# High efficiency processing for reduced amplitude zones detection in the HRECG signal

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**Summary** – This article presents part of a more detailed research proposed in the medium to long term, with the intention of establishing a new philosophy of electrocardiogram surface analysis. This research aims to find indicators of cardiovascular disease in its early stage that may go unnoticed with conventional electrocardiography. This paper reports the development of a software processing which collect some existing techniques and incorporates novel methods for detection of reduced amplitude zones (RAZ) in high resolution electrocardiographic signal (HRECG).The algorithm consists of three stages, an efficient processing for QRS detection, averaging filter using correlation techniques and a step for RAZ detecting. Preliminary results show the efficiency of system and point to incorporation of techniques new using signal analysis with involving 12 leads.

## 1. Introduction

At the present, the cardiovascular diseases are a leading cause of death [1]. One of the most used for the study of cardiac pathologies methods lies in the electrocardiographic assessment [2]. The cardiac signals measurement is a noninvasive technique that is realized capturing the signal with electrodes placed on the skin surface and the information obtained is plotted in a record called electrocardiogram or ECG [3]. Modern studies show the relationship between cardiovascular disease and time intervals in ECG signal elements [4].Relations between the ST and ischemia, QT changes in drugs response, QRS alterations depending on the cardiopathy and other indices, suggest treatment or patient intervention based on the specialist medical evaluation [5 ] [6].

But recent studies have also shown that ECG conventional has limitations. An example is the case of patients with left ventricular wall abnormalities motion and reduced ejection fraction. This situation increases cardiac risk and frequently only is diagnosed when the advanced cardiovascular damage is done. Typical case linked to Chagas disease [7].

The conventional ECG is acquired to display signals with a bandwidth from 0.05 to 120 Hz. For which the digitized signal from 300 to 500 samples per second with 8 bits per sample resolution. This resolution allows an ECG graph with sufficient definition for human viewing, but it is shown that many significant details cannot be captured. A typical signal that goes unnoticed is the late potential at the QRS complex end content [8], see Fig. 1.

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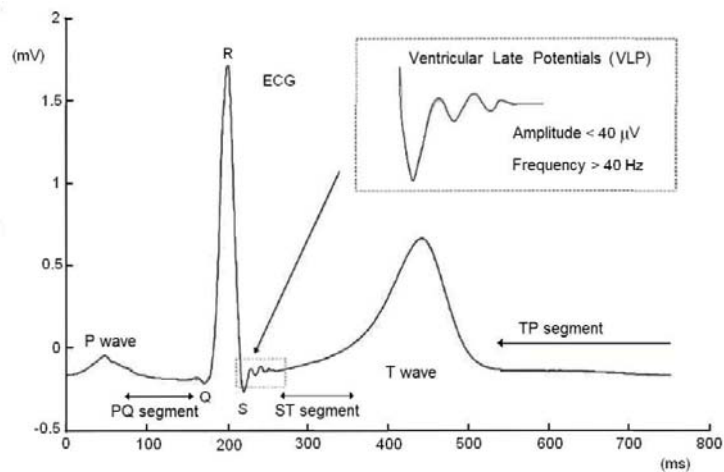
Fig. 1, Ventricular late potentials detection [8].

Some time, with the aim to increase the details of trace, high resolution electrocardiography (HRECG) is used [9]. The HRECG is used to perform the signal acquisition with higher definition and a greater bandwidth when required in conventional electrocardiography. One application of ECGAR allows the detection of myocardial zones affected by some pathology kind. This technique is also known as reduced amplitude zones (RAZ) detection [10] [11]. It involves in high frequency components of QRS complex contained (HF-QRS) analysis, looking for abnormal frequency components decrease in the range of 150 to 250 Hz. The Fig. 2 shows an example of HF-QRS signal averaged and filtered of lead I, at healthy subject.



Fig. 2, HFQRS signal from a healthy patient.

A RAZ occurs when are present two local maxima of the upper envelope or two local minima of the lower envelope at least, in the signal analyzed (originally defined by Abboud [10]), see Fig. 3.



Fig. 3, HFQRS with a RAZ zone of a heart disease patient.

The RAZ testing is a relatively new, non-invasive, economic and feasible technique in real time. However it has not been massively implemented given the complexity and time involved on

processing with this technology. This technique is more accurate than ECG conventional to detect heart disease such as affections of coronary arteries and myocardial ischemia.

Another important feature arises from the 12 leads HRECG simultaneous analysis [12]. Previous data Maehara et al. [13] and Delgado et al. [14] suggest that 12 leads HRECG can be highly sensitive and specific for detecting a cardiomyopathy presence and early manifestations of cardiac damage. Schlegel [15] and other researchers have shown that 12 leads electrocardiography increases notoriously the sensitivity in the detection of diseases caused by coronary artery damage and left ventricular hypertrophy. Schlegel has increased positive predictive value in detecting left ventricular systolic dysfunction.

The high resolution electrocardiogram analysis involving 12 leads would be particularly useful to detect early manifestations of cardiac damage in patients whom otherwise could not be diagnosed. There are few studies associating HD techniques of analysis in a practical system and that in turn can be massively implemented in public health centers. Furthermore, frequently some kind of algorithms and procedures have such complex that they hinder their use by themselves.

Since 2009, the Biomedical Engineering Group (GIBULA) in University of Los Andes (ULA) at Bolivarian Republic of Venezuela together with the Regional Institute for Bioengineering (IRB) of National Technological University (UTN) at Republic Argentina, have generated a series of products with technological innovation in 12 lead HRECG acquisition hardware and software signal analysis.

These research and scientific development aims to achieve a more efficient and easy implementation of systems with the objective of wide spreading their use on massive populations around the world.

This article reports one of the algorithms developed in the framework of a larger project. This algorithm implements techniques for RAZ detection, in efficient software and with friendly features for the operator of the instrument.

## 2. Methodology

The associated work between GIBULA and IRB has developed an electrocardiograph that allows the 12 leads HRECG simultaneous acquisition signal. The project developed under the name DIGICARDIAC [16] [17], is an instrument consisting of a multichannel acquisition hardware with high noise rejection in common-mode and a computer designed software. The system works under an environment designed like an electronic health record (EHR) applied to cardiology [18].

The DIGICARDIAC instrument, besides presenting excellent performance as a tool for clinical diagnosis, allows manipulating the acquisitions for deployment at research field. Additionally, the EHR software is designed with features that allow activating the signal analysis module. This module can incorporate any type of signal analysis application. This is done in order to provide the specialist a more detailed assessment of the clinical examination.

The algorithm aims to bring together some of the criteria set by researchers, in an efficient software that analyzes the signal HRECG looking for RAZ. The Fig. 4 diagram, show the steps of system operation, which they are: heartbeat detection, reducing of baseline bleed by averaging filtering using correlation techniques and the step for RAZ detecting. The developed processing is executed by analyzing a branch at a time, but the research points to the implementation of the 12 leads.
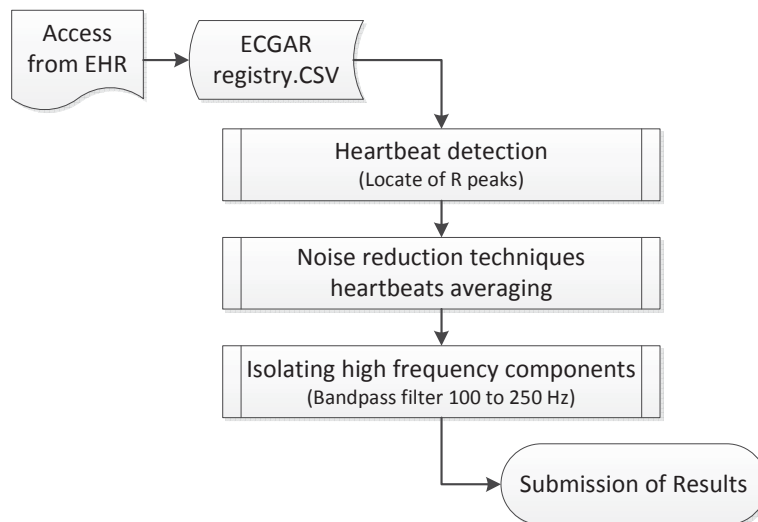
Fig. 4, Work sequence at developed algorithm.

*2.1. Heartbeat detection*

Heartbeat detection is designed for detecting the QRS occurrence through electrocardiogram. The processing of Pan and Tompkins [19], involves converting the QRS complex in well-defined peaks while are discarded the other ECG components. Then the system applies adaptive thresholds of time and amplitude to discard false QRSs. Dolinsky and Stoyanov [20] used two criteria in QRS detection, one based on the evaluation of peaks slope and the second by the biphasic waveforms occurrence to identify ectopic beats.

Other techniques have been highlighted as Ivaylo Christov I. [21], Mohamed Ben Messaoud [22], Chouhan and Mehta [23], Dugarte et al. [24], Lena Wahab [25], and other researchers who have achieved a good approximation at QRS location.

For obtained the QRS is developed an algorithm by combining some used criteria by Pan and Tompkins with some used criteria by Dotsinsky and Stoyanov. The obtained software is relatively simple to implement, efficient, and involves low computational requirement. The procedure involves R peaks detecting on a signal with altered morphology, where the QRS amplitude is highlighted at positive single pulse while the rest of the components of each pulse is attenuated.

The process starts with a recursive high-pass filter [26], with cutoff frequency of 0.65 Hz. It is defined by equation (1), where X forms the input signal, Y output data, C1 and C2 are filter coefficients.

$$Y(i) = C1[X(i) - X(i-1)] + C2[Y(i-1)] \qquad (1)$$

The (2) and (3) equations allow calculation the C1 and C2 coefficients, were Fc is cutoff frequency and T is sampling period.

$$C1 = \frac{1}{1 + tg(Fc \cdot \pi \cdot T)} \qquad (2)$$

$$C2 = \frac{1 - tg(Fc \cdot \pi \cdot T)}{1 + tg(Fc \cdot \pi \cdot T)} \qquad (3)$$

The next step is to process signal with a low-pass filter at cutoff frequency of 35 Hz. The filter implemented is defined by equation (4), where X forms the data input signal, Y data output to 1 / N represents the filter coefficients. Fc = 35 Hz is achieved with N = 26.

$$Y(i) = \frac{1}{N}[X(i) + X(i-1) + \cdots X(i-(N-1))] \tag{4}$$

The application in cascade the filters described in equations (1) and (4) is performed to work as a band-pass filter with cutoff frequency between 0.65 and 35 Hz. With this filtering a signal with low noise and good correction of baseline is obtained, but cannot be used in diagnosis because it has been altered, however it is optimal for heartbeat detecting.

Next, the filtered signal is derived to magnify the QRS amplitude changes. By applying equation (5), an approximation of signal derivative is obtained, where X represents the signal input and Y is the derived signal.

$$Y(i) = 2\,X(i) + X(i-1) - X(i-3) - 2\,X(i-4) \tag{5}$$

The next step in the algorithm is to apply a rectifier filter, which consists of squaring the derivative signal. This is done in order to obtain only positive peaks. Then, the signal is subjected to low-pass filter, identical to described by equation (4) but with cutoff frequency of 15 Hz. This allows the integration of peaks obtained in a single pulse of high amplitude, but without altering the length of QRS complex occupied space by. The delay caused by the filter is removed by introducing the appropriate time correction factor.

The Fig. 5 shows, three seconds of signal original at the top, in middle at result of deriving and the final at result obtained with equation 5. In the image, it stands the peaks generated as response of QRS complex, while the remaining signal components almost have disappeared. Note that no matter the original signal morphology, even if the QRS complexes are negative or deformed, the resultant signal always generates a positive pulse for each QRS interval found.
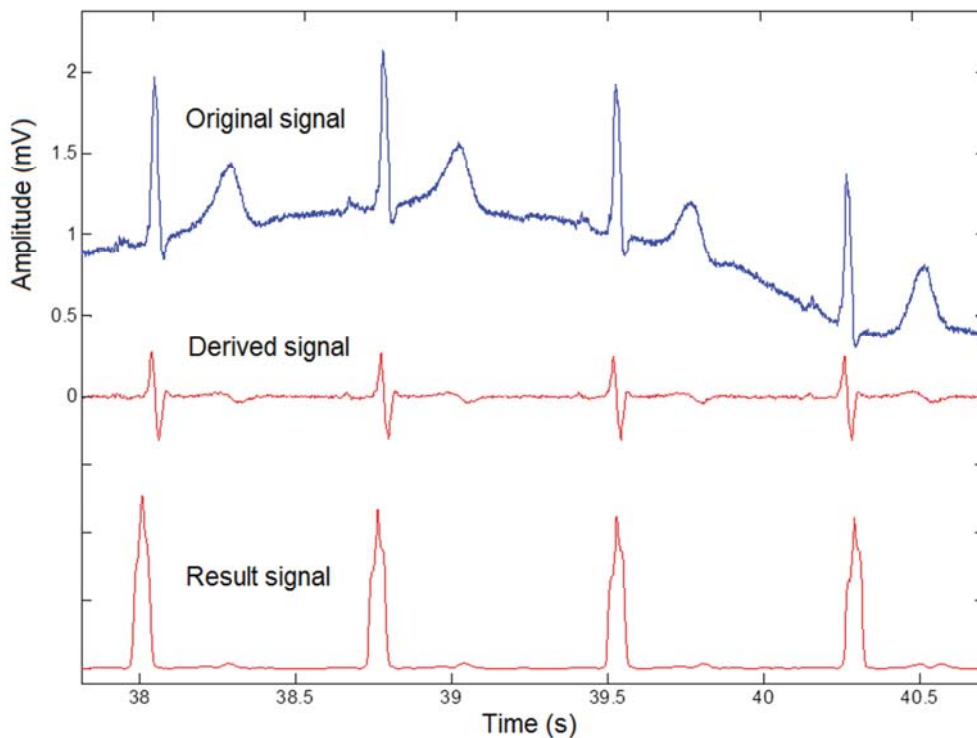


Fig. 5, Results obtained in the firsts stages the signal processing.

The next stage is to find and evaluate the pulses generated with the above processing to verify if it is a QRS, a generated artifact by noise or an ectopic beat. It is to locate the maximum amplitude in each of the signal pulses and apply some criteria defined by adaptive thresholds. The first criterion is established by amplitude comparisons. This adaptive threshold is obtained by averaging the amplitude of the last 6 peaks R accepted as true. Amplitude discrimination is done considering that an R peak is true if its amplitude is contained within a range of ± 20% of the adaptive threshold. The second evaluation criterion is established function of time. It is based on the RR interval time cannot change by more than 30% between one heartbeat and the next. The adaptive threshold time is obtained at average the last 6 RR accepted as true.

In the next step, the markers are relocated in each QRS of original signal. The Fig. 6 shows a fragment of 3 seconds of original signal, with marker lines indicating the R peaks location in each QRS.
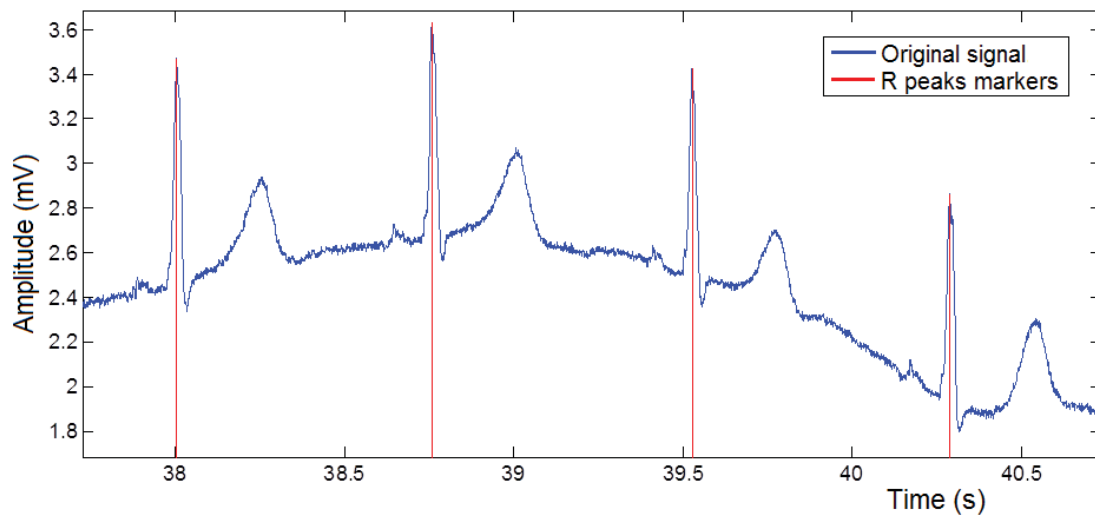


Fig. 6, Original signal with R peaks markers.

*2.2. Noise reduction by averaging heartbeat*

For analysis and measurement of potential intra-QRS abnormal [10] [11] [12] [13] is requires that the ECG signal is properly filter. The noise reduction technique by averaging [11] is to perform an averaging of the heartbeat at deemed with deformation minimum. It is assumed that the signal noise is uncorrelated between a beat and the following; therefore, considered random noise, it is progressively removed by complex averaging more.

The first processing step is to perform the automatic selection of a fragment that contains a complete record heartbeat, to be used as comparison template. The template interval starts 0.2*RR seconds before the R peak and reaches 0.4*RR seconds after the R peak, the selected beat.

The automatic template selection process initially takes the registry beat third. If the percentage of accepted beats less than 60% in register at end of iterations, this template is discarded, the next beat is taken as a possible template and the process is repeated. If the system cannot find an optimal heartbeat after 5 discarded templates, it is considered that the registry has too many alterations to apply the method.

The precise location of intervals for averaging is performed by comparing selected template with each heartbeat found. This comparison is performed by coefficient correlation Pearson calculating [8] [11] [27]. Pearson's coefficient can be calculated using the relationship given by equation (6).

$$r_{xy}(i) = \frac{cov(X,Y)}{\sqrt{\sigma_x^2 * \sigma_y^2}} \; donde: \; -1 \leq r_{xy}(i) \leq +1 \tag{6}$$

Equation (6) specifies $r_{xy}(i)$ as the Pearson correlation coefficient. This coefficient is the comparison between X and Y signals. Where X is template vector and Y represents the beat vector bounded by template alignment.

Pearson coefficient can generate values between +1 and -1, where 1 is overall positive correlation, 0 indicates no correlation and -1 is totally negative correlation [27]. The i range is defined by the times number that template is compared with the beat. In this procedure is $-50 \geq i \geq 50$, where i = 0 indicates that the template and the beat are matching at the peak R.

The covariance ratio cov(X,Y) can be calculated using equation (7). The vectors variance $\sigma_z^2$ can be found by equation (8), where Z may values take the X o Y vectors, N identifies the samples number of Z, and n are the vectors samples.

$$cov(X,Y) = \frac{1}{N}\sum(X(n) - \bar{X})(Y(n) - \bar{Y}) \tag{7}$$

$$\sigma_z^2 = \frac{1}{N}\sum(Z(n) - \bar{Z})^2 \tag{8}$$

To preserve the medical interest components in SAECG signal, the beats with a less 0.98 correlation value are discards [11]. If the Pearson coefficient value is above 0.98 is proceed to add the obtained interval with the accumulation vector and the variable that is used as accepted beats counter is increases. When finished a beat cycle analysis, is proceed to correlation calculate of next beat with the template. This process is repeated until all beats contained in the register are analyzed. Upon completion the processing is proceed to divide the accumulation vector between the accepted beats number.

The obtained signal retains all frequency components of ECGAR recording but with high noise attenuation. The Fig. 7 shows 0.55 seconds of ECGAR signal acquired de of a sick patient. In the image of original record a heartbeat is seen in contrast with the obtained signal as result. Were analyzed 171 beats, 28 beats automatically discarded and the resulting signal it is obtains averaging 143 beats.
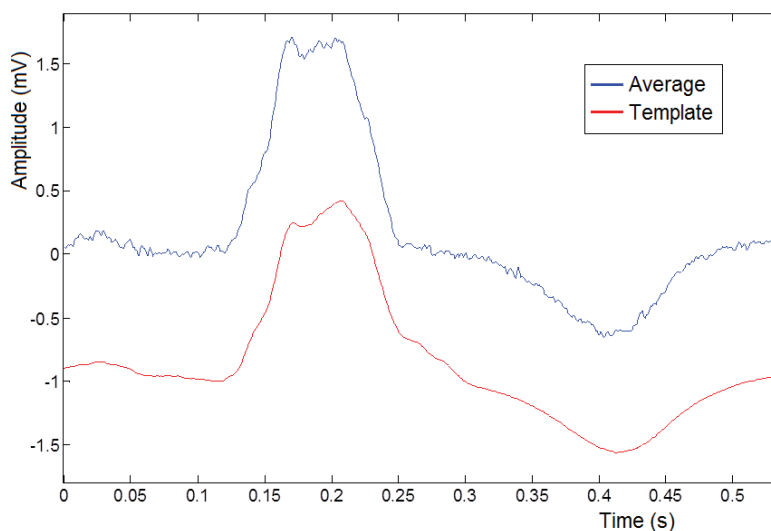


Fig. 7, Original signal and obtained signal from 143 average beats.

*2.3. RAZ detecting step*

It consists of applying a band-pass filter at obtained signal in 2.2 section. An FIR type filter as described by Equation (9) is used. The filter coefficients are calculated for cutoff frequencies between 150 and 250 Hz.

$$Y(n) = \sum_{k=0}^{N-1} b_k * X(n-k) \tag{9}$$

The next stage of processing, detects the maximums and minimum in sign contour and draw lines envelope highlighting as correspond to the QRS interval. The Fig. 8 shows a fragment of obtained result after band-pass filter applying to averaged signal shown in Fig. 7. The plot corresponds to the QRS interval. The RAZ marks are manually positioned by the specialist in order to turning points highlight identified.
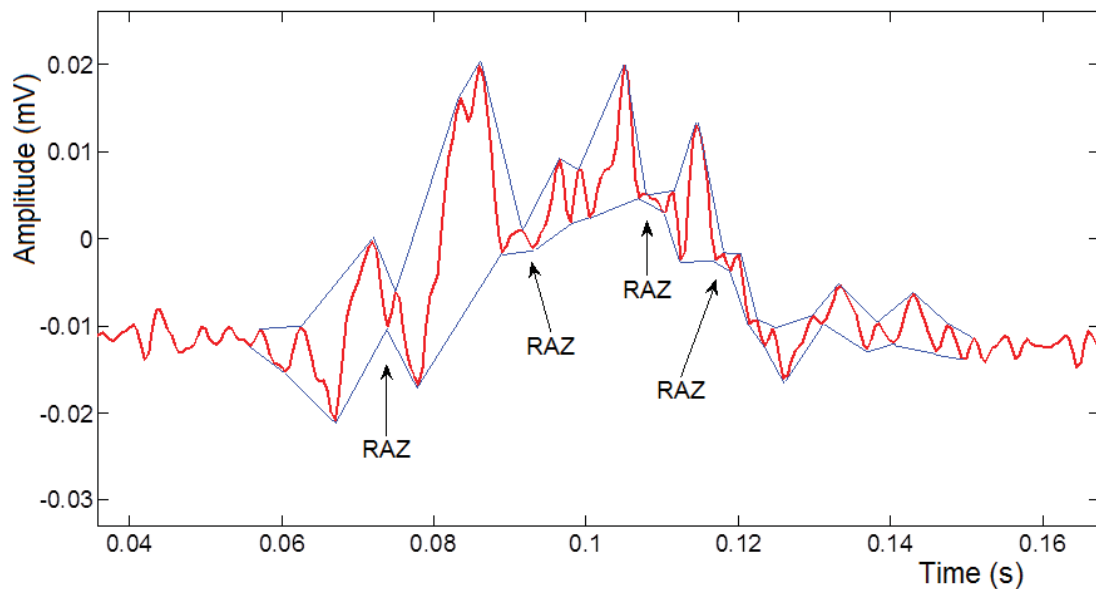


Fig. 8, Zoom of HFQRS with RAZ zones marks.

## 3. Results

The system evaluation was performed by acquired signals analyzing with DIGICARDIAC instrument in two test groups. In the first group, the software was tested with acquisitions made in the laboratory under controlled conditions, a group of 12 volunteers offered as control patients. In these tests, not found heartbeat detection errors. Of cardiologist evaluation no indicative results of cardiac pathologies. The automatic analysis does not present RAZ indicators.

The second tests group involves analyzing at 30 patients acquisitions in a medical center. The errors obtained in QRS detection are below 0.1%, which represents a performance comparable with most processing algorithms reviewed in the literature [19] [20] [21] [22] [23], but with the premise to get the results in a relatively shorter time. Evaluation of high frequency components, by the system, presented evidence that 12 of the 30 patients had RAZ markers. The cardiologists evaluating showed that 10 of the 12 patients had proven pathologies and the remaining two were reported on inconclusive studies, but with signs of sick possible.

## 4. Conclusions

The importance of the elimination of noise in the signal is very useful in the application of advanced signal analysis. Evaluations of high frequency components in QRS complex are indicators of diseases that can be detected before the damage is too severe and therefore constitute an application that can help save lives.

The used technique in processing is relatively simple, however it is possible to use more complex algorithms to improve the estimate. Preliminary results consulted in literature point out that the 12 leads technique is highly sensitive and predictive.

Given the technical capability of simultaneous acquisition of 12-lead DIGICARDIAC instrument, only is required to develop appropriate algorithms for detecting indicators of cardiovascular disease in its early stage.

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