ECG SIGNAL FILTERING USING VIRTUAL INSTRUMENTATION

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Abstract: Interferences' assessment during medical investigations and the way that these can be removed, represents an important issue in medical equipment design; without solving this problem, the equipment cannot accomplish the producer's specifications. Thus, we considered approaching the subject from the Virtual Instrumentation point of view, because it brings a great advantage during the fabrication process: modeling, analysis, simulation and testing phases are not separated any more.

The present paper aims to solve the problem of cleaning the ECG signal by noise filtering. Both ECG and noises have been generated and added using LabVIEW. Subsequently, the noises were filtered using different filter types provided by the LabVIEW platform.

Introduction

Throughout the fabrication process of a system with complex architecture, the simulation phase is very important because it allows to verify the algorithms and models in order to eliminate design errors; the results thus obtained also allow to evaluate system's performances, before even it was physically realized. The economical advantage has to be also taken into consideration because through simulation, the testing costs can be reduced and the time required to develop the product decreases also. [1]

The concept of "Virtual Instrumentation" appeared with the idea to combine the programmable instrument with the standard PC; thus, in the new generation of instruments, the functionality is defined by the user and not by the producer. [7]

The basic principle of VI is the separation of the three measuring functions - acquisition, processing and presentation. Some of these functions are supported by software (programs running on a PC) but it also needs a hardware interface added to the PC in order to ensure the interaction between the VI and the measured object. [7]

Thus, the virtual instrument is the software and/or hardware interface added to a PC so that the user can interact with the quantity to be measured, in a simple manner, as if it is working with traditional, classic instrument.

Mathematical generation of a ECG signal

To this purpose we used the mathematical model described in [6], which generates a spatial (tridimensional) history of (x,y,z) coordinates.

The qvasiperiodicity of the resulted ECG signal is reflected in the modification of the trajectory around a limit circle in the (x,y) plane. Each revolution in this circle corresponds to a R-R heart beat interval.

The variation in between the heartbeats is reproduced through the movement in "z" direction. The characteristic points of the ECG cycle, like P, Q, R, S and T are described by events that correspond to a maxim or minim in "z" direction. These events are placed at fix angles around the limit circle and are given by the angles θ_P, θ_Q, θ_R, θ_S, and θ_T. When the trajectory approaches one of these events, it is pushed up or down from the limit circle and then returns towards it [6].

The set of differential equations that simulates the ECG signal are described, as follows [6]:

$$\dot{x} = \alpha x - \omega y$$
$$\dot{y} = \alpha y + \omega x$$
$$\dot{z} = -\sum_{i \in \{P,Q,R,S,T\}} [a_i \Delta\theta_i e^{-\frac{\Delta\theta_i^2}{2b_i^2}} - (z - z_0)] \qquad (1)$$

where : $\alpha = 1 - \sqrt{x^2 + y^2}$
$\Delta\theta_i = (\theta - \theta_i) \bmod 2\pi$
$\theta = \mathrm{atan2}(y, x)$
ω = the angular velocity of a point on the trajectory, as it is moving around the limit circle.

By solving this system, the result materializes a PQRST complex shape, similar to that of a real ECG. The result obtained after processing the data in MatLab, is presented in the following figure:

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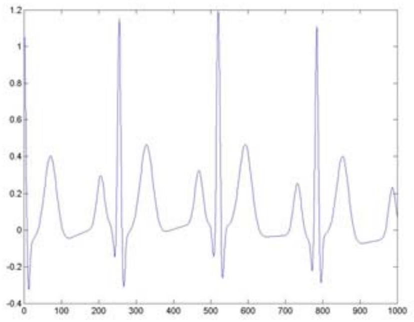

Figure 1: Succession of EKG complexes obtained through mathematical generation

In this mathematical model of generating ECG complexes, the R-R interval (the interval between two cardiac consecutive cycles) represents the time required to complete a entire lap around the limit circle. The variation of R-R intervals can be obtained by modifying the angular velocity ω. [6]

Noise contamination and filtering of the generated ECG signal

Using the signal generated in Matlab, as described above, we transferred the signal in LabVIEW where it suffered the following set of operations:

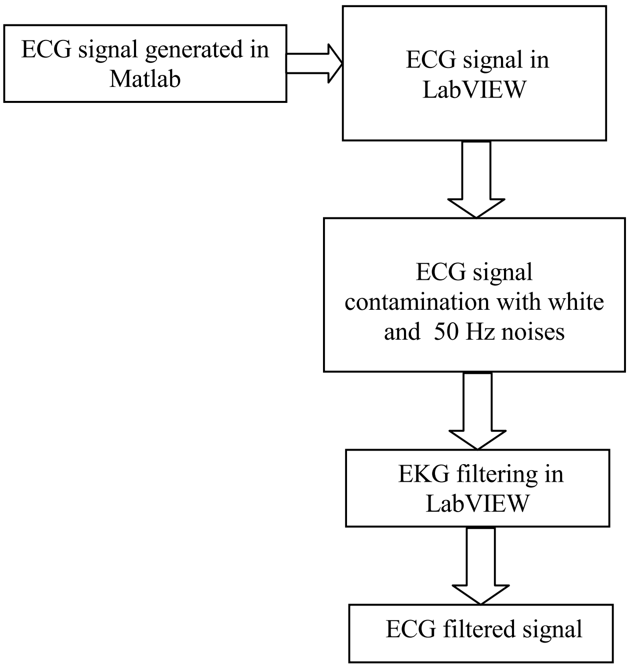

Figure 2 : The schema of the created virtual instrument

The signal thus obtained in LabVIEW is processed, according to fig. 2 [2],[3]:

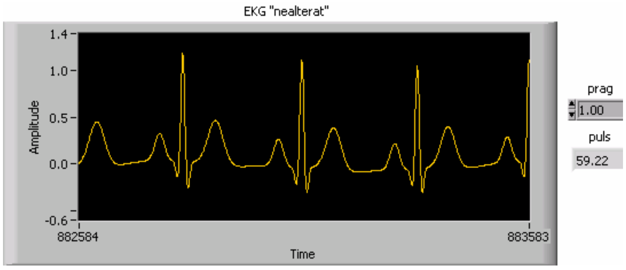

Figure 3: Pure ECG signal and pulse detection

Biomedical signals are used to extract useful information from the investigated biological signals. In practice, the simple measurement of the signal is not sufficient, being necessary to process it using specific algorithms to obtain the useful information. Thus, in order to apply the best algorithm, it is recommended to know some aspects concerning the investigated signal [8]:

- The purpose of the processing (filtering for example)
- The conditions in which the test (signal acquisition) was made
- The characteristics of the signal

In practice, some interferences (noises) can be avoided, others cannot; among the noises that often contaminate the ECG signal, we have considered the white noise and the 50 Hz [8]. The amplitude of the noises was 10% of the original signal's amplitude.

Results

The new signal, with the two noises already added, and its spectrum have to look as in the next figures:

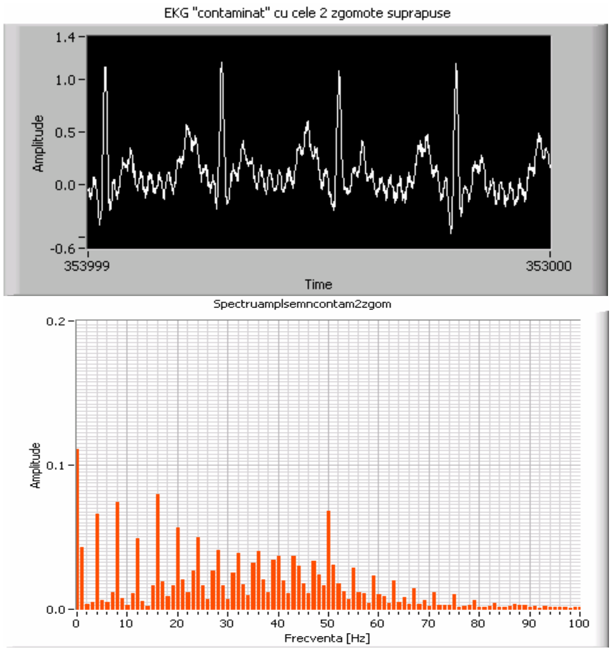

Figure 4: ECG signal affected by white noises; note the additional component given by the 50 Hz noise.

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Within the filtering processes, we considered Butterworth, Cebyshev, Eliptic and Bessel filters, to observe which of then suits better. The tests showed that Butterworth filters offer the best filtering for both noises.

Thus, using a Butterworth „band-stop" filter of superior order (8), with the band-stop between 49,9Hz – 50,1Hz, we filtered the 50Hz noise; it results an intermediary signal, contaminated only with the white noise, presented below:

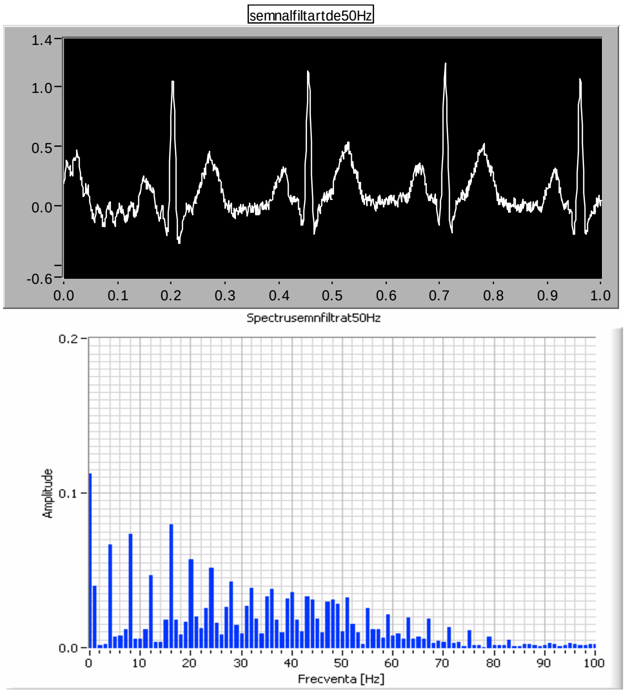

Figure 6: ECG contaminated with white noise (time and frequency domain)

The analises in the frequency domain shows that the 50Hz interference caused by the power suply was eliminated.

Using a Butterworth low-pass filter, the ECG signal was cleaned also by the white noise, as shoed by the following graph:

Figure 8 : Final signal, resulted after the filtering processes

Conclusions

In the process of noise contamination and filtering of the ECG signal we used facilities offered by the virtual instrumentation, simulating thus real situations, which facilitate to know how a real signal will behave when such noises interfere and how to choose the right filter. Then, the flexibility offered by the virtual instrumentation in choosing the parameters of the interference (amplitude, frequency) recommend LabVIEW as a good platform for simulating medical signals' filtering.

The filtering attempt in frequency domain cannot eliminate completely the noise. The difficulty consists in that the noise has a frequency domain theoretically infinite and thus it will continue to exist in the frequency domain where the filter does not work.

The Cebyshev filters require a lower number of parameters than the Butterworth filters, for identical design requirements. Then, this filter introduce ripple in the cut-of domain (for low pass, high pass and band pass filters), respectively in the rejection band for the band-stop filters. Thus, it exists the possibility that the frequency that we want to reject (in this case 50Hz) to be rejected more or less, depending if it finds a min or a max of the ripple. The main objective of the filtering is to attenuate as much as possible the rejection frequency, in the case of Butterworth filters the attenuation being maximal. Of course, in the Butterworth filtering we may have a larger rejection domain than for the Cebyshev filtering, but our simulation shows that for both situation considered (50Hz noise and white noise), the Buterworth filtering is more convenient. [4],[9]

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