Morphology Preserving ECG Denoising with TQWT–TV and PSO

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Introduction: Overlapping electromyographic (EMG) interference with the ECG spectrum during acquisition remains challenging. State-of-the-art multiresolution analysis techniques, including DWT, EMD, and VMD, typically rely on fixed parameters or thresholds, which limit their ability to suppress EMG noise without morphological distortion. **Methodology**: We propose a Particle Swarm Optimization (PSO)-tuned, sub-band-adaptive total variation (TV) denoiser in the Tunable Q-factor Wavelet Transform (TQWT) domain to attenuate EMG while preserving clinically relevant ECG morphology. Performance depends critically on the smoothing parameters; fixed settings are ineffective across sub-bands that contain noise with varying characteristics. The proposed method addresses these limitations while preserving ECG features. The noisy signal is decomposed into sub-bands containing different frequency components. Instead of using fixed thresholds, adaptive TV is applied to each sub-band, with optimal parameters selected automatically using PSO. The proposed approach is tested using an ECG database containing signals contaminated with real EMG noise (110 pairs of ECG recordings from 14 patients with Fs=500Hz). Metrics include MSE, SNR improvement, CC, and PRD, which are used for evaluation. **Results**: Significant improvements are achieved across related approaches: a 8.07% improvement in SNRimp over the Hybrid Adaptive ECG Denoising method (HAED, 2025), 10.37% over the iterative regeneration method (IRM, 2024), 17.99% over the Adaptive Wavelet Wiener Filter (AWWF,2012). Across all ECG recordings, mean CC was 0.981 (median 0.988), and median PRD was 0.158, indicating strong performance. **Conclusion**: Overall, the proposed approach achieved efficient performance in removing real-world EMG noise while preserving ECG morphology.

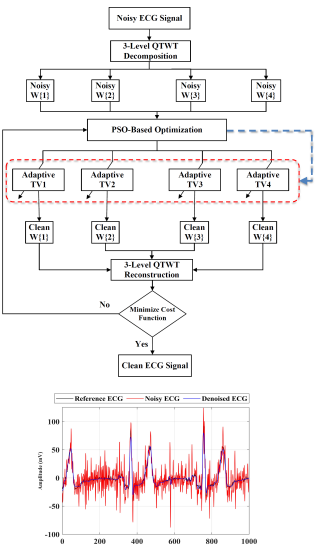

Fig. 1. Flowchart of the Proposed ECG Denoising Method.

SNRin	SNRimp		
	IRM (2024)	HAED (2025)	Proposed Method
< 4	10.31	10.37	**10.5**
4 – 8	10	**10.05**	9.74
8 – 12	7	5.87	**7.13**
12 – 16	5.17	4.52	**5.41**
16 – 20	3.36	3.38	**4.59**
> 20	1.32	1.97	**2.79**

Table 1: Comparative Performance Analysis