

ECG Signal Noise Cancellation: A Review

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Abstract— The detection of cardiac disorders relies heavily on electrocardiogram [ECG] readings, but these signals are frequently tainted by a variety of noise sources, including motion-induced disruptions, powerline drift, and muscle artifacts. In order to improve the integrity of ECG recordings, several noise cancellation techniques have been developed. Conventional methods use digital filtering techniques, such as zero phase bandpass filters, to successfully reduce noise while maintaining crucial signal properties. Empirical mode decomposition (EMD)-based adaptive approaches have been developed by advances in signal processing which convert ECG data into intrinsic mode functions, making it easier to remove certain noise components. In order to improve the accuracy of ECG readings, new deep learning techniques or hybrid algorithms have shown exceptional performance in eliminating intricate noise patterns such as baseline, wander, and motion artifacts. All of these developments work together to enhance patient outcomes and diagnostic precision in clinical ambulatory settings by enabling more dependable ECG signal capture.

Key Words— ECG, Signal, Noise, EMD, Powerline, Wander, Muscle Cancellation.

I. INTRODUCTION

A crucial non-invasive diagnostic technique that tracks the heart's electrical activity over time is an electrocardiogram (ECG). The ECG records electrical impulses produced by the heart's rhythm and conduction system by applying electrodes to the skin, usually on the arms, legs, and chest. Arrhythmias, myocardial infarctions, and other cardiac abnormalities can be diagnosed with the use of this recording, which offers vital information on heart rate, rhythm, and general cardiac health.

A. Comprehending ECG Signals

An ECG is a technique used to measure and record the heart's electrical activity. In order to detect the heart's impulses, electrodes are applied to the skin. The signal waves are recorded are in the form of waves using a 12-lead system, which involves placing ten electrodes on the patient's body to capture the heart's electrical activity from different angles. Clinicians can identify anomalies in cardiac anatomy and function thanks to this all-encompassing perspective [01].

The recorded ECG normal wave patterns with peaks are depicted as indicated in the figure 1.

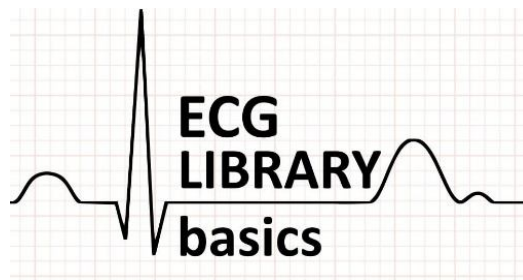


Fig. 1. ECG Waves

B. ECG Signal Noise and Typical Forms of ECG Noise

Unwanted disturbances that might distort the real cardiac electrical activity recorded are known as artifacts, or noise in ECG readings. These disruptions may make it challenging to accurately read the ECG, perhaps leading to a misdiagnosis. Noise is frequently caused by baseline drift, power-line interference, muscle activity (electromyography), and motion artifacts.

Many kinds of noise and aberrations can taint ECG readings, masking or simulating abnormal results. Accurate interpretation depends on an understanding of these interferences. Baseline Wander: Low-frequency noise (0.15–0.3 Hz) brought on by body motions, breathing, or inadequate electrode contact. IMFs (ScienceDirect mode functions), which allow the identification and elimination of noise elements. The Pan-Tompkins technique is a real-time technique that enhances QRS complex detection. Electromyographic noise, or muscle artifacts, are high-frequency noises produced by skeletal muscle activity that frequently coincide with the frequencies of ECG signals that enhances QRS complex detection. [02] Power-Line Interference: Filtering and thresholding stages caused by electrical mains interference produce sinusoidal noise at 50 or 60 Hz. Electromyographic noise, or muscle artifacts, are high-frequency noises produced by skeletal muscle activity that frequently coincide with the frequencies of ECG signals. Transient signal distortions caused by variations in electrode-skin impedance brought on by movement are known as electrode motion artifacts. Sharp transients brought on by sporadic contact between the electrode and skin are known as electrode contact noise indicated in the figure 2.

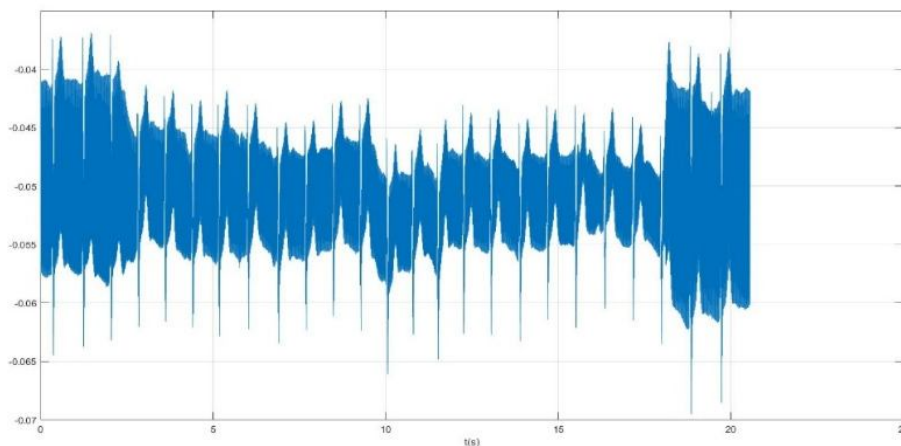


Fig. 2. ECG Noise Waveform

C. Methods for ECG Signal Noise Reduction

Several signal processing methods are used to improve the quality of ECG recordings, including Notch Filters: Target and get rid of particular frequencies, such power-line interference at 50/60 Hz. High-Pass Filters: eliminate baseline drift and other low-frequency elements. Muscle artifacts and other high-frequency noise are attenuated using low-pass filters. The wavelet transform breaks down the ECG signal into several frequency components, enabling selective noise reduction without causing the signal to become noticeably distorted. Adaptive filtering efficiently suppresses noise that overlaps with the ECG signal by dynamically adjusting filter parameters using reference noise signals. Decomposition of the Empirical Mode (EMD) uses a series to break down the ECG signal into its intrinsic signal-to-noise ratio.

D. Superior Methods

Wavelet transform and total variation techniques are used in Stationary Wavelet Total Variation (ST WA TV) to increase noise reduction in data distortions.

The Hankel Matrix Method: isolates and eliminates noise components using matrix decomposition methods. [03]

Adaptive Noise Cancelling (ANC): This technique isolates fetal cardiac signals by eliminating maternal ECG interference, which is very helpful in fetal ECG monitoring indicated in figure 3.

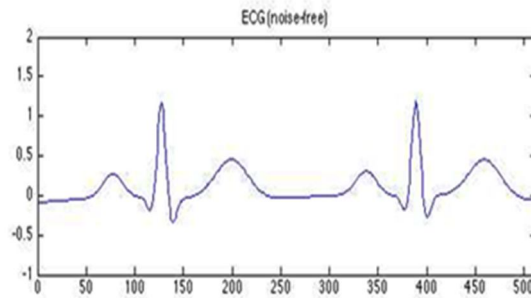


Fig.3. ECG without Noise waveform

E. Suppression of interference and Techniques

Interference suppression is a technique used when undesired signals (interference) disrupt or interfere with the functioning of electronic equipment or communication networks. This is accomplished through a variety of tactics, from hardware solutions like shielding and filters to software techniques like signal processing algorithms. Interference suppression is a technique used when undesired signals (interference) disrupt or interfere with the functioning of electronic equipment or communication networks. This is accomplished through a variety of tactics, from hardware solutions like shielding and filters to software techniques like signal processing algorithms.

Filters: EMI/RFI filters, which employ coils and capacitors to prevent high-frequency interference pulses from reaching connected equipment, are one type of filter.

Shielding: According to a prior search result, electromagnetic radiation can be prevented. by shielding materials or metal casings, keeping it from interfering with devices.

Grounding: Appropriate grounding helps prevent a buildup of electrical potential differences that might lead to interference.

The Value of Suppressing Interference: For electronic systems and gadgets to operate accurately and dependably, interference reduction is essential. It aids in avoiding.

Data corruption: Inaccurate readings or faults might result from interference that distorts

System Failure: Devices may crash or stop working altogether due to extreme interference.

Degradation of performance: Interference can cause equipment to run more slowly or inefficiently. Updates for software

Interference Cancellation: Techniques like Kalman filters may be used to model and remove interfering signals

Deep Learning: Based on an earlier search

Safety risks: Interference can pose a threat to critical systems, such as automobile radar or medical equipment. [03].

II. LITERATURE SURVERY

TABLE I

Name/Author	Title	Methodology	Summary
Juya Zhang et.al. Elsevier [04] Volume 250, 15 June 2025, 117067 https://doi.org/10.1016/j.measurement.2025.117067	Opportunities and challenges of noise interference suppression algorithms for dynamic ECG signals in wearable devices: A review	1) A range of noise reduction techniques for dynamic ECG signals 2) The techniques for reducing noise in the frequency, time, time-frequency, and artificial intelligence domains.	1)examines various noise reduction techniques for dynamic ECG signals. 2)Reduce three forms of noise in the dynamic ECG output in an efficient manner.

Zhen Wang et.al [05] Elsevier Volume 89, March–April 2025, 153858 https://doi.org/10.1016/j.jelectrocard.2024.153858	Mr Senet: Electrocardiogram signal denoising based on multi-resolution residual attention network	1)Multi-resolution fusion in deep network architecture eliminates noise from ECG readings, including baseline drift, muscle artifacts, and electrode motion. 2) The approach of empirical mode decomposition	1) In deep network architecture, multi-resolution fusion removes noise from ECG measurements, such as electrode motion, baseline drift, and muscle artifacts. 2) The empirical mode decomposition method In ECG signals, the model can successfully remove noise signals of various intensities and kinds.
Juya Zhang et.al. Elsevier [06] Volume 250, 15 June 2025, 117067 https://doi.org/10.1016/j.measurement.2025.117067	Opportunities and challenges of noise interference suppression algorithms for dynamic ECG signals in wearable devices: A review	1) A range of noise reduction techniques for dynamic ECG signals 2) The techniques for reducing noise in the frequency, time, time-frequency, and artificial intelligence domains.	1)examines various noise reduction techniques for dynamic ECG signals. 2)Reduce three forms of noise in the dynamic ECG output in an efficient manner
Ameet Shah et.al Springer [07] 2025 Mar 18;15:9230. doi: 10.1038/s41598-025-93906-5	Electrocardiogram analysis for cardiac arrhythmia classification and prediction through self-attention-based auto encoder	1)Denoising technique for power line interference. 2) The self-attention-AE model is the suggested algorithm execution steps.	1)The suggested Modified Kalman Filter, which uses dual signal filtration to denoise the ECG signal, outperforms the current models. 2) Accuracy in the classification of arrhythmias is provided by self-attention algorithms and autoencoder architectures, like the one proposed. 99.7% accuracy, 99.91% precision, and 99.86% recall are achieved in the prediction of ECG signals.
Weidong Gao et.al [08] MDPI 31 October 2024 https://doi.org/10.3390/electronics13214274 [11]	Sudden Cardiac Death Risk Prediction Based on Noise Interfered Single-Lead ECG Signals	1)Data Preprocessing: The study adds electrode motion artifact noise to single-lead ECG signals in order to replicate real-world circumstances that wearable ECG devices may experience. This results in a signal-to-noise ratio (SNR) of 12 dB. 30-minute ECG segments before the onset of ventricular fibrillation are chosen for cases of sudden cardiac death (SCD). For a typical sinus in cases of congestive heart failure (CHF) and non-susceptible cardiac rhythm (NSR), random 30-minute chunks are selected. The signal quality is then improved by resampling and filtering these segments. 2)Feature Extraction: Three main characteristics are to be extracted from the ECG signals in this study: arrhythmia. average forecast accuracy is 93.22%.	1)Prediction Accuracy: In the 30 minutes before sudden cardiac death (SCD), the algorithm's average prediction accuracy was 93.22%. The accuracy increased to 95.43% when the normal sinus rhythm (NSR) database was used as the sole control group. Interestingly, the algorithm achieved a recognition level of 99.25% accuracy at 27 minutes prior to the commencement of SCD. 2) Comparison with Current Techniques: The study showed that its algorithm performed better than current techniques in terms of accuracy. For example, the recognition accuracy was 97.25% at 29 minutes before SCD, which was higher than conventional methods. 3) Congestive Heart Failure (CHF) Data Inclusion: The algorithm maintained a recognition accuracy of 94.33% within 10 minutes before to SCD and an average accuracy of 93.22% over 30 minutes by using CHF data as an additional control. 4)Sudden Cardiac Death Index (SCDI): The study presented the SCDI, a thorough index that incorporates characteristics such as the corrected QT interval (QTc) and RMS40 standard deviations. This index efficiently separates normal ECG signals from high-risk SCD signals, offering useful information for clinical evaluation. With single-lead, noise-interfered ECG readings, these results demonstrate the algorithm's

			capacity to reliably forecast SCD and emphasize its suitability for wearable device settings. Over a 30-minute period, the average accuracy is 93.22%.
Madhava Rao Alla et.al Elsevier [09] https://doi.org/10.1016/j.bspc.2024.106434 September 2024, 106434	A robust ECG signal enhancement technique through optimally designed adaptive filters	1. ANC, or adaptive noise cancellation: 2. Reptile Search Algorithm (RSA) Optimization: 3. Analysis of Actual ECG Signals: 4.Measures of Performance: 5. Classification via Integration with Deep Learning;	In order to reduce the root, mean square error (RMSE) between the filtered and intended signals, this method dynamically modifies the filter coefficients. Real PhysioNet ECG signals tainted with several kinds of noise, such as baseline wander (BW), electrode motion (EM), and muscular artifacts (MA), were used to test the technique. powerline, or additive white Gaussian noise, and POWER interference (PLI). Vital cardiac information was successfully preserved by the RSA-based ANC, which showed better noise reduction than methods based on the flower pollination algorithm (FPA) and artificial bee colony (ABC). Additionally, the method correctly identified arrhythmia (ARR) and normal sinus rhythm (NSR) when combined with a deep convolutional neural network (CNN)-based ECG multi-class diagnosis system and super let transform (SLT.) after noise elimination presents a technique for improving electrocardiogram (ECG) signals through adaptive noise cancellation (ANC) that is optimized using the reptile search algorithm (RSA). In order to reduce the root mean square .
Mariana Dias1 et.al Springer [10] Nature Journal Accepted: 29 May 2024 https://doi.org/10.1007/s42979-024-03017-7	Cleaning ECG with Deep Learning: A Denoiser Tested in Industrial Settings	1]Recurrent Units with Gates 2] Pre-processing of data	1]Enhanced Signal Strength 2]Improved Precision in Diagnosis On average, results show that after denoising the signal, over 70% of the missing peaks are accurately identified. With regard to WP, about half of the incorrectly identified peaks have been fixed. 3] Sturdiness in Practical Situations 4] Improved Wearable and Remote Monitoring Usability 5] Contrast with Conventional Approaches
Pingping Bing 1, et.al[11] National Institutes of Health PMCID: PMC11064874 PMID: 38699582	A novel approach for denoising electrocardiogram signals to detect cardiovascular diseases using an efficient hybrid scheme	1]Empirical mode decomposition [EMD] wavelet transform 2] One value Breakdown 3] Deep learning and adaptive filtering	This approach is more suited for processing ECG readings since it not only greatly reduces the noise present in the signals but also better maintains their features. 1] Better quality ECG signal quality 2] Performance of noise reduction 3] Improved accuracy in detecting cardiovascular disease 4] A reduced noise level in an ECG signal that preserves important cardiac rhythm characteristics improves the detection and diagnosis of cardiovascular illnesses
Jianlin Ren a, et.al Elsevier [12] https://doi.org/10.1016/j.enbuild.2023.113797 Volume 303, 15 January 2024, 113797	Experimental evaluation of ECG signal denoising methods based on HRV indices and their application in indoor thermal	1]Acquisition of ECG Signals 2] Evaluation of ECG Denoising Techniques 3] Denoising Methods Evaluation Metrics	The Butterworth filter demonstrated a more thorough and smoother approximation of the original ECG signal when the effectiveness of four denoising techniques was assessed using the electrocardiogram. Butterworth had

	comfort study under different temperatures	4)Use in Research on Indoor Thermal Comfort	the highest signal-to-noise ratio, the lowest mean square error, and the lowest percent root-mean-square difference when the evaluation was based on denoising indices. On the other hand, Chebyshev's signal-to-noise ratio was the least smooth. 1)[95–98%] Wavelet Transform 2) The overall accuracy of ECG denoising using all approaches varied between 80% and 98%.
Sakarie M. Muhumed[13] ASIAN JOURNAL OF ELECTRICAL AND ELECTRONIC ENGINEERING April 2023 DOI:10.69955/ajoeee.2023.v3i1.43	Noise Reduction Techniques in ECG Signal	1)Traditional signal processing a) Wavelet Transform b) Adaptive Filtering c) Empirical Mode Decomposition 2) Deep Learning-Based Denoising a) Autoencoders [AE] b) Convolutional Neural Networks [CNNs] c) Recurrent Neural Networks [RNNs]/LSTMs d) Generative Adversarial Networks [GANs]	1) Enhanced SNR (signal-to-noise ratio) 2) Improved R-wave identification for peaks 3) Minimize Powerline Interference and Baseline Wander 4) Better Disease Detection Accuracy Accuracy improvements of 5–20% are typical.
Roberto Holgado-Cuadrado Et.al [14] Springer 03 April 2023	Characterization of noise in long-term ECG monitoring with machine learning based on clinical criteria	1)Data collecting and annotation 2) ML techniques [multi-layer]	1)High Accuracy of Noise Detection; 2) Clinically Relevant Labelling; 3) Improved Evaluation of Signal Quality; 4) Effect on Diagnostic Confidence; and 5) Model Efficiency ECG segments may be classified with 93.1% accuracy as either diagnostically useful or noise-intolerant. Further performance indicators Accuracy: ~92.6% 91.5% sensitivity
Yuying Liu MDPI [Multidisciplinary Digital publishing Institute] [15] 18 January 2023 https://doi.org/10.3390/app13031313	An Automatic ECG Signal Quality Assessment Method Based on Resnet and Self-Attention	The accuracy of automatic ECG signal analysis has increased thanks to machine learning algorithms.	1) Training is done on network models with and without attention modules. 2) The model's performance with the attention module is contrasted with that of other models 1)Overall categorization accuracy range:95–99% 2) Assessment with Relation to Traditional Methods: 85–92%

III. CONCLUSION

The evolution of ECG noise reduction technologies has led to more accurate and reliable cardiac assessments. By leveraging hybrid signal processing techniques, adaptive filtering, and machine learning models, these advancements have significantly improved the quality of ECG signals.

Continued research and development in this field promise further enhancements in diagnostic capabilities and patient care.

The multi- scale ResNet model with attention mechanism demonstrates its promising capabilities in accurately detecting and localizing myocardial infarction using 12-lead ECG signals.

This approach enhances diagnostic precision and holds potential for integration into automated cardiovascular diagnostic systems pending further validation by effectively extracting relevant features and emphasizing spatial lead importance.

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