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COMPARATIVE ANALYSIS OF DIGITAL FILTERS FOR ELECTROGASTROGRAPHY (EGG) SIGNAL PREPROCESSING

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ABSTRACT: *This paper presents a comparative analysis of three digital bandpass filters—Butterworth, Chebyshev Type I, and FIR Hamming window—for enhancing electrogastrography (EGG) signal preprocessing. EGG signals are severely compromised by physiological interference (~0.25 Hz respiration, ~1 Hz cardiac activity) and motion artifacts in the ultra-low-frequency band (0.015–0.15 Hz). Using synthetic EGG signals, filter performance is quantified using signal-to-noise ratio (SNR) improvement. Results demonstrate that FIR Hamming achieves the highest SNR improvement (+16.88 dB), while Butterworth produces the smoothest temporal output suitable for clinical interpretation, and Chebyshev Type I offers optimal computational efficiency. These findings provide practical guidance for filter selection based on clinical diagnostic and machine learning requirements.*

KEYWORDS: *Electrogastrography, digital filters, Butterworth filter, Chebyshev Type I filter, FIR filter, signal preprocessing, signal-to-noise ratio (SNR), biomedical signal processing, noise suppression, gastric slow wave preprocessing.*

INTRODUCTION

Electrogastrography (EGG) is a non-invasive biomedical technique for recording and analyzing gastric electrical activity, which reflects the mechanical function of the stomach. EGG signals are characterized by ultra-low frequency content (0.015–0.15 Hz) and are often contaminated by physiological interference including respiration (~0.25 Hz), electrocardiographic activity (~1 Hz), and muscle noise, as well as motion artifacts. The extremely low amplitude of EGG signals (10–500 μV) makes effective noise suppression essential for reliable signal preprocessing.

Digital filtering is fundamental to EGG preprocessing and serves as the foundation for accurate feature extraction and subsequent machine learning applications. The selection of an appropriate filter design directly impacts the quality of downstream analysis and

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diagnostic accuracy. This study presents a comparative evaluation of three widely-used bandpass filter designs—Butterworth, Chebyshev Type I, and FIR Hamming window—to assess their effectiveness in EGG signal preprocessing. Using synthetic signals with realistic noise characteristics, we quantify filter performance using signal-to-noise ratio improvement as the primary metric. This comparative analysis provides practical guidance for selecting optimal filter designs based on specific application requirements.

II. Materials and Methods

A. Synthetic EGG Signal Generation

To enable controlled and reproducible evaluation of digital filters without relying on noisy and heterogeneous clinical data, we constructed a synthetic EGG signal approximating typical characteristics of gastric surface recordings. The clean gastric slow-wave component was modeled as a sinusoidal signal with fundamental frequency $f_g = 0.05$ Hz (3 cpm), falling within the normal EGG range. We superimposed two deterministic sinusoidal interference signals: respiration at $f_r =$

0.25 Hz (~15 breaths per minute) and cardiac

activity at $f_c = 1$ Hz (60 beats per minute). Zero-mean white Gaussian noise was added to create realistic SNR conditions. The composite signal x(t) can be expressed as:

$$x(t) = A_g \sin(2\pi f_g t) + A_r \sin(2\pi f_r t) + A_c \sin(2\pi f_c t) + n(t)$$

where A_g, A_r, A_c are amplitudes and n(t) is additive white Gaussian noise. The sampling frequency was set to $f_s = 10$ Hz, providing adequate resolution for the 0–1.5 Hz band of interest, with signal duration of 600 s.

B. Filter Designs

Three bandpass filters were designed to preserve the 0.015–0.15 Hz band:

1. Butterworth (4th order): Maximally flat passband magnitude response
2. Chebyshev Type I (4th order, 1 dB ripple): Steeper roll-off than Butterworth
3. FIR Hamming (201 taps): Linear-phase design with narrow transition band

C. Performance Metrics

Signal-to-noise ratio improvement was computed as the primary performance metric:

$$\Delta SNR = SNR_{after} - SNR_{before}$$

III. Results

The simulation results demonstrating SNR improvement across all three filter types are summarized in Table I. The baseline SNR before filtering was approximately -9.72 dB, reflecting a realistic scenario where noise power exceeds signal power. After applying each filter, we observed the following SNR values and improvements:

TABLE I. SNR IMPROVEMENT FOR EACH FILTER

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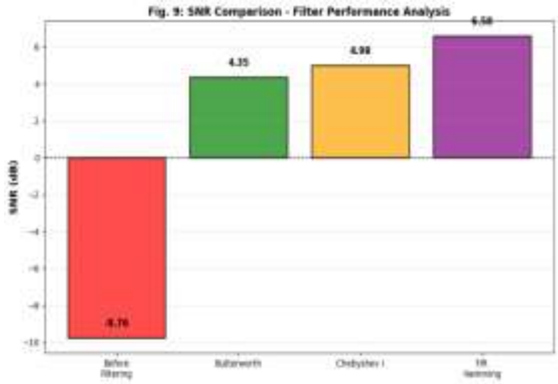

The FIR filter achieved the highest SNR improvement of +16.88 dB, while the Butterworth and Chebyshev filters provided +13.07 dB and +12.96 dB, respectively. This ranking reflects the superior frequency selectivity of the high-order FIR design and the steeper roll-off of the Figures 1-4 present the time-domain waveforms and frequency-domain spectra illustrating these results.

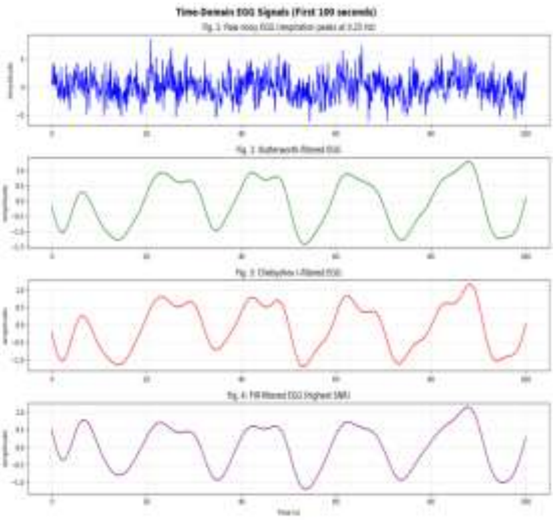

Fig. 2. Butterworth filter output showing smooth time-domain waveforms with SNR improvement of +4.35 dB.

Chebyshev filter compared to Butterworth. Frequency-domain analysis revealed effective attenuation of respiratory (0.25 Hz) and cardiac (1 Hz) components for all filters, with the FIR filter providing the strongest suppression.

IV. **DISCUSSION**

This comparative simulation study demonstrates that classical digital bandpass filters can effectively preprocess EGG signals by isolating the gastric slow wave and suppressing dominant physiological and broadband noise sources. All three filter designs tested yielded substantial SNR improvements in the range of +12.96 to +16.88 dB, enabling clearer visualization and more reliable quantitative analysis of the gastric rhythm.

From a quantitative perspective, the FIR filter with Hamming window provided the largest SNR improvement,

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reflecting its superior frequency selectivity and narrow transition band. The linear-phase property of FIR filters ensures minimal waveform distortion, a significant advantage when phase-based features or morphological indices are extracted. However, the 201-tap filter length increases computational load and introduces latency, which may be limiting in resource-constrained devices or strict real-time applications.

The Chebyshev Type I filter represents an efficient compromise, achieving strong noise suppression at 4th order by trading controlled passband ripple for steeper transition bands. This design may be preferred for implementations where computational efficiency and near-real-time processing are prioritized.

The Butterworth filter, while achieving the smallest SNR improvement among the three, produces the smoothest time-domain output. This property can be valuable for clinical visual inspection, where smooth waveform representation aids diagnostic interpretation [2][3].

Future work should validate these preprocessing methods using real clinical EGG recordings and integrate them with machine learning pipelines for automated gastric motility classification [4][5].

V. CONCLUSION

This study presented a systematic comparison of three digital filters—4th-order Butterworth, 4th-order Chebyshev Type I, and 201-tap Hamming-windowed FIR—for preprocessing electrogastrography signals in the ultra-low-frequency band (0.015–0.15 Hz). Using synthetic EGG signals with realistic noise and interference characteristics, we quantitatively evaluated filter performance using signal-to-noise ratio as the primary metric. The FIR filter yielded the highest SNR improvement (+16.88 dB), followed by Chebyshev (+12.96 dB) and Butterworth (+13.07 dB), while also producing smooth, artifact-free waveforms suitable for both automated analysis and clinical interpretation.

These findings establish a reproducible baseline for EGG preprocessing and provide practical guidance for selecting appropriate filter designs based on specific application requirements: FIR filters for maximum SNR improvement in offline analysis, Chebyshev for balanced performance, and Butterworth for smooth visual representation and real-time systems with limited computational resources.

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APPENDIX A: IMPLEMENTATION DETAILS

The EGG filtering pipeline can be summarized as follows:

1. Signal Generation
   - Gastric (0.05 Hz) + Respiration (0.25 Hz) + Cardiac (1 Hz) + Gaussian noise
   - Sampling: 10 Hz, Duration: 600 seconds
2. Filter Design
   - Butterworth (4th order): scipy.signal.butter()
   - Chebyshev I (4th order, 1 dB ripple): scipy.signal.cheby1()
   - FIR Hamming (201 taps): scipy.signal.firwin()
3. Filtering
   - Apply zero-phase filtfilt() to avoid phase distortion
   - Passband: 0.015–0.15 Hz (normogastria and harmonics)
4. Performance Analysis
   - Compute SNR = 10*log10(P_signal / P_noise)
   - Extract frequency response at 0.05, 0.25, 1.0 Hz
   - Generate time/frequency-domain plots

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5. Results Export
   - CSV table with SNR metrics
   - PNG figures for publication

Completecode:
https://colab.research.google.com/drive/1rURgQUnHJtHFby8yk3hCOxOhX-IgIrQ5?usp=sharing