Filtering Techniques for Ventricular Late Potentials Analysis

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Abstract- **This work presents a comparative study of filtering techniques for ventricular late potentials (VLP) analysis. We compare linear-phase FIR and IIR filters, with bidirectional nonlinear-phase IIR filters (IIR-BF). The comparison is done in terms of the recovered VLP signal energy at the output of the different filters, using a simulated QRS complex with added VLP as input signal. The comparison shows that the IIR-BF are the filters that best performe. This behaviour is due to the nonlinear phase of the IIR-BF and to the temporal distribution of VLP with respect to the QRS complex. Group delay at QRS frequencies is higher than at VLP ones. It produces a temporal separation of these signals that makes the IIR-BF the more suitable filters for VLP analysis.**

I. INTRODUCTION

High resolution electrocardiography (HRECG) is the technique for recording low-amplitude and high-frequency cardiac waveforms, not available with standard electrocardiography [1]. Among the most important applications of the HRECG is the detection and quantification of ventricular late potentials (VLP) in the terminal QRS complex. VLP analysis is of great clinical interest, since it provides information for identifying patients at risk of ventricular tachycardia after myocardial infarction [2].

During the last fifteen years many studies about VLP analysis have been published, and recently there appear several commercial systems for HRECG. Nevertheless different criteria have been used for recording, processing and defining the VLP. Therefore, it is not always possible to compare the results of these studies, due to their differences.

Most recently a Task Force Committe between the European Society of Cardiology, the American Heart Association and the American College of Cardiology has establish standards for data acquisition and analysis of VLP [3]. The Committee has collected the technical considerations that have obtained a consensus, and it has recognized several areas that need subsequent studies before standards can be defined.

With regard to the digital filters employed in time-domain analysis of VLP, the Committee recognizes that most studies have employed the so-called Bidirectional Filter (BF) [4] with a high-pass cut-off frequency of 25 or 40 Hz. Nevertheless, it considers that other filters or other cut-off frequencies may improve the detection of VLP. Therefore this technical aspect is still open to improve the VLP analysis.

In this work we study finite impulse response (FIR) and infinite impulse response (IIR) filters, including BF, for time-domain VLP analysis. In particular, we compare the time response, magnitude and phase response, and the group delay of each filter. Their effect in the VLP filtering is studied by means of the output signal energy of each filter to a simulated HRECG record input.

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II. FILTERING TECHNIQUES

In general, a specially desirable characteristic of digital filters for biomedical signals is linear-phase response. The influence of phase shifts can be important in the determination of the waveforms and in temporal measurements on the filtered signal.

FIR filters can be easily designed to have linear-phase, because are all-zero filters. On the contrary, causal and stable IIR filters can not achieve linear phase, except for the special case where all the poles are on the unit circle at the z-plane. IIR filters are more efficient than linear-phase FIR filters for a given amplitude response specification, with regard to computational complexity. Thus, for the particular case of time-domain processing of VLP, where the filtering can be done off-line, noncausal IIR filters with zero phase could also be considered. These filters are based on multipass IIR filters and time reversal [5].

The aim of this work is to analyse the performance of FIR and IIR filters regarding the statement by the Task Force Committee [3]. The frequency components of VLP and their location at the terminal QRS complex require special characteristics of the filters. Thus, we consider the following high-pass filters with a cut-off frequency of 40 Hz:

1. Noncausal zero-phase FIR filters of 128 coefficients designed by: a) Hamming window method (WFIR), and b) optimum approximation (Chebyshev) (OFIR).

2. IIR filters designed from 4-pole analog filters, using the bilinear transformation: a) Butterworth (BIIR), b) Chebyshev (CIIR), and c) Elliptic (EIIR). These filters are implemented in three different modes:

   - Forward in time filter (FF). It is a causal and nonlinear-phase filter.
   - Bidirectional mode filter (BF). It is a nonlinear-phase filter that works in a forward mode during the first 40 ms of the QRS complex and then it is reset and processes the signal backward in time up the same point [4].
   - Two-pass filter (TPF) in cascade with time reversal [5]. It is a noncausal zero-phase filter.

III. SIMULATION STUDY

In order to evaluate the performance of the filters, a test signal (x_k) was generated to simulate a QRS complex. A triangle signal was selected with a duration of 100 ms and an amplitude of 2 mV_{pp}, sampled at 1000 Hz. At the end of this artificial QRS a sinusoidal pulse of 80 Hz was added with a duration of 60 ms and amplitude of $2\mu V_{pp}$, to simulate VLP activity (Fig. 1).

Applying the filters to the test signal (x_k) quoted in the previous section, we obtain different output signals y_k (Fig. 2) . These differences have been evaluated by means of cumulative signal energy

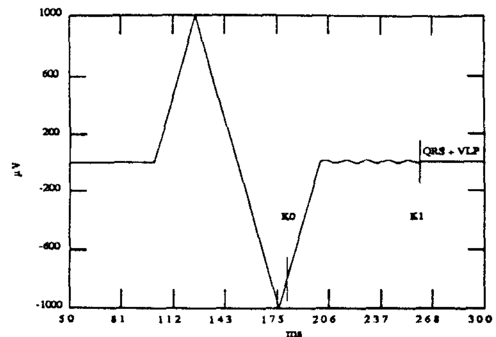

Figure 1: Original QRS + VLP

($SE(N) = \sum_{n=0}^{N} y^2_{k_1-n}$, where $N = 0, k_1 - k_0$), measured in backward direction from the end of VLP (k_1) to 20 ms before the end of QRS (k_0). These values were compared with the SE of VLP before the filtering (Fig. 3).

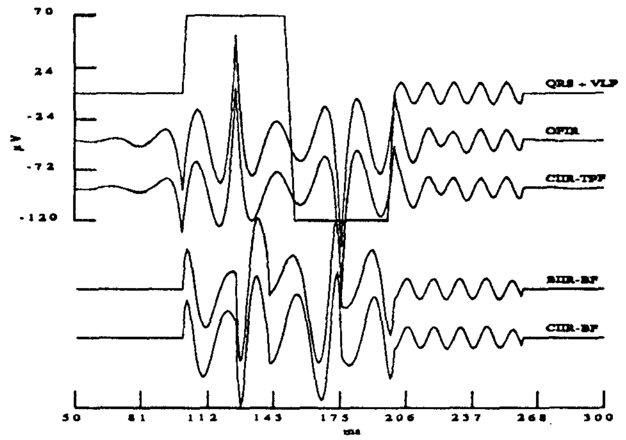

Figure 2: Original and filtered output signals for different filters

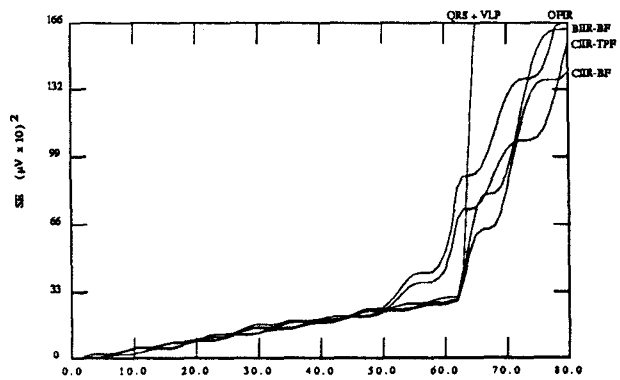

Figure 3: Signal energy SE(N)

IIR filters implemented forward in time (IIR-FF) shown to be not appropriated for VLP analysis, because their non linear-phase and non constant group delay (Fig. 4) produce a shift of filtered components of QRS to VLP location. Then, a correct analysis of VLP at the end of the QRS is not possible.

Zero-phase filters (FIR and IIR-TPF) improve this problem, since phase distortions are not introduced. But a time overlapping of the QRS and VLP are still obtained, after the filtering (Fig. 2). The amplitude ratio of these signals, their close location, and their near frequency components cause that the convolution of the impulse response with the QRS signal hides the initial part of filtered VLP.

For the specific characteristics of VLP and QRS complex, IIR filters implemented backward in time, including the special case of the bidirectional filter (BF), achieve the best results (Fig. 2 and 3).

We see that effectively the SE at the IIR-BF output is the one that recovers the true original SE of VLP during more time. Then it allows to recover VLP activity more close to the QRS complex than with the other filter structures. It is due to a priori non desirable characteristic of the filter, such as a highly non constant group delay, that provides a time separation of the filtered QRS and VLP. These characteristics can be seen in Fig. 4, where the amplitude and group delay of the IIR filters are shown as well as the signal spectrum.

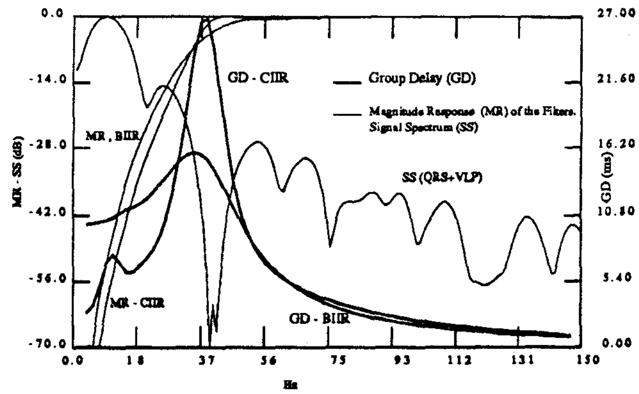

Figure 4: QRS+VLP spectrum, magnitude response and group delay of BIIR-BF and CIIR-BF

IV. CONCLUSION

The particular time and frequency characteristics of the VLP cause that the linear-phase filters are not the best choice to filter VLP. An analysis of the signal energy at the filter output has shown that the effect of a highly non constant group delay permits a more appropriate analysis of the cardiac activity at the end of QRS (IIR-BF filter).

In these filters the QRS frequency components have a group delay higher than the VLP components. Thus, the filter separates in time VLP from remaining QRS complex, given that the temporal distribution of VLP at the end of the QRS. Further studies to design filters optimizing this property would be desirables.

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