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Original article

Digital fractional order differentiation-based algorithm for P and T-waves detection and delineation

Algorithme basé sur la dérivation d'ordre fractionnaire pour la détection et la segmentation des ondes P et T de l'électrocardiogramme

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Abstract

The paper presents a new algorithm based on digital fractional order differentiation for P and T-waves detection and delineation. It is simple to implement and performs in one step high frequency noise filtering and differentiation. The characteristics of the resulting filter depend only on two parameters: the fractional negative order (fractional integration) and the filter order. Tests of the algorithm on ECG signals taken from the Massachusetts Institute Of Technology/Beth Israel Hospital (MIT/BIH) database prove its capability to detect and delineate P-waves and T-waves in noisy ECG as well as low amplitude P-wave and inverted T-wave.

Résumé

Dans cet article, nous présentons un nouvel algorithme fondé sur la dérivation d'ordre fractionnaire pour la détection et la segmentation des ondes P et T. C'est une méthode simple à appliquer utilisant un filtrage du bruit haute fréquence et une dérivation du signal. Les caractéristiques du filtre résultant dépendent seulement de deux paramètres : l'ordre négatif fractionnaire (l'intégration fractionnaire) et l'ordre du filtre. La méthode originale testée sur des signaux de la base de donnée MIT/BIH a montré sa capacité à détecter et segmenter les ondes P et T dans le cas des signaux ECG bruités, de faible amplitude P et présentant des ondes inversées.

Keywords: Electrocardiogram; P-wave; T-wave; Waves detection; Delineation; Fractional order differentiation

Mots clés : ECG ; L'onde P ; L'onde T ; Détection des ondes ; Segmentation ; Dérivation non entière

1. Introduction

The amplitude and interval measurements used in automated electrocardiogram (ECG) analysis require accurate detection and delineation of the ECG waves (P-wave, QRS complex and T-wave). Reliable P-wave and T-wave detection is more difficult than the QRS complex detection for several reasons including low amplitudes, low signal-to-noise ratios, amplitude and morphology variability and possible overlapping of the P-wave with the T-wave or the QRS complex. The P-wave may be even absent from some ECG's traces.

Over the last few years, the P and T-waves detection and delineation problem has been addressed using different

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approaches [1–10] and is still far from being completely resolved. Each developed method has its own advantages and weaknesses. Fractional order differentiation is a mathematical tool possessing interesting proprieties for features extraction from noisy signals. An algorithm based on digital fractional order differentiation has been already applied successfully to QRS complex detection [11,12]. The algorithm presented in this paper is simple to implement and performs in one step high frequency noise filtering and differentiation, that is, it combines a lowpass filter for reducing EMG noise, 50 or 60 Hz power interference, ... with a highpass filter for eliminating baseline deviation and enhancing slopes. The filter characteristics depend only on two parameters: the fractional negative order (fractional integration) and the filter order. The both parameters were adjusted according the ECG spectra analysis [13]. Tests of the algorithm on ECG signals taken from the Massachusetts Institute Of Technology/Beth Israel Hospital (MIT/BIH) database prove its capability to detect P-waves and T-waves in noisy ECG. Low amplitude P-wave and inverted T-wave were also successfully detected and delineated.

2. Digital fractional order differentiation-based lowpass differentiator

2.1. Design

The filter considered in this paper for detecting P and T-waves is a lowpass differentiator since it performs in one step lowpass filtering and differentiation. Its output is the difference of forward and backward truncated temporal fractional integral. Fig. 1 shows the block diagram of this filter. The backward time fractional integral and forward time fractional integral are respectively given by [14]

$$y_b(k)=\frac{1}{(Ts)^n}\sum_{i=0}^{\infty} a_i x(k-i) \tag{1}$$

$$y_f(k)=\frac{1}{(Ts)^n}\sum_{i=0}^{\infty} a_i x(k+i) \tag{2}$$

where x(k) are the samples of the ECG signal sampled with period T_s, n is the negative fractional order of integration and a_i are binomial coefficient which are given by

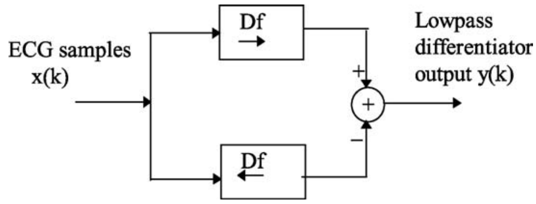

Fig. 1. Lowpass differentiator block diagram. Top path : forward time fractional derivative. Bottom path : backward time fractional derivative.

$$a_0=1 \ and \ a_i=\frac{i-n-1}{i}a_{i-1},\ i = 1,2,3,... \tag{3}$$

The lowpass differentiator output can be written as follows

$$y(k)=\sum_{i=-\infty}^{\infty} h(i)x(k-i) \tag{4}$$

with

$$h(i)=\begin{cases} -\dfrac{a_i}{(Ts)^n}, & i=1,2,\ldots_2 \\ 0, & i = 0 \end{cases} \tag{5}$$

and

$$h(-i)=-h(i) \tag{6}$$

The sequence h(i) can be considered as the discrete-time non causal antisymmetric impulse response of the system. We truncate the sequence h(i) between - (M-1)/2 and (M-1)/2, where M is an odd integer. Under these circumstances we obtain a FIR filter whose frequency response is given by

$$H_M(jf)=2j\sum_{i=1}^{(M-1)/2} h(i)\sin(2\pi fiTs) \tag{7}$$

The frequency corresponding to the maximum amplitude (central frequency) and the bandwidth are dependent of the parameters M and n.

2.2. Implementation

We have exploited the recursion property of the binomial coefficients to avoid their explicit calculation. The lowpass differentiator response is then written as follows

$$y(k)=\frac{1}{(Ts)^n}\left\{-n\left\{u(k-1)+\frac{1-n}{2}\left\{u(k-2)+\ldots+\frac{(M-5)/2-n}{(M-3)/2}\left\{u\left(k+1-\frac{M-1}{2}\right)+\frac{(M-1)/2-n-1}{(M-1)/2}u\left(k-\frac{M-1}{2}\right)\right\}\ldots\right\}\right\}\right\} \tag{11}$$