Jurnal Teknologi

Full paper

Frequency Analysis for Surface Electrocardiogram Of Atrial Fibrillation

Anita Ahmad[a*], Salinda Buyamin[a], Nurhamizah Senin[a]

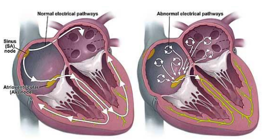
[a]*Process Tomography and Instrumentation Engineering Research Group (PROTOM-i), Infocomm Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: anita@fke.utm.my

Article history

Received :30 April 2013
Received in revised form :
9 July 2013
Accepted : 3 August 2013

Graphical abstract



Abstract

This paper presents the behaviour of the dominant frequency of the electrocardiogram (ECG) signal for atrial fibrillation patients before and after preprocessing. The preprocessing method (QRST subtraction) is useful to obtain a clean atrial signal before performing frequency analysis. The QRST subtraction was performed and the dominant frequency before and after QRST subtraction was compared. This study demonstrates a positive result with this technique in comparison with another established technique.

Keywords: Dominant frequency; atrial fibrillation; electrocardiogram

■1.0 INTRODUCTION

Atrial fibrillation (AF) is one of the arrhythmias, which means irregularities of heart rhythm. Arrhythmia is divided into two categories: AF and VF (ventricular fibrillation). AF indicates the irregularities of rhythm within the atrium of the heart, whereas the irregularities are within the ventricular part with VF. The cause of AF is that the electrical pulse that should be initiated at the sinoatrial node (SA node) is not started at that particular point, but is instead started at several other points within the atrium, causing the atrium to fibrillate and not beat normally. This causes the blood in the atrium (right and left) to not be completely pumped into the ventricle part (right and left). This is illustrated in Figure 1. The normal heart rate is between 60–100 beats per minute; the heart rate with AF is between 100–175 beats per minute [1, 2].

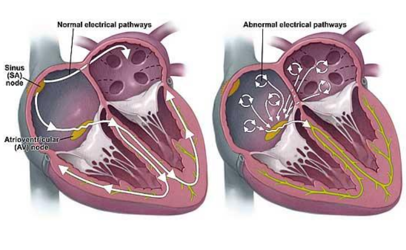


Figure 1 Normal and abnormal electrical pathways[2]

At the SA node, the approximation of normal firing rate is 60–80 per minute during rest and 180–200 per minute during peak exercise. However, the abnormal firing rate is around 400 per minute and can reach 600 per minute [3]. This is because the pulse is no longer initiated at one point (SA node) but at several points around the atrium. However, the abnormality is based on the pattern of the patient's heart itself and not at a fixed rate. Thus, the range of frequencies evaluated in this study were between 4 and 10 Hz, although is the frequency range was not yet standardised.

According to research conducted by American Medical, the prevalence of AF increases at older age (more than 55 years old) and men have a higher risk for AF compared with women [4]. However, people who are aged above 80 years have a higher risk compared with those who are 55 years old.

■2.0 METHODOLOGY

Electrocardiography is a method to record the electrical activity in the heart using electrodes placed on the body surface. The recorded electrocardiogram (ECG) is used for diagnosis of heart condition [2]. Figure 2 shows standard fiducial points on an ECG trace. PQRST represents different phases of electrical activity in the heart. The P wave indicates the depolarisation of atrial muscle; the QRS complex represents the depolarisation of ventricular muscle; and the T wave represents the repolarisation of ventricular muscle [2]. However, the acquisition of an ECG is an indirect method (surface of the body), with various kinds of noise generated by the equipment and movement of the human body. Hence, the signal needs to be filtered to reduce the noise. The filter used in this study was a low pass filter, due to its ability to reduce noise such as muscle noise and power line interference. The signal from the ECG wave was transformed into the frequency domain by performing Fast Fourier Transform (FFT) with frequency resolution 0.29 Hz.

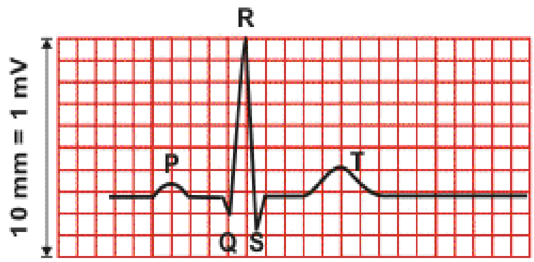


Figure 2 Electrocardiogram recording showing standard fiducial points (PQRST wave)[5]

Figure 3 shows the methodology implemented for frequency analysis of AF ECG signal for five patients. First, the data were loaded into MATLAB and displayed as graph voltage versus time. On the graph, we were able to locate the PQRST point roughly. The next step was to transform the obtained signal (time domain signal) into frequency domain signal using the FFT technique.

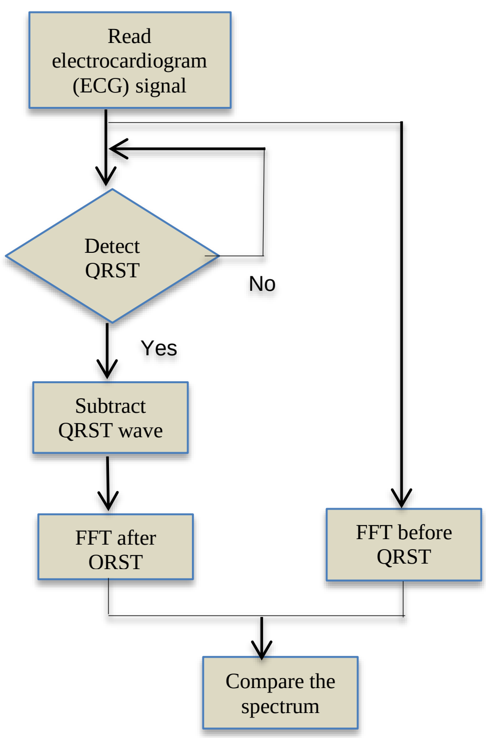


Figure 3 Workflow of Electrocardiogram (ECG) signal processing

QRST wave detection was performed using Pan Thomkin's algorithm while flat interpolation was used to replace QRST signals. The signal after QRST subtraction was then transformed into frequency domain signal using the FFT technique. The spectra before and after QRST subtraction were compared and analysed.

3.0 DOMINANT FREQUENCY ANALYSIS

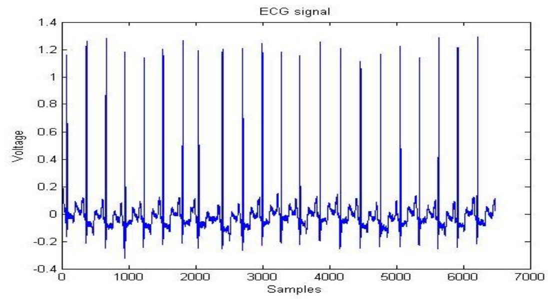
The analysis of uncoordinated AF ECG signal cannot be performed using time domain analysis due to certain limitations. Thus, researchers have used frequency domain analysis as another option in an attempt to overcome the limitation [5]. The FFT is crucial for transforming the signal from time domain to frequency domain. It is able to decompose the continuous signal to a sum of weighted sinusoidal function, which is then adapted for digital signals. The ECG wave is a complex form of wave due to its analogue pattern, which makes it difficult to analyse using time domain analysis. Beside using FFT, there are several proposed methods for obtaining the domain frequency of ECG. However, for this research, FFT was chosen due to its high speed compared with other methods, such as Blackman Tukey (BT), Autoregressive (AR), and Multiple Signal Classification (MUSIC) [6]. Ng and Goldberger has found that the dominant frequency (DF) is the highest peak of frequency in the magnitude spectrum and all the other peaks are called the harmonics [5]. The way to obtain a better DF is by executing a preprocessing step on time domain to obtain the raw signals that resemble a sinusoidal wave. DF analysis has been used to detect rapid activation within the atrium of the heart. Normally, typical ECG can have a very sharp biphasic waveform due to rapid depolarisation taken either from bipolar or unipolar electrode configurations. A few preprocessing steps are required for these types of signals to obtain clean atrial signals. These steps include:

1. Band pass filtering
2. Low pass filtering
3. QRST detection using adaptive threshold technique
4. QRST subtraction using flat interpolation

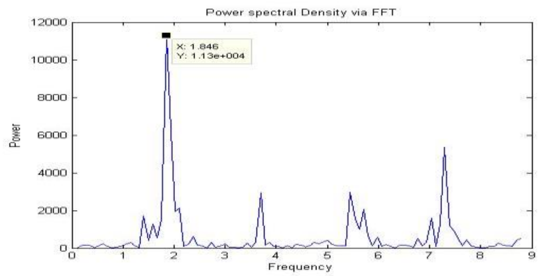
FFT was then applied to the clean signals to estimate the DF before and after QRST subtraction.

4.0 RESULTS AND DISCUSSION

Figure 4 shows the normal ECG signal in the time domain and frequency domain. The frequency sampling for normal ECG was 360 Hz, while for the AF ECG it was 1200 Hz. Since the signal in time domain could not be directly interpreted, we used the information from the frequency domain (Figure 4b) for the analysis. Normally, for normal ECG, the DF is within the range of 1 to 2.5 Hz. The DF represents the activation rate within the atrium while the other peak is the harmonics of the graph that shows that the original signal had periodicity [5].



(a)

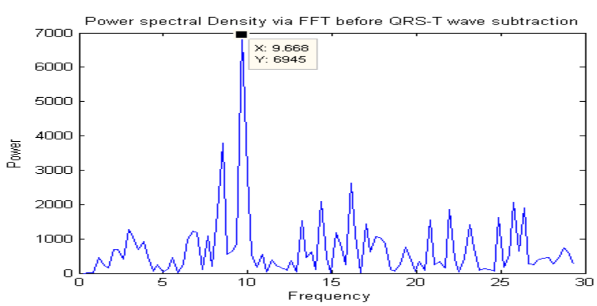


(b)

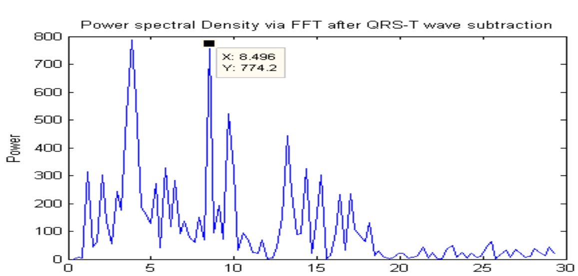
Figure 4 (a) Time domain of normal electrocardiogram (ECG) signal, (b) frequency domain of normal ECG signal

All five patient's data were processed as shown in the flow chart (Figure 3). The DF was obtained for all patients. This ranged between 4–10 Hz due to an abnormal firing rate, as discussed in section 1.0.

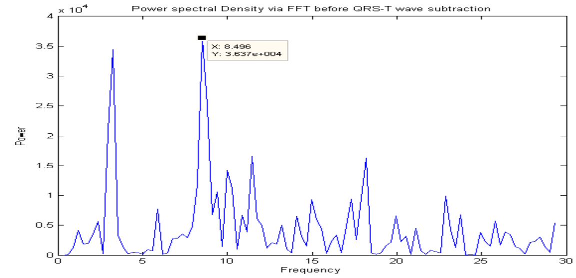
Figure 5 shows the power spectral density using FFT before and after QRST wave subtraction, with its DF. In general, the power of harmonics was reduced after QRST subtraction. Harmonics can be of any amplitude; they usually become smaller as they increase in frequency (sharp edges result in a higher frequency).



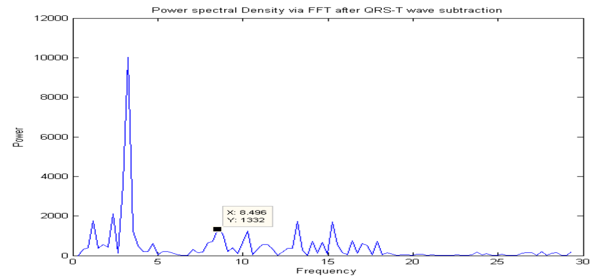
Patient 1: before QRST subtraction



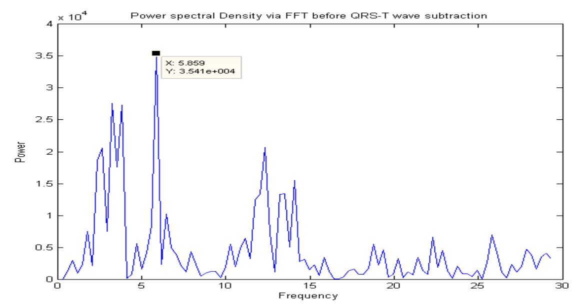
Patient 1: after QRST subtraction



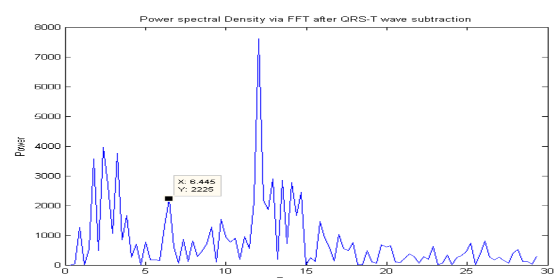
Patient 2: before QRST subtraction



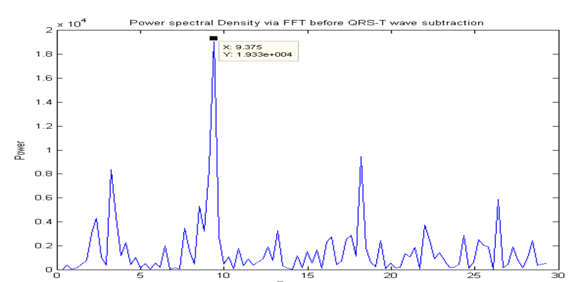
Patient 2: after QRST subtraction



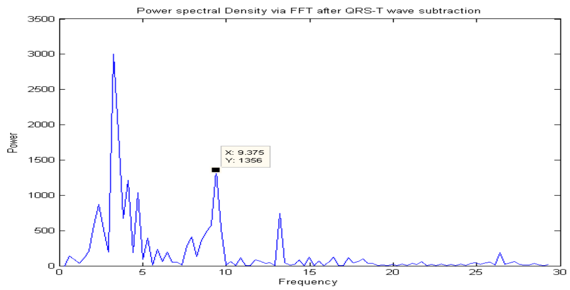
Patient 3: before QRST subtraction



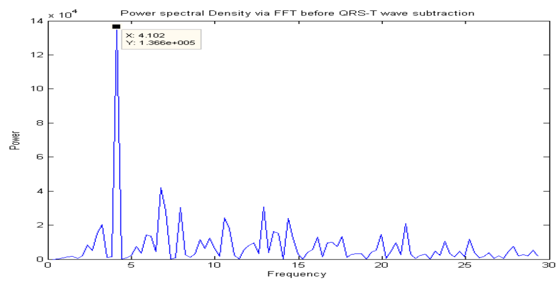
Patient 3: after QRST subtraction



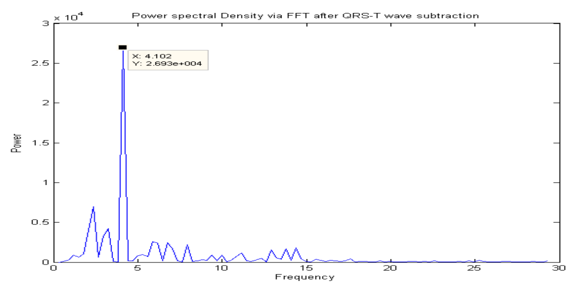
Patient 4: before QRST subtraction



Patient 4: after QRST subtraction



Patient 5: before QRST subtraction



Patient 5: after QRST subtraction

Figure 5 Power spectral density via Fast Fourier Transform (FFT) before and after QRST wave subtraction with its dominant frequency for five patients

The dominant frequencies before and after QRST subtraction are summarised in Table 1.

Table 1 Dominant frequency (DF) before and after QRST wave subtraction

Patient	DF (before subtraction), Hz	DF (after subtraction), Hz
1	9.668	8.496
2	8.496	8.496
3	5.859	6.445
4	9.375	9.375
5	4.102	4.102

With the DF of all patients, the signal was in a chaotic form, showing that it was not only the DF that had high amplitude but other points of the frequency also had high amplitude. This means that several other regions that had reentry pulses existed in the atrium. Cases have been reported in which the DF does not occur in the left atrium; it can also be at the pulmonary vein or in the area of the right atrium [7,8]. Although we could not locate the exact point of the rotor, we know that within this range, the rotor resides in either the right or the left atrium, or both.

The results for patient 2, patient 4, and patient 5 (before and after QRST subtraction) showed that the DF was located at 8.496 Hz, 9.375 Hz, and 4.102 Hz, respectively. Although the patterns were largely different, the location of the DF was the same before and after subtraction. It seems that subtraction of the ventricular signal does not affect the overall signal for patient 2, patient 4, and patient 5.

5.0 CONCLUSION

For AF ECG, the DF area of atrium that have a higher activation frequency than other regions, suggesting that these areas may be the drivers that maintain AF. As shown in Table 1, we observed DFs with a different frequency for before and after QRST subtraction and also those that remained at the same frequency before and after QRST subtraction. There are several causes for the DF to remain the same before and after QRST subtraction. It is possible that the particular point of activation rate happens at the same DF. Thus, the differences could not be seen clearly. In reality, the pattern of ECG for each patient is unique and this also contributes to imperfections in the detection and subtraction process, which lead to the introduction of a small error in frequency domain analysis. As an example, the subtraction process for patient 5 involved only QRS subtraction, with no T subtraction. We were unable to detect and subtract the T wave because it could not be seen clearly from the time domain. Therefore, we can consider this as imperfect cancellation and shows the same frequency for both cases.

Acknowledgement

The authors would like to thank the Ministry of Higher Education and Universiti Teknologi Malaysia for supporting this research under SLAI scholarship.

References

[1] Luca Mainardi, Leif Sornmo, Sergio Cerutti. 2008. *Understanding Atrial Fibrillation: The Signal Processing Contribution*. Morgan & Claypool Publishers.

[2] Tortora, G. J. & Derrickson, B. H. 2009. *Principles of Anatomy and Physiology.* John Wiley & Sons, Inc.

[3] Stanley Nattel. New Ideas About Atrial Fibrillation 50 Years On. Insight review Articles.

[4] Go, A. S., Elaine M. Hylek, Kathleen A. Phillips, Yuchiao Chang, Lori E. Henault, Joe V. Selby & Daniel E. Singer. 2001. Prevalence of Diagnosed Atrial Fibrillation in Adults National Implications for Rhythm Management and Stroke Prevention: the Anticoagulation and Risk Factors In Atrial Fibrillation (ATRIA) Study. *JAMA*. 2370–2375.

[5] Ng, J. & Goldberger, J. J. 2007. Understanding and Interpreting Dominant Frequency Analysis of AF Electrograms. *J Cardiovasc Electrophysiol*. 18: 680–685.

[6] Ahmad, A., Schlindwein, F. S. & Ng, G. A. 2010. Comparison of Computation Time for Estimation of Dominant Frequency of Atrial Electrograms: Fast Fourier Transform, Blackman Tukey, Autoregressive and Multiple Signal Classification. *Journal of Biomedical Science and Engineering (JBiSE).*

[7] Moussa Mansour. 2006. Highest Dominant Frequencies in Atrial Fibrillation: A New Target for Ablation? J. Am. Coll. Cardiol. 47: 1408–1409.

[8] Sanders, P., Omer Berenfeld, Mélèze Hocini, Pierre Jaïs, Ravi Vaidyanathan, Li-Fern Hsu, Stéphane Garrigue, Yoshihide Takahashi, Martin Rotter, Fréderic Sacher, Christophe Scavée, Robert Ploutz-Snyder, José Jalife & Michel Haïssaguerre. 2005. Spectral Analysis Identifies Sites of High-Frequency Activity Maintaining Atrial Fibrillation in Humans. *Circulation*. 789–797.