



INTISARI

Penyakit kardiovaskular merupakan penyebab utama kematian global, menyoroti pentingnya pemantauan detak jantung (*heart-rate*, HR) secara kontinu untuk deteksi dini. Sistem tertanam (*embedded system*) berbasis Elektrokardiogram (ECG) menawarkan solusi portabel untuk pemantauan ini, namun kinerjanya sangat rentan terhadap derau, terutama artefak *baseline wander* frekuensi rendah. Penelitian ini bertujuan untuk mengevaluasi dan membandingkan secara komparatif kinerja tiga metode *digital High-Pass Filter* (HPF), yaitu *Finite Impulse Response* (FIR) berbasis jendela Blackman (dipilih sebagai representasi metode FIR), *Infinite Impulse Response* (IIR) Butterworth, dan *Moving Average* (MA) untuk eliminasi *baseline wander* secara *real-time*. Ketiga metode diimplementasikan pada mikrokontroler ESP32 yang terhubung dengan sensor EKG AD8232 dan diuji pada enam skenario sinyal EKG, termasuk sinyal stabil dan aritmia non-stasioner. Kinerja dievaluasi berdasarkan kualitas sinyal, akurasi estimasi BPM (diukur dengan *Mean Absolute Error*), dan latensi pemrosesan. Hasil penelitian menunjukkan bahwa filter HPF FIR Blackman mencapai presisi spektral tinggi pada sinyal stabil, namun memiliki latensi pemrosesan yang lebih tinggi (32–56 ms) dan akurasi yang menurun pada kasus *Atrial Fibrillation*. Filter IIR Butterworth menunjukkan kinerja yang paling tidak stabil, dengan MAE melonjak hingga 22,37 BPM pada skenario *Sinus Arrhythmia* akibat distorsi fasa. Sebaliknya, metode *Moving Average* secara konsisten memberikan keseimbangan terbaik, dengan akurasi yang superior pada sinyal patologis (MAE serendah 0.30 BPM pada kasus PVC), latensi yang sangat rendah (6–8 ms), dan beban komputasi paling ringan. Kesimpulan dari penelitian ini adalah metode HPF berbasis *Moving Average* merupakan solusi paling optimal untuk aplikasi pemantauan EKG pada arsitektur sistem tertanam sederhana yang dipilih dalam penelitian ini, karena menawarkan kompromi terbaik antara robustisitas, akurasi fungsional, dan efisiensi sumber daya.

Kata kunci: elektrokardiogram (EKG), estimasi *heart-rate*, sistem tertanam, *digital filtering*, *baseline wander*.



ABSTRACT

Cardiovascular disease is the leading cause of global mortality, highlighting the importance of continuous heart-rate (HR) monitoring for early detection. Electrocardiography (ECG)-based embedded systems offer a portable solution for such monitoring, yet their performance is highly susceptible to noise, particularly low-frequency baseline wander artifacts. This research aims to evaluate and comparatively analyze the performance of three digital High-Pass Filter (HPF) methods, a Finite Impulse Response (FIR) filter using the Blackman window (selected as the representative FIR method), an Infinite Impulse Response (IIR) Butterworth filter, and a Moving Average (MA) filter. All of these methods are applied for real-time baseline wander removal. The three methods were implemented on an ESP32 microcontroller interfaced with an AD8232 ECG sensor and tested across six distinct ECG signal scenarios, including stable signals and non-stationary arrhythmias. Performance was evaluated based on signal quality, BPM estimation accuracy (measured by Mean Absolute Error), and processing latency. The results demonstrate that the HPF FIR Blackman filter achieves high spectral precision and accuracy on stable signals but incurs higher processing latency (32–56 ms) and reduced accuracy in Atrial Fibrillation scenarios due to spectral transparency to f-waves. The IIR Butterworth filter exhibited significant instability, with its MAE escalating to 22.37 BPM in the Sinus Arrhythmia scenario due to phase distortion. Conversely, the Moving Average method consistently provided the best overall balance, demonstrating superior accuracy in pathological signals (MAE as low as 0.30 BPM in PVCs), minimal latency (6–8 ms), and the lightest computational load. This study concludes that the HPF Moving Average method is the most optimal solution for simple, low-resource embedded ECG monitoring applications, as it offers the best trade-off between robustness, functional accuracy, and resource efficiency.

Keywords: Electrocardiogram (ECG), heart-rate estimation, embedded system, digital filtering, baseline wander.