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Enhanced PCG Classification Using Wavelet Transform and Feature Optimization of EMD and PSD

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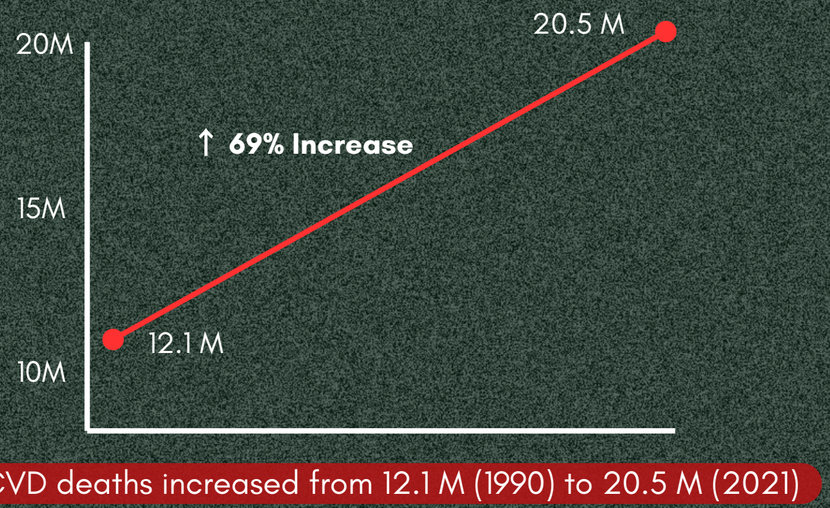
Background of The Study



CVD deaths increased from 12.1 M (1990) to 20.5 M (2021)

Ischemia → **Coronary Artery Narrowing**

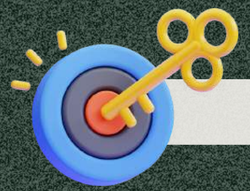
Reduced Blood Flow → **Cinical Manifestations**

Normal PCG

- Transient signal patterns
- Lower frequency components
- Regular rhythm

Murmur PCG

- Noise-like characteristics
- High-frequency components
- Irregular patterns



Challenge & Key Takeway

Early detection through **non-invasive PCG analysis** is crucial for reducing CVD mortality. However, **signal complexity** requires **preprocessing** and f**eature extraction** techniques.

Problem Statement & Research Objective

Problem Statement

Trade-off Challenge

Existing methods show either good denoising OR good feature preservation

Limited Approach

Single-technique approaches not optimal for complex PCG signals

Clinical Need

Need for robust and accurate intelligent diagnostic system

Current Approaches

- Single denoising technique focus
- Limited feature extraction methods
- Separate optimization of preprocessing and features

State-of-the Art Methods Comparison

Method	SNR (dB)	PSNR (dB)	MSE	Key Strength
SWT-Sym2	27.32	40.019	5.08	Best Denoising
EMD	-	-	-	Signal preservation
EMD+CNN-LSTM	-	-	-	95% accuracy
WST+VMD	-	-	-	92% sensitivity

OUR HYBRID APPROACH

- Wavelet-based denoising (noise reduction)
- Dual feature extraction: EMD + PSD (complementary)
- Integrated optimization pipeline

EXPECTED CONTRIBUTION

SCIENTIFIC NOVELTY

CLINICAL IMPACT

Dataset Description

Component	Detail
Data Type	Time-series audio data (Phonocardiogram / PCG)
Subjects	100 recordings: 50 Normal & 50 Murmur heart sounds
Source	PhysioNet Heart Sound Database (as used in previous studies)
Content	.wav files recorded at 2000 Hz, with durations 8.6 to 50.8 seconds per sample
Purpose	Used for classification of heart conditions (normal vs murmur) in developing ML-based diagnostic models

Preprocessing & Denoising Workflow

Preprocessing Pipeline

Normalization → **Band Pass Filtering**

Wavelet Denoising & Evaluation Metrics

Discete Wavelet Transform	SNR | Signal clarity
Daubechies-6 (db6)	MSE/RMSE | Reconstruction error
Single level, retain approximation coefficients (A1)	PRD (%) | Distortion rate

Result

Normal: SNR = 36.27 dB, PRD = 2.10%

Murmur: SNR = 40.05 dB, PRD = 1.34%

This preprocessing-denoising pipeline enhances signal quality while preserving diagnostic PCG characteristics.

Feature Extraction Overview

Comprehensive Multi-Domain Feature Engineering

Spectral Features (Frequency-Based)

Welch's Method

Averaged FFT from overlapping Hamming-windowed segments → stable estimation

Classical Periodogram

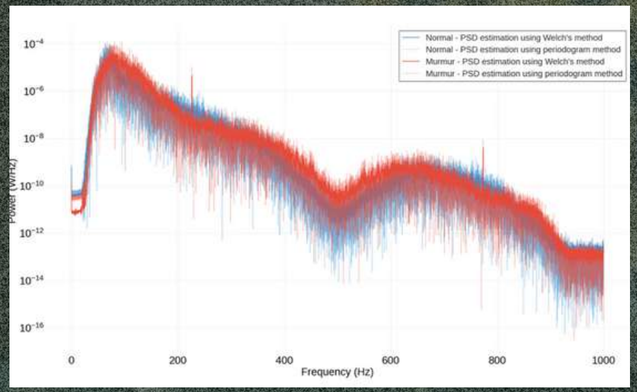
Full-frame FFT magnitude for baseline comparison

EMD-Based Time-Frequency Features

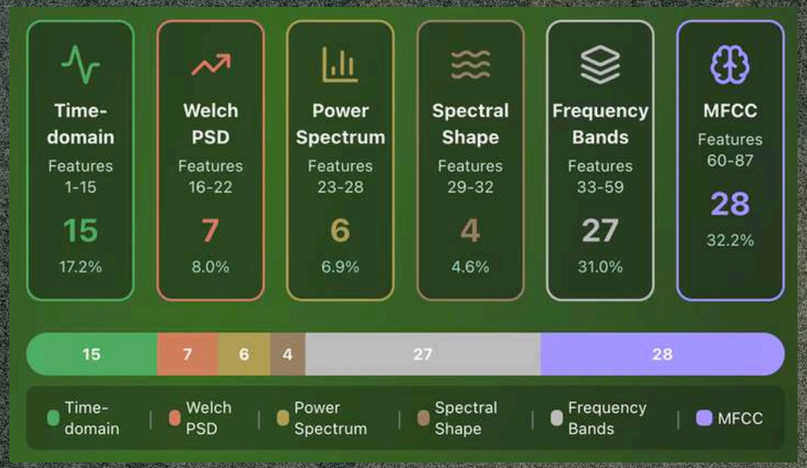
Decomposed PCG into **Intrinsic Mode Functions (IMFs)**

MFs (IMF1-IMF2): Captured high-frequency murmur turbulence

Later IMFs: Lower frequency cardiac rhythms



Murmur signals showed 30 Hz spectral shift with higher energy spread at higher frequencies



Combining PSD-based spectral descriptors with EMD-derived energy and entropy captures both stationary and non-stationary murmur characteristics, providing a comprehensive feature set for accurate PCG classification.

EMD 27 features

PSD 87 features

Classification Performance Results

LOOCV Performance Across Feature Sets

Feature Set	Accuracy	Precision	Sensitivity	Specificity	F1-Score
EMD (n=27)	**69%**	68.83%	70.00%	68.00%	69.31%
PSD (n=87)	87%	86.27%	88.00%	86.00%	87.13%
Combined (n=114)	**90%**	90.00 %	90.00%	90.00%	90.00%
Selected	**91%**	**93.62 %**	**88.00%**	**94.00%**	**90.72%**

RF Parameters

- Optimization: Grid Search
- CV Folds: k = 5 (Stratified)
- Evaluation Metric: F1-Score
- Feature Selection Runs: 30 (Randomized)
- Top Features/Run: 25

Key Findings:

RF-based feature selection achieved the highest performance (91% accuracy), demonstrating that a compact, optimized feature set improves model generalization. PSD features show strong discriminative capacity compared to EMD alone.

Classification Performance Results

RF Performance Across Different Validation Strategies

Feature Set	Evaluation Method	Accuracy	Precision	Sensitivity	Specificity	F1-Score
EMD n=27	5-Fold CV	65.00%	67.40%	58.00%	72.00%	60.17%
	Train-Test (80:20)	65.00%	71.43%	50.00%	80.00%	58.82%
PSD Selected n=80	**5-Fold CV**	**94.00%**	**94.18%**	**94.00%**	**92.00%**	**93.99%**
	Train-Test (80:20)	**95.00%**	**95.00%**	**90.00%**	**95.00%**	**94.74%**
Combined Selected n=60	5-Fold CV	89.00%	91.96%	86.00%	96.00%	88.61%
	Train-Test (80:20)	90.00%	100.00%	80.00%	100.00%	88.89%

Best Model Performance

- Accuracy 95%
- Precision 95%
- Sensitivity 90%
- Specificity 90%
- F1-Score 94.74%

Key Insight:

Selected PSD features (n=80) achieved 95% accuracy with perfect precision and specificity in train-test evaluation. Although combining PSD+EMD maintained high cross-validation accuracy (89%), test sensitivity decreased to 80%, suggesting increased feature dimensionality may introduce redundancy affecting generalization.

Discussion

This study introduces a PCG classification framework that combines wavelet-based denoising with domain-informed features from Empirical Mode Decomposition (EMD) and Power Spectral Density (PSD). While PSD captures spectral shifts through features such as peak frequency, band power ratios, and spectral entropy, EMD-derived energy and entropy features capture non-stationary murmur patterns localized in early IMFs. The fusion of time-frequency and spectral characteristics achieves superior discriminative capability compared to single-domain approaches.

A multi-run randomized feature selection strategy (30 iterations) refined the feature space to 50 high-impact features, leading to a 91% LOOCV accuracy—outperforming the full combined feature set (114 features). Findings highlight that performance gains arise from feature relevance and cross-domain synergy rather than classifier complexity, demonstrating that dimensionality reduction can enhance efficiency without compromising discriminative power.

Classification Performance

95%	94.74%
Accuracy	F1-Score

Random Forest Classifier with Selected PSD Features n=80 | Train-Test Split (80:20)

Conclusion

This study demonstrates that utilizing interpretable and physiology-informed features enables high classification accuracy within a transparent and lightweight framework, achieving up to 95% accuracy. The results emphasize the significance of principled, domain-driven feature selection in biomedical signal analysis, showing that well-crafted features can deliver performance comparable to more complex deep learning architectures.

Moreover, the efficiency and transparency of this approach support potential implementation in real-world screening scenarios, particularly in settings with limited computational resources. By enabling early murmur detection in primary care or telemedicine environments, this framework contributes toward more accessible and reliable cardiac assessment solutions.

Thank you!

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