23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

ALGORITHM FOR ANALYSIS OF ATRIAL FIBRILLATION BY CANCELLATION OF VENTRICULAR ACTIVITY ON ELECTROCARDIOGRAM

Miriam Ferraz de Paulo
Eduardo Guy Perpétuo Bock
Federal Institute of Technology in Sao Paulo, Rua Pedro Vicente, 625 - Caninde, Sao Paulo - SP, Brazil
ferraz.miriam@gmail.com, eduardo_bock@yahoo.com.br

Dalmo Antonio Ribeiro Moreira
Institute Dante Pazzanese of Cardiology, Av. Dr. Dante Pazzanese, 500 - Vila Mariana, Sao Paulo - SP, Brazil
dalmoantonio@gmail.com

Abstract. *Atrial fibrillation is a common heart disease and it reaches between 1.5% to 2% of the global population. It occurs when different spreading patterns emerge in the atria electrical activity and it can affect the pulse by changing the heart beat to irregular and faster pulsation. The Electrocardiogram (ECG) represents the heart electrical activity. It is divided in waves that receive letters names. The P wave represents the atrial cells depolarization. During atrial fibrillation, a wandering baseline takes place of the P wave. Despite the symptoms such as palpitations, sudden tiredness, dizziness, discomfort in breathing, patients can live with the disease. But after years, it can lead to complications such as systemic thromboembolism and it can cause a stroke or a thrombosis accident. The diagnosis of atrial fibrillation requires the medical confirmation of his electrocardiogram records. As atrial activity occurs independently of ventricular activity, the proposed algorithm aims to analyze and characterize atrial fibrillation cancelling the ventricular activity from ECG. Thus, it will be possible to observe only the atrial activity after removing the QRS complex and the T wave. Since P wave is synchronized with the atrial contraction, it is possible to detect the atrial fibrillation and analyze its behavior. In order to evaluate the algorithm performance, ECG waves of atrial fibrillation were collected from Physionet database and tested in MATLAB environment. In future, the algorithm will be used in patients of Institute Dante Pazzanese of Cardiology providing real ECG for algorithm validation.*

Keywords: *atrial fibrillation, QRST cancellation, cancellation of ventricular activity*

1. INTRODUCTION

Among the arrhythmias Atrial Fibrillation (AF) is the most common in clinical practice, it is estimated that it is responsible for 33% of all hospitalizations for arrhythmia and it is associated with increased morbidity and mortality (Zimerman *et al.*, 2009).

According to the Heart Rhythm Society (2014), in United States AF affects more than 2.5 million people and, in the European Union about 4.5 million people. In Brazil it is believed that there are 1.5 million patients with this arrhythmia (Zimerman *et al.*, 2009).

AF affects 1.5% to 2% of the general population (Camm *et al.*, 2012), but as its incidence increases with age, it comes to affect 10% of individuals over 80 years (Moreira and Habib, 2001).

In a heart with normal operation a single electrical activation is propagated from the atria to the ventricles, but failure at the origin of this stimulus or on your driving by heart chambers can cause the onset of heart rhythm disorders, called arrhythmias.

Atrial fibrillation is an arrhythmia that occurs when there are multiple uncontrolled impulses within heart atria, where small parts of the atrial muscle contract simultaneously caused by multiple roaming waveform in the atria with different spreading patterns (Stridh and Sörnmo, 2001).

Some symptoms lead a person with atrial fibrillation to seek the emergency room as palpitations, sudden tiredness, dizziness, inability to perform usual efforts caused by dyspnea (Thaler, 2013).

In despite of these symptoms, the person can live months or even years with the disease. But with reduced overall heart pumping, the long-term efficiency can lead to complications, such as systemic thromboembolism, blood clots in the heart and arteries clogging in different parts of the body. This blockage can cause a heart stroke and, in this scenario, the brain commitment responds for 80% of cases with risk of death (Moreira and Habib, 2001).

In the presence of cited symptoms, the cardiologist confirmed the diagnosis of atrial fibrillation through visual inspection of the electrocardiogram (ECG), which records the electrical potential generated by the electric current running throw the heart (Zimerman *et al.*, 2009) (Thaler, 2013) (Moreira and Habib, 2011) .

The ECG of a patient with AF is characterized by absence of well-defined atrial electrical activity, *i.e.* absence of P waves, which are replaced by rapid irregular waves in a frequency higher than 400 bpm, irregular morphology and amplitude varying wave called f (Fig. 1) (Serrano Jr. *et al.*, 2009).

This uncontrolled electrical discharges in the atria is reflected in the ventricles, as a result, the heartbeat becomes irregular and usually rapid.

Observe that a normal ECG is comprised of the P wave, the QRS complex and the T wave the QRS complex consists of three distinct waves, Q wave, R-wave and S wave

The P wave is caused by electrical potentials generated when the atria depolarize (more positive potential) before the contraction.

The QRS complex is caused by potentials generated when the ventricles depolarize before contraction, that is, when the depolarization wave spreads the ventricles. Both the P wave and the QRS complex components, however, are waves of depolarization.

The T wave is caused by potentials generated as the ventricles recover the state of depolarization. This process occurs in ventricular muscle 0.25 to 0.35 seconds after depolarization, which is known as surge wave repolarization (more negative potential).

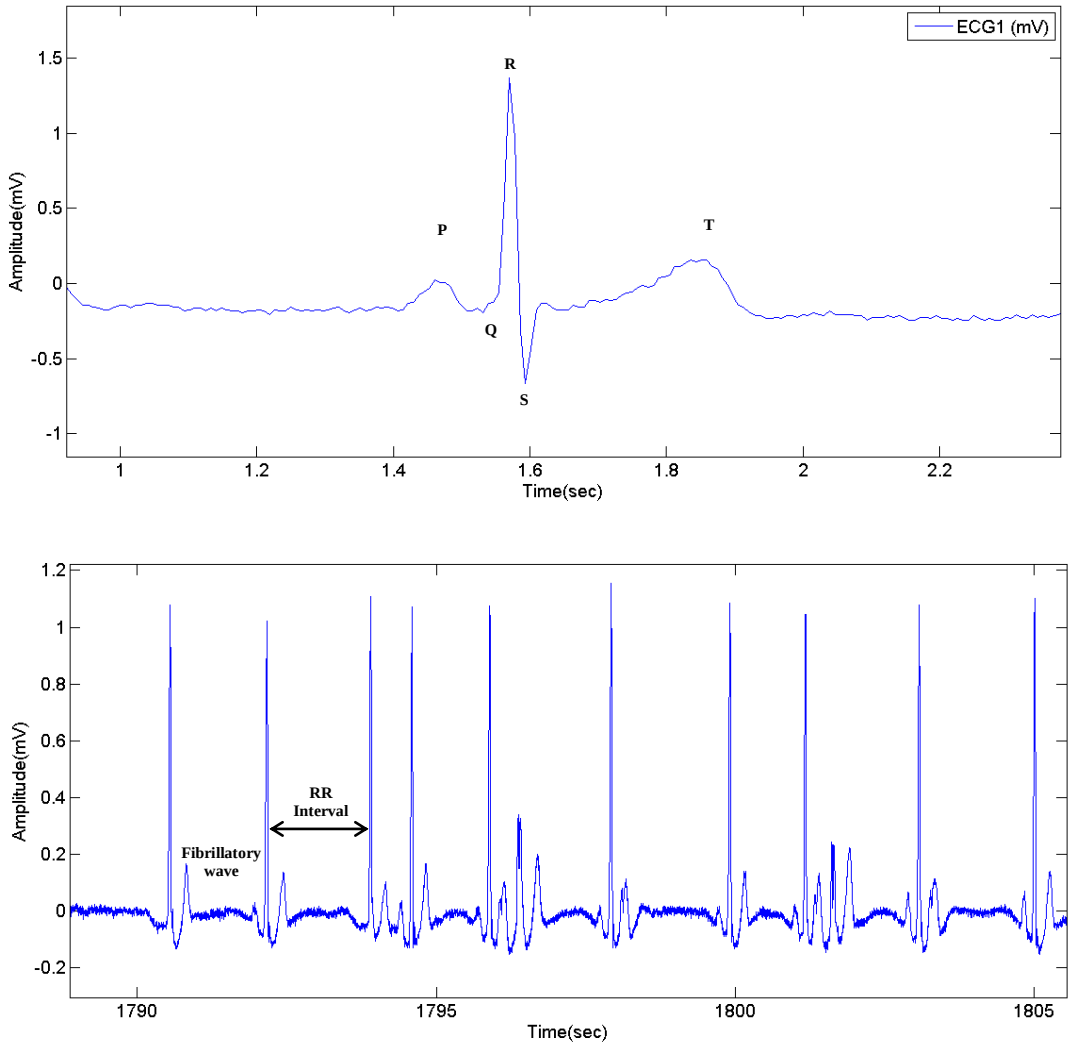

Figure 1. - Normal cardiac cycle record 16272 MIT-BIH Normal Sinus Rhythm (on the top) and Atrial fibrillation episode record 201 MIT-BIH Arrhythmia Database (down)

The treatment of AF is more empirical than rational because the mechanisms involved in the origin of the disease have not been definitely clarified so far. Current tests are not even able to predict the natural history of arrhythmias or its response to treatment (Serrano Jr *et al.*, 2009) (Sandberg, 2007).

In clinical practice, techniques are available to characterize and evaluate the AF, as the endocardial or epicardial electrogram mapping. But these methods are invasive, making it difficult to disease investigation for practical and ethical reasons (Stridh *et al.*, 2001) (Holm *et al.*, 1998).

Therefore, studies of the AF have been developed using ECG to be a non-invasive diagnostic method, low risk and cost. Besides being able to be obtained repeatedly during a longer duration than the invasive measures also contains information about the electrical and mechanical function of the atria during AF (Holm *et al.*, 1998).

The information of fibrillatory waves (waves f) can be explored using computational techniques for signal analysis. Some research has identified mechanisms underlying AF and provided therapeutic efficacy of drugs (Bollmann *et al.*, 2006).

Analyzing the atrial activity on ECG is complicated because the simultaneous presence of ventricular activity represented by the QRS complex and T wave with magnitude greater than the atrial waves. But the atrial signal occurs anyway, besides the ventricular signal.

Thus, for further study of the disease, ventricular signal must be canceled before the atrial signal analysis (Sandberg, 2007).

The final aim of this work is to create a computational tool that performs the cancellation of ventricular activity containing AF from ECG, in order to get the residual atrial activity to later analysis. In order to assist the cardiologist, this program needs to extract useful clinical information of this disease that is so common, but complex to interpret.

Considering that the atrial and ventricular activities appear in the ECG spectral overlap, which requires the use of non-linear signal processing techniques. There are several studies to cancel this ventricular activity in the ECG and the vast majority based on two physiological properties, the ventricular and atrial activity uncoupled during AF and atrial and ventricular activities originate from different sources bioelectrical (Lemay, 2007) (Couceiro, 2006).

There are some methods for this, as wavelets, neural networks, and subtraction of the QRS-T complex average. (Mainardi *et al.*, 2008) (Couceiro, 2006) (Sörnmo *et al.*, 2009).

In another approach where the atrial and ventricular electrical activity originating from independent sources, the methods used for this are based on the theory separation sources, such as Independent Component Analysis, Principal Component Analysis, Wavelet Separation and Blind Source Separation Spatiotemporal (Mainardi *et al.*, 2008) (Couceiro, 2006) (Sörnmo *et al.*, 2009).

Other methods have also been presented where ventricular activity is reduced through Wiener filtering using a time-delay Artificial Neural Network, multiresolution analysis based on wavelet packets, Bayesian estimation, or empirical mode decomposition (Mainardi *et al.*, 2008).

This paper proposes an algorithm for suppression of ventricular activity using the ABS method (Average Beat Subtraction) based on the work of Stridh and Sörnmo (2001) and Lemay (2007). This method uses conventional arithmetic average of the QRST signals to subtract the ventricular activity of the ECG.

Thus, the scope of this paper is the detection of R peaks, AF detection and detection of the QRS complex and T wave.

2. METHODS

A program is being developed in MATLAB R2012b in order to perform the detection of the R wave with an algorithm based on a proposed Pan and Tompkins, 1985 (Sedghamiz, 2014). The detection of atrial fibrillation from the RR intervals (Tatento and Glass, 2001). Where the signal in question contains AF is performed for filtering the ECG minimize noise, the detection of the QRS complex and T wave for identification of the cardiac cycles. Following, the deletion of ventricular activity uses ABS method. Finally, with the residual atrial signal, the analysis module of atrial fibrillation applies Fourier analysis to get the fibrillatory signal power spectrum and thus the dominant spectral peak.

Each cardiac cycle is represented by a matrix Y (NxL), N samples and L leads. The identification of the waves which make up the cycle from the peak R which was obtained above in the detection of AF.

From the peak R, a detection area should be created to find the S, Q and T waves. The duration of the Q wave detection area is 160ms. Typically, the PR interval is 120 ms to 200 ms. The P wave detection area has a period of 160 ms. Therefore, 160ms includes at least half the duration of the QRS complex.

The beginning of Q wave should be dividing the waveform of the detection area Q in four parts and it is the minimum point or inflection point of wave Q. The S wave is detected by the same method used for wave detection Q. For P wave and T it is necessary to find the maximum point in the wave detection area.

After get the QRS complex and the T wave signal in all leads available, the ventricular activity is canceled by ABS method based on the Eq. (1) and Eq. (2). The QRS complexes and T waves are grouped based on the morphology of each of the leads.

The ABS method is widely used in the literature to reasonable results, it has proved to be reliable for detecting atrial fibrillatory signals in numerous studies, such as diagnosis of AF, noninvasive assessment of atrial cycle length of the frequency analysis of atrial fibrillation, effects drugs and classification of paroxysmal and persistent AF (Lemay, 2007).

This method considers that the atrial activity is decoupled from ventricular activity. Therefore a QRST complex model is subtracted from each QRST complex in the ECG signal resulting in a residual signal containing the atrial fibrillatory waves. The complex QRST model is obtained by the arithmetic average of the QRST complex with similar morphologies (Stridh and Sörnmo, 2001).

A crucial point for the success of the method is the time alignment between the QRST complexes of the ECG and the QRST complex model (Sandberg, 2007).

The performance can be further limited for signals with short periods of time, which complicates the construction of a good model QRST (Lemay *et al.*, 2007).

As the AF is decoupled from ventricular activity, each cycle was modeled as a sum of atrial activity (YA), ventricular activity (YV) and an additive noise (W '):

$$Y = YA + YV + W' \quad (1)$$

An average rate X was used to represent YV that will be aligned in time (Jτ matrix) correcting the misalignment of time between the QRST signal observed and the average rate X. From the QRST ECG signals, the average rate is calculated and is then aligned in time:

$$YV = J\tau X \quad (2)$$

At this point the QRST cancellation is effectively performed by subtracting the ECG lined QRST signal only getting atrial activity (YA).

It is possible to observe in Fig.2 the procedure starting by placing the first QRST to be analyzed in one set. The next QRST signal must be aligned in time with the first R peaks and the morphology of the two QRSTs is compared by cross correlation between the corresponding columns (leads).

Will be considered similar if all the values corresponding to correlation leads are above a given threshold, then the second QRS complex is the same as the first set, but it is placed into a new set.

The average of the QRSTs is calculated for each set, if a set has a single QRST will be canceled.

This average for each QRST morphology is used to be subtracted from each of the ECG in question considering the QRST morphology and corresponding residual order to obtain the atrial signal.

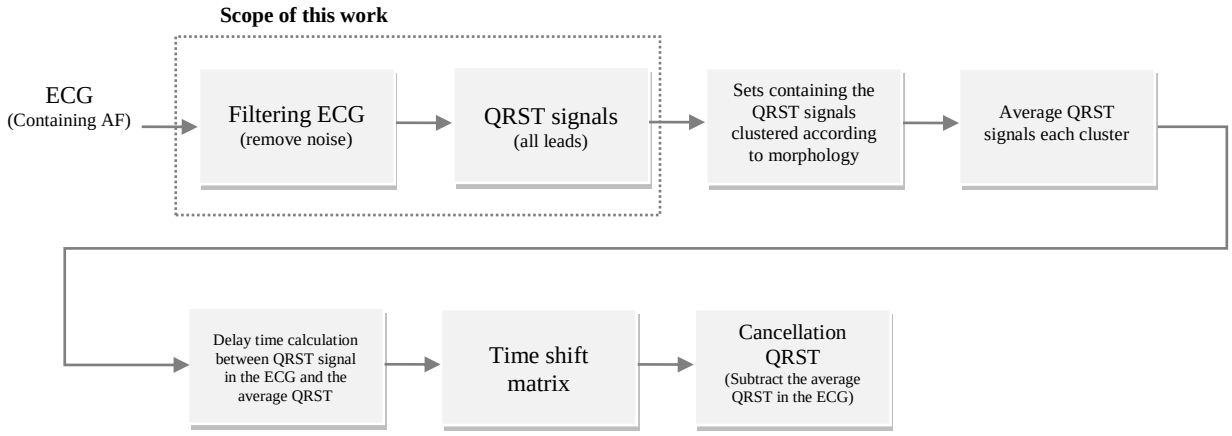

Figure 2. Flowchart cancellation of ventricular activity with the ABS technique

2.1 Database

For the initial tests of detection of R peaks and detection of AF they were used ECG signals with and without AF *Physionet* which is a site that offers free access to a physiological signal database (Physionet, 1999).

For preliminary studies were used to Arrhythmia Database, MIT-BIH Arrhythmia Database and the MIT-BIH Atrial Fibrillation Database because the sections containing AF are identified in *Physionet* site (Goldberger *et al.*, 2000).

In Atrial Fibrillation Database there are 25 ECG recordings from human patients with atrial fibrillation lasting 10h, sampled at 250 Hz and 12 bit resolution in a ± 10 mV range.

The Arrhythmia Database has 48 data portions of half an hour ECG obtained from 360 subjects with 47 Hz sampling rate and 11 bit resolution in a range of 10mV.

3. RESULTS OF VENTRICULAR ACTIVITY ON ELECTROCARDIOGRAM

The work is being developed in MATLAB R2012b environment. And so far have been designed in part the modules the detection of R peaks, AF detection and detection of the QRS complex and T wave.

The detection of R peaks was applied an algorithm based on a proposal of Pan and Tompkins, 1985. The ECG filtered after the four phases of the algorithm, band pass filter, differentiation and power of 2, the moving average filter and compared with a threshold. The first three steps for determining the energy of the signal, the last detection of the most power surges, so the peak R.

The detection threshold is calculated independent of the signal. If the energy is greater than the threshold there is an energy peak detected QRS complex and energy being less than the peak threshold is not considered.

To illustrate refer to Fig. 3, after defining detection areas around the peak were collected Q R waves, S and T.

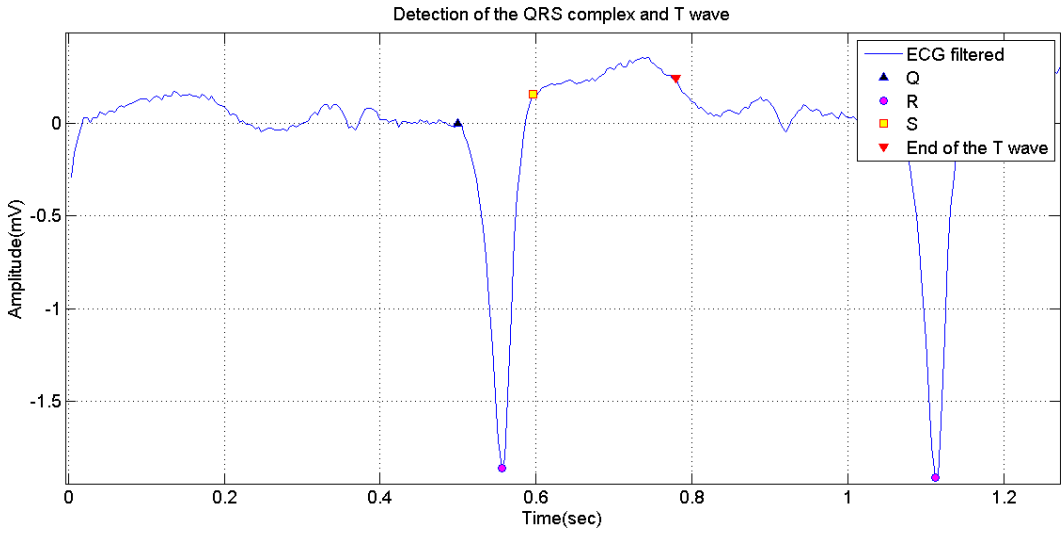

Figure 3. Detection of the QRS complex and T wave record 04043 MIT-BIH Atrial Fibrillation Database

With the R peaks was taken identified the detection of atrial fibrillation, from the RR intervals, based on the work Tateno and Glass, 2001.

Through the notes presented in the databases studied it was possible to select passages containing AF and without AF stretches.

From the selected excerpts the CV test was applied to the RR intervals and the ΔRR intervals. Observe the Tab. 1 some indices obtained through the algorithm developed at the AF detection module.

Table 1: CV test of the RR intervals and intervals ΔRR for some samples from the MIT-BIH Arrhythmia Database

Coefficient of Variation			
Sample	RR intervals	ΔRR intervals	AF
201	0.208	0.303	x
202	0.007	0.109	-
203	0.355	0.511	-
210	0.230	0.362	x
217	0.111	0.155	-
219	0.186	0.259	x
221	0.586	0.861	-
222	0.067	0.109	-

According to the working Tateno and Glass, 2001 CV values for test containing AF RR intervals vary between 0.156 and 0.324. And for ΔRR intervals vary between 0.221 and 0.459.

According to the figures obtained in the CV test the sections of the samples 201, 210 and 219 have AF. Already in the notes sections of the samples with AF are 201, 203, 210, 219 and 221.

4. CONCLUSIONS

The methodology chosen for the detection of the R peak of the QRS complex and T wave was considered adequate to moment. Even, until now, our algorithm did not detect atrial fibrillation and all the passages in question, perhaps because of the amount of beats considered, as in the article by Tateno and Glass, 2001. CV test was applied in sets at least 100 beats. In the sample 203 were considered 100 beats to calculate and note that the CV values are very close to acceptable values. In the sample 221 were obtained only 16 beats which probably has hindered the achievement of CV values.

The optimal result expected is to improve the quality using longer time intervals for further study.

Preliminary tests of cancellation of the ventricular activity have been shown to be promising to explore information carried by fibrillatory waves of the ECG. Through this work it will be possible to study more deeply the various forms and treatment of this pathology.

5. FUTURE WORK

In the phase of ventricular activity cancellation module, correlating the QRS complexes and T waves to group them based on their morphology. Following obtaining the average of each set and then, align them in time with the ECG and finally perform subtraction of QRST average ECG getting residual atrial activity.

The future work will use ECG signals from healthy patients plus a simulated AF through a sine wave and its harmonics generating a signal similar tooth saw the AF and the unsteady behavior will be created by introducing an amplitude varying as time and tooth signal cycle length saw. In this way we can better assess the techniques used at each stage of the project.

The simulated AF will be added to the selected normal signals the bank MIT-BIH Normal Sinus Rhythm of *Physionet* site bank (Goldberger *et al.*, 2000), which offers free access to a physiological signal database. This database includes 18 long-term ECG recordings made at the Laboratory at Beth Israel Hospital Boston. The data were collected from five men between 26 and 45, and thirteen women aged 20 to 50. In the records of ECGs there are no significant arrhythmias records.

Adjustments have to be made in the detection phase of the following R peaks that will be present an idea of how the results will be evaluated in the future. For detection of AF, the objective is to evaluate the extracts analyzed into four categories: true positive (TP) when the atrial fibrillation is classified as atrial fibrillation; true negative (TN) when no atrial fibrillation and is classified as non-atrial fibrillation; false positive (FP), when no atrial fibrillation and is classified as atrial fibrillation; false negative (FN), if atrial fibrillation and is classified as non-atrial fibrillation.

Calculating the sensitivity and specificity are defined by TP / (TP + FN) and TN / (TN + FP), respectively. The predictive value of a positive test (PV +) and the predictive value of a negative test (PV-) are defined by TP / (TP + FP) and TN / (TN + FN), respectively. Our group expects to reach levels of 80% or more in accuracy, compared to similar studies as Tateno and Glass, 2001.

The evaluation of the ventricular blanking will be based on Stridh and Sörnmo, 2001 article is based on the fact that AF activity is known in the simulated ECGs enabling make a thorough study of the performance of the QRST cancellation. The performance measure reflects the QRS-related errors as well as errors due to the electric axis that is not constant throughout the cardiac cycle, and thus the errors associated with the T wave are introduced.

6. REFERENCES

Bollmann, A., Husser, D., Mainardi, L., Lombardi, F., Langley, P., Murray, A., Rieta, J. J., Millet, J., Olsson, S. B., Stridh, M., Sörnmo, L., 2006. “Analysis of surface electrocardiograms in a trial fibrillation: techniques, research, and clinical applications”. *The European Society of Cardiology*, Vol. 8, 911–926.

Camm, A.J., Lip, G.Y.H., Caterina, R., Savelioeva, I., Atar, D., Hohnloser, S.H., *et al.*, 2012. “2012 focused update of the ESC Guidelines for the management of atrial fibrillation - An update of the 2010 esc guidelines for the management of atrial fibrillation. Developed with the special contribution of the European Heart Rhythm Association”. *European Heart Journal*. Vol. 33, p. 2719-47.

Couceiro, R., 2006. *Life-Stream Análise de ECGs e detecção de episódios de fibrilhação auricular*. University of Coimbra, Portugal.

Couceiro, R., Carvalho, P., Henriques, J., Antunes, M., Harris, M., Habetha, J, 2008. “Detection of Atrial Fibrillation Using Model-based ECG Analysis”. *19th International Conference on Pattern Recognition*, ICPR, p. 1-5.

Goldberger, A.L., Amaral, L.A.N., Glass, L., Hausdorff, J.M., Ivanov, P.C.H., Mark, R.G., Mietus, J.E., Moody, G.B., Peng, C.K., Stanley, H.E, 2000. “PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Resource for Complex Physiologic Signals”. *Circulation*, Vol. 101, n.23, p. 215-220**.**

Holm, M., Pehrson, S., Ingemansson, M., Sörnmo, L, Johansson, R., Sandhall, L., Sunemark, M., Smideberg, B., Olsson, C., Olsson, S. B, 1998. “Non-invasive assessment of the atrial cycle length during atrial fibrillation in man: Introducing, validating and illustrating a new ECG method”. *Cardiovascular Research*, Vol. 38, p. 69–81.

Lemay, M, 2007. *Data Processing Techniques for Thecharacterization of Atrial Fibrillation*. École Polytechnique Fédérale de Lausanne, Lausanne.

Mainardi, L., Sörnmo, L., Cerutti, S., 2008. *Understanding Atrial Fibrillation:The Signal Processing Contribution*. Morgan & Claypool Publishers, San Rafael, CA.

Moreira, D.A.R. and Habib, R.G, 2001. "Tratamento Da Fibrilação Atrial Na Sala De Emergência - Management Of Atrial Fibrlllation In The Emergency Room". *Revista Ciências em Saúde*, p. 1-14.

Pan, J. and Tompkins, W.J, 1985. "A Real-Time QRS Detection Algorithm". *IEEE Transactions on Biomedical Engineering*, Vol. 32(3), p. 230-55.

Physionet, 1983. "MIT-BIH Atrial Fibrillation Database". 7 Aug. 2014 <http://physionet.org/physiobank/database/afdb/>.

Physionet, 1999. "How to use the PhysioBank ATM". 7 Aug. 2014 <http://www.physionet.org/cgi-bin/atm/ATM>.

Physionet, 2001. "MIT-BIH Arrhythmia Database". 7 Aug. 2014 <http://physionet.org/physiobank/database/mitdb/>.

Sandberg, F., 2007. *Time-Frequency Analysis of Atrial Fibrillation*. Lund University, Sweden.

Sedghamiz, H., 2014. "Complete Pan Tompkins Implementation ECG QRS detector". 7 Aug. 2014 <http://www.mathworks.com/matlabcentral/fileexchange/45840-complete-pan-tompkins-implementationecg-qrs-detector>.

Serrano Jr, C. V., Timerman, A., Stefanini, E., 2009. *Tratado de Cardiologia SOCESP*. Manole, Barueri, SP, 2nd edition.

Sörnmo L., Stridh, M., Husser, D., Bollmann, A., Olsson, B., 2009. "Analysis of atrial fibrillation: from electrocardiogram signal processing to clinical management". *Philosophical Transactions of The Royal Society - Series A*, Vol. 367, p. 235-53.

Stridh, M. and Sörnmo L., 2001. "Spatiotemporal QRST Cancellation Techniques for Analysis of Atrial Fibrillation". *IEEE Transactions on Biomedical Engineering*, p. 105-11.

Stridh, M., Sörnmo, L, Meurling, C. J., Olsson, S. B, 2001. "Characterization of Atrial Fibrillation Using the Surface ECG: Time-Dependent Spectral Properties". *IEEE Transactions on Biomedical Engineering*, Vol.48, n.1, p.19-27.

Tateno, K., Glass, L, 2001. "Automatic detection of atrial fibrillation using the coefficient of variation and density histograms of RR and ΔRR intervals". *Medical & Biological Engineering & Computing*, Vol. 39, p.664-71.

Thaler, M.S, 2013. *Ecg Essencial: Eletrocardiograma na prática diária*. Artmed, Porto Alegre, 7th ed.

Zimerman, L.I., Fenelon, G., Martinelli Filho, M., Grupi, C., Atié, J., Lorga Filho, A., et al., 2009. "Diretrizes Brasileiras de Fibrilação Atrial. Arq Bras Cardiol ". *Sociedade Brasileira de Cardiologia*, Vol. 92(6 supl.1), p. 1-39.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.