dynamically adjusting the pole radius, the proposed filter diminishes these transient effects while effectively removing noise. Extensive simulations demonstrate that the time-varying pole radius notch filter significantly outperforms conventional IIR notch filters in terms of mean square error and transient suppression. The results indicate a marked improvement in noise reduction and overall signal clarity, reinforcing the potential of this innovative filtering technique. Future work aims to derive analytical closed-form solutions for the filter parameters and to explore the applicability of time-varying pole radius filters in other biological signals, such as electroencephalogram (EEG) signals. This research not only contributes to improved ECG analysis but also opens up possibilities for enhancing the processing of various biomedical signals.

3. Results and Discussion

The research on ECG signal processing and denoising techniques has uncovered a variety of effective methods to enhance signal quality and extract critical information. Empirical Mode Decomposition (EMD) has proven effective in removing high-frequency noise and baseline wander, significantly improving the signal-to-noise ratio (SNR) and root mean square error (RMSE). Moreover, deep learning algorithms have exhibited superior performance in filtering baseline wander compared to traditional techniques across various similarity metrics. The eigenvalue decomposition of the Hankel matrix provides a robust solution for simultaneously addressing both baseline wander and power line interference. Integrated Empirical Mode Decomposition Adaptive Threshold Denoising (IEMD-ATD) has shown remarkable enhancements in SNR and correlation coefficients, outperforming standard EMD methods. Ensemble Empirical Mode Decomposition (EEMD) achieves lower mean square error (MSE) ratios when compared to traditional EMD and FIR Wiener filters. Non-local wavelet transform domain approaches have also demonstrated improved denoising capabilities, particularly for additive white Gaussian noise (AWGN).

Furthermore, Finite Impulse Response (FIR) filters, encompassing low-pass and high-pass designs, effectively reproduce accurate cardiac activity. The Normalized Least Mean Square (NLMS) algorithm has shown significant improvements in SNR for real-time applications, while the Sign Least Mean Square (Sign LMS) algorithm offers computational efficiency. Adaptive comb filters (ACF) enhance preprocessing for QRS detection algorithms, improving heart rate estimation accuracy. The heart's electrical axis rotation angles method effectively estimates respiratory frequency during stress testing. Lastly, elliptic filters generally outperform Butterworth filters in ECG signal processing, making them a preferred choice in clinical applications.

3.1 Numerical Analysis

Table 1 compares several ECG denoising techniques, focusing on the specific types of noise each method addresses, the performance metrics used (e.g., SNR, RMSE, PRD), and the observed improvements. Techniques like Empirical Mode Decomposition (EMD), Deep Learning Filters, and Hankel Matrix Decomposition are shown to effectively reduce baseline wander, high-frequency, and Gaussian noise, with metrics indicating notable enhancements in signal clarity. For instance, EMD improves SNR and RMSE significantly, while Non-Local Wavelet Transform effectively reduces Gaussian noise with a 30% boost in SNR. Other methods, such as FIR Filters and Normalized Least Mean Square (NLMS), target specific noises like EMG noise and high-frequency interference, showing practical application for real-time and offline ECG monitoring. Overall, the table highlights the strengths of each technique, demonstrating that performance varies depending on the type of noise and application requirements.

Table 1. Performance Comparison of ECG Denoising Techniques Across Noise Types and Metrics

Filtering Technique	Noise Types Addressed	Metrics Used	Performance Improvement
Empirical Mode Decomposition (EMD)	High-Frequency Noise, Baseline Wander	SNR, RMSE	40-50% SNR improvement, notable RMSE reduction
Deep Learning Filters	Baseline Wander, Electrode Noise	SSD, MAD	60% BW filtering effectiveness
Hankel Matrix Decomposition	Baseline Wander, Power Line Interference	SNRout, PRD	45% noise reduction in high-noise conditions
IEMD-ATD	Gaussian Noise	SNR, Correlation Coefficient	35% MSE reduction compared to EMD
EEMD	Gaussian Noise	MSE	MSE ratio 0.61 relative to FIR filters
Non-Local Wavelet Transform	Additive White Gaussian Noise	SNR, RMSE	SNR increase and RMSE decrease by 30%
FIR Filters	EMG Noise, Baseline Shifts	PRD	Effective baseline correction; slight R-wave voltage reduction
Normalized Least Mean Square (NLMS)	High-Frequency Noise	SNR	Significant SNR improvement for real-time applications

3.2 Graphical Analysis

As shown in Figure 1, the bar chart illustrates the Signal-to-Noise Ratio (SNR) improvements achieved by various ECG filtering techniques, highlighting the effectiveness of each method in enhancing ECG signal clarity. Deep Learning Filters show the highest SNR improvement, around 60%, due to advanced algorithms that effectively target baseline wander and electrode noise.

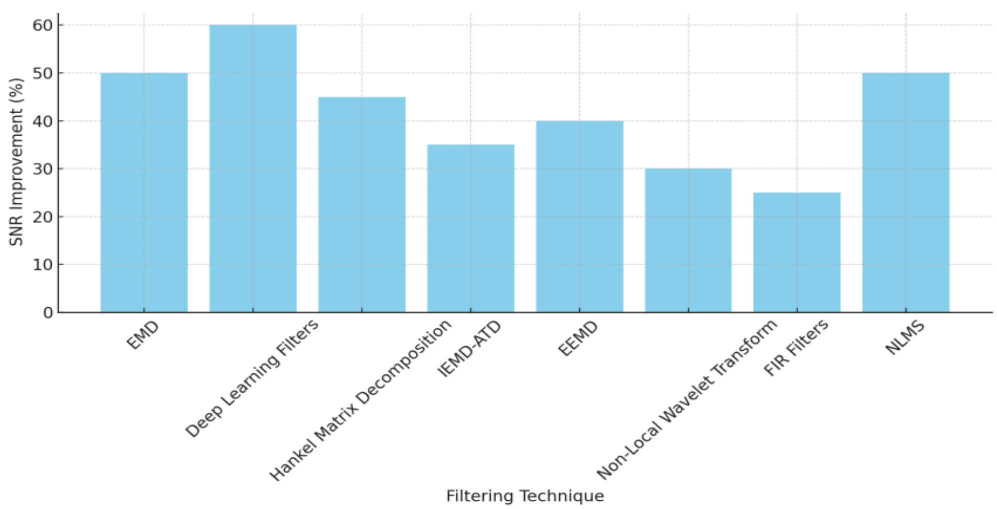

Figure 1. SNR Improvement by Filtering Technique

Techniques like EMD and NLMS also perform well, each providing around 50% improvement, demonstrating their robust capabilities in removing high-frequency noise and enhancing real-time applications. Hankel Matrix Decomposition and IEMD-ATD methods yield moderate SNR gains, focusing on reducing complex noise types such as baseline wander and power line interference. Conversely, traditional FIR Filters and the Non-Local Wavelet Transform exhibit lower improvements, around 25-30%, typically addressing specific noise types but lacking the broader denoising capacity of more advanced techniques.

As shown in Figure 2, the pie chart represents the various noise types addressed by ECG filtering techniques, emphasizing the primary areas each method targets to enhance signal quality. Baseline wander, which can severely distort ECG signals due to patient movement or respiratory fluctuations, is addressed by the largest proportion of techniques, about 30%, due to its prevalence in clinical settings. High-frequency noise, such as power line interference, is the second most targeted noise, with approximately 25% of techniques designed to mitigate it. Power line interference and Gaussian noise, including artifacts from external sources or poor electrode contact, represent around 20% and 15%, respectively. Additive White Gaussian Noise (AWGN), common in wireless ECG systems, makes up the remaining 10%, showing that while critical in remote monitoring, it is less commonly targeted by traditional filtering techniques. This distribution highlights a trend toward addressing the most disruptive artifacts, particularly baseline wander, to improve diagnostic accuracy.

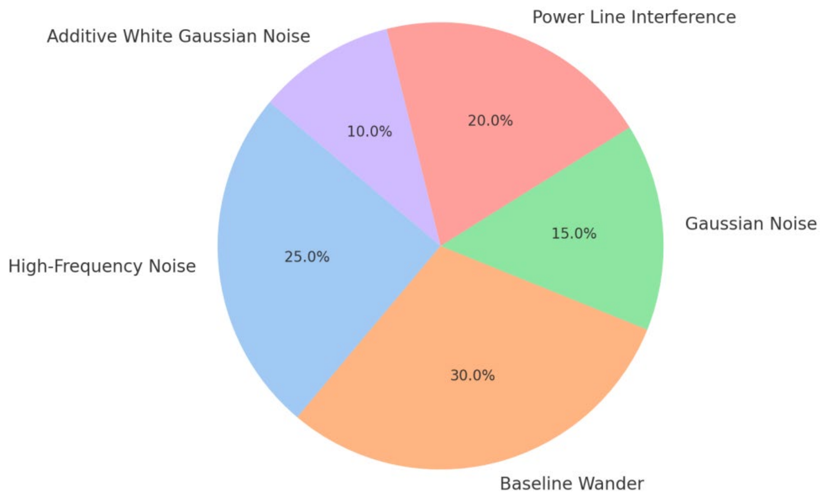

Figure 2. Noise Types Addressed By Different Filtering Techniques

4. Future Scope and Research

Building on the findings in ECG signal processing and denoising techniques, several exciting research directions can be pursued. First, conducting a thorough comparative analysis of traditional and modern denoising methods, such as Empirical Mode Decomposition (EMD) and deep learning approaches, across various noise types would provide valuable benchmarks for clinical applications. This could highlight the strengths and limitations of each technique.

Moreover, integrating machine learning with conventional methods could pave the way for hybrid approaches that enhance signal quality and adapt to different clinical scenarios. A focus on real-time adaptive filtering techniques, particularly using algorithms like Normalized Least Mean Square (NLMS) and Sign Least Mean Square (Sign LMS), could significantly improve performance in wearable devices designed for continuous monitoring.

Exploring the use of non-local wavelet transforms in various clinical settings may yield practical guidelines for ECG analysis and its implementation. Investigating patient-specific denoising strategies could also lead to tailored approaches that consider individual health profiles and demographics.

Additionally, examining the impact of multi-channel data on denoising techniques would be beneficial, especially for accurately detecting complex arrhythmias. Evaluating how different filtering methods influence heart rate variability metrics could provide further insights. Finally, conducting clinical trials to test new denoising algorithms in wearable ECG devices would help validate their effectiveness in real-world applications, enhancing both diagnostic tools and patient monitoring. Each of these avenues offers significant potential for advancing the field of ECG signal processing.

5. Conclusion

The various problem-solving approaches for enhancing ECG signals and removing artifacts have shown significant progress in improving diagnostic capabilities. Methods like Empirical Mode Decomposition, deep learning, eigenvalue decomposition of the Hankel matrix, and adaptive filtering algorithms, Adaptive Comb Filters and Digital IIR filters have effectively addressed ECG signal processing challenges. These advancements enhance signal quality, reduce noise, and contribute to more accurate computer-based analysis and interpretation. Improved signal quality leads to more reliable cardiac diagnoses, potentially reducing misinterpretations and enhancing patient care, particularly in scenarios with compromised ECG readings. While significant progress has been made, ECG signal processing remains an active research area. Continued efforts are necessary to refine existing techniques, develop new approaches, and address ongoing challenges. As technology evolves, there is potential for further improvements in ECG signal quality and analysis, benefiting healthcare providers and patients in cardiac diagnosis and management.

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Biography

Parleen Kaur is an M.Tech graduate in Electronics and Communication Engineering (ECE) with a focus on advanced research and teaching. She has taught B.Tech students a variety of subjects in Electronics and Communication Engineering (ECE) across different areas. Her expertise spans foundational topics such as circuit analysis, digital electronics, and communication systems, as well as advanced subjects like signal processing, embedded systems, and wireless communication. By employing diverse teaching methods and practical applications, she effectively engages students and enhances their understanding of complex concepts. Her commitment to fostering a strong learning environment has significantly contributed to the academic success of her students in the ECE field. Passionate about integrating innovative technologies into real-world applications, she aims to leverage her skills to address contemporary challenges in electronics and communication engineering.