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A New Concept of Filters for Biomedical Data Processing Needs

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This paper presents a new class of filters that can meet biomedical signal processing needs. The paper is written in a technical note style, therefore, the proposed filters are not discussed with respect to a specific problem appearing in processing of a particular biosignal. The class of filters presented in this note should be treated as a new effective tool which can be applied to many cases of biomedical signals, especially when the processing time is very important. Nevertheless, a simple example of biomedical signal filtering is presented. This paper presents a new concept of continuous-time Butterworth filters whose parameters are varied in time. Thanks to the variation of the filter parameters, the time-varying filter response is considerably faster in comparison with the traditional time-invariant filters. Therefore, we can measure and register a lot of details in the initial stage of signal duration, which is not possible in the case of traditional time-invariant filters due to their long-lasting transients. Results verifying the effectiveness of the proposed filters are presented and compared to the traditional time-invariant filter structures.

Keywords: signal processing, data smoothing, biomedical signals, transient state, time-varying systems

1. Introduction

In [1] Robertson et al. present some investigations over traditional Butterworth and critically damped filters. The review of traditional filters, which has been carried out in this paper is very useful. However, the advantages and disadvantages of these filters are well known, and their description was reported by Chen [2], Schaumann et al. [3], and Su [4]. Nowadays, there is a need for looking for a new filter structure which will be able to work as fast as possible. The most common filter responses are the Butterworth, Chebyshev, elliptic, and Bessel-Thomson types.

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The Butterworth filters are often chosen for smoothing biomedical data because their gain response is maximally flat in the passband, and the roll-off rate is at adequate level. In the time domain, the Butterworth low-pass filters are characterized by undesirable overshoots and quite long transients. The magnitude response of the low-pass Butterworth filter can be written as follows:

$$\left|H_F(j\omega)\right|^2 = \frac{h_0}{1+\left(\dfrac{\omega}{\omega_c}\right)^{2n}} \tag{1}$$

where n is the filter order, h_0 is the DC gain (gain at zero frequency), and ω_c is the 3 dB limit frequency.

In many cases of biomedical signal analysis, there is a need for a data filtering. One of the main aims of the filtering is to smooth the data as fast as possible. This requirement is related to improvement of the filter properties in the time domain. The problem of improving the transient performance has been considered by Kaszynski et al. [5] to successfully reduce the time of processing of the brain average-evoked potentials.

The commonly used smoothing filters are, in many cases, useless due to their long-lasting transients and undesirable overshoots. For traditional time-invariant filters there are only small possibilities of transient reduction, since the filter parameters are calculated on the basis of the assumed approximation method. This fact guarantees that the frequency requirements are satisfied without taking into consideration the characteristic of the transient state. If the requirements on the frequency characteristic are imposed, we can slightly influence the shortening of the transient state duration of the n-th order filter by choosing different approximation methods. The uncertainty principle states that it is not possible to achieve a shorter rise time of a low-pass filter output signal when the filter passband is constant. However, one can obtain significant changes of the transient state duration by variation of the filter passband. This procedure is related to the change of the value of filter coefficients. Such a kind of technique has been used in success by Piskorowski et al. [6] for elimination of undesirable effects of the group delay compensation. The theory of linear time-varying continuous-time systems is well established and was widely described by Claasen et al. [7], Margrave [8], and Zadeh [9,10].

In this note, a new concept of the Butterworth filters whose parameters are varied in time is presented. Thanks to variation of the filter parameters, the time-varying filter response is considerably faster and free from overshoots in comparison with the traditional time-invariant filters. The outline of the paper is as follows.

In Section 2, the mathematical formulation of the time-varying low-pass filter is presented. Section 3 then presents the results of simulations carried out with the aid of Matlab-Simulink software. The conclusions are presented in Section 4.