



Techniques for Detection of Paroxysmal Atrial Fibrillation in Signal Processing

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Abstract: This paper reviews the various techniques for detection of Paroxysmal Atrial Fibrillation (PAF) with their performance analysis. Paroxysmal Atrial Fibrillation (PAF) is common Coronary Artery disease (CAD). PAF is a condition in which the heart beats irregularly or rate of rhythm of heart goes irregular. It is now well established fact that PAF worsens the quality of life and requires frequent hospitalization and also has a higher rate of mortality. With such high rate of mortality and less efficiency in detection of PAF through Electrocardiogram (ECG) & Holter, this cardiovascular disease is becoming threatening to lives of masses. Scientists and Health Professionals are working together to find different ways to detect the PAF cases in advance by studying recorded ECG signals. While a group of researchers are also developing the algorithms which can detect the PAF. These algorithms are tested on various open ECG and AF databases to find out their specificity and sensitivity. ECG is a signal which is formed due to electrical activity of heart. Signal processing algorithms can be applied to detect the various parameters of ECG signals. Algorithms for analysis of signals can be broadly classified in three different domains which are: (i) Time Domain Analysis or Temporal Analysis, (ii) Frequency Domain Analysis and (iii) Non-Linear Analysis. All of these techniques are reviewed and compared in this paper with their performance analysis. Algorithms are classified in one of these domains and their efficiency is measured in terms of Specificity and Sensitivity.

Keywords: Paroxysmal Atrial Fibrillation

I. INTRODUCTION

In India 18.8 % of total deaths were due to cardio vascular diseases in 2001-2003 [1]. Cardiovascular disease will be the largest cause of death and disability in India by 2020 [2]. World Health Organization has declared India the coronary artery disease capital of the world [3]. Paroxysmal Atrial fibrillation (PAF) is disease which also falls in class of Cardiovascular diseases. PAF is also found to be one of the major causes of Stroke which is a coronary artery disease [4]. Stroke is also number four cause of death and a leading cause of long-term disability in the U.S, it accounted for 1 in every 19 deaths in 2009 [5]. Paroxysmal Atrial fibrillation (PAF) is the most common cardiac arrhythmia, with its prevalence increasing each year. Arrhythmia is a condition in which the heart beats irregularly or rate of rhythm of heart goes irregular. However, this condition is not to be confused with irregular heart rate as the two do not necessarily occur together. Arrhythmia can occur with normal heart rate, or with one that is either slow or rapid. The global burden of PAF is ever increasing at an exponential rate and proper diagnosis is need of hour. Paroxysmal Atrial fibrillation is also the major cause of ischemic strokes. Ischemic stroke is a condition in which blood supply to brain is suddenly interrupted because of formation of clot in blood vessel. The presence of Paroxysmal Atrial fibrillation is associated with five-fold risk of ischemic strokes. In stroke, the brain cells suddenly die because of a lack of oxygen. A stroke can be caused by an obstruction in the blood flow, or the rupture of an artery that feeds the brain. The patient may suddenly lose the ability to speak, there may be memory problems, or one side of the body can become paralyzed. Paroxysmal Atrial Fibrillation is strong risk factor of stroke. Atrial fibrillation and flutter account for 10% of all strokes and 50% of cardio embolic strokes [6]. Stroke associated with AF carries a poor prognosis as more than 50% of the survivors remain with a severe deficit in quality of life, and recurrence may be as high as 12% per year [6]. Atrial Fibrillation (AF) can be of following types: Paroxysmal, Persistent, Permanent. In paroxysmal AF the heart beat goes out of rhythm for very less time and come to normal mode on its own. In persistent AF heart beat goes out of rhythm but does not come back to normal mode, it requires to consult doctor for treating this AF for bringing heart rhythm. In permanent AF the heart goes out of rhythm permanently. Paroxysmal AF (PAF) is defined as an AF episode that lasts longer than 2 min but less than 7 days [7]. Detection rate of Paroxysmal Atrial is very less because of its spontaneous nature. Although PAF is short-lived, it shares similar stroke risks with long-lasting persistent AF. ECG records the activity of heart for a defined time, and because of spontaneous nature of PAF, it may not get recorded during the time in which ECG is done. This makes a definitive diagnosis of PAF even harder to provide. Holter or event loop recorder recorders can be used to capture the episodes of AF. Using 24-h Holter monitoring, only 23% of cases were detected among PAF patients whose diagnosis was confirmed by continuous bedside electrocardiograph (ECG) monitoring, which indicates an underestimated detection of PAF leading to inadequate treatment [7]. Using 7-day event-loop

recording, 5.7% of cases that were missed by 24-h Holter monitoring were revealed to be PAF [7]. So it becomes evident that only ECG or Holter misses some subjects of AF and bedside ECG of longer duration improves the efficiency. All patients may not like to undergo an ECG for such a long time. Prediction methods have been studied in order to suppress PAF episodes. ECG not only helps to diagnose heart block but also detects and records the heart's electrical activity. An ECG records the strength and timing of electrical signals as they pass through the heart. With the help of technology now ECG signals can be recorded also. These recorded signals can be used for analysis in any of the following signal processing methods: Time domain, frequency domain and Non-Linear analysis method. Any of these analyses can be done to obtain the impact and depth of Cardio Vascular disease. Boston's Beth Israel Hospital (now the Beth Israel Deaconess Medical Center) and Massachusetts Institute of Technology (MIT) have supported the research into arrhythmia analysis and related subjects. They have maintained a database of ECG signals. The database is generally available with set of standard test material for evaluation of arrhythmia detectors. Same database signals and many other databases that are available freely have been used by various researchers to test their algorithms. When any algorithm or a accepted tested mechanism is able to detect PAF, the subject may undergo clinical treatment for maintaining normal sinus rhythm (NSR).

II. TIME DOMAIN ANALYSIS

The ECG is the electrical activity of the heart as it cycles through consecutive beats with respect to time. In clinical practice, doctors inspect ECG visually. Each individual beat is represented on the ECG as the "PQRST complex" as shown in Figure 1. Each sequential letter represents a sequential discrete part of the complex and each represents a different portion of the cardiac cycle as shown below:

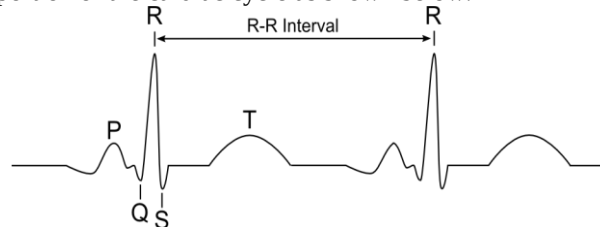


Figure 1. A common ECG signal showing R-R Interval

The RR-interval starts at the peak of one R wave to the peak of the next R wave. It represents the time between two QRS complexes useful in calculating heart rate. Time domain analysis of ECG signals is easiest of all. The process of bringing out the parameters related to analysis for Heart's health is called Heart Rate Variability (HRV) feature extraction. RR interval can be generated from a manually-annotated ECG file or automatically through the use of a QRS detection Algorithm in MATLAB or any other analysis software. In each RR interval set, the following HRV features are calculated: mean heart rate (mean HR), mean heartbeat intervals (mean RR), standard deviation of NN interval (SDNN), the standard deviation of 5-minute means of NN intervals (SDANN), root mean square of successive differences (RMSSD/rMSSD), and percentage heartbeat intervals with difference in successive heartbeat intervals greater than 50 ms (pNN50). Root Mean Square of the Successive Differences (RMSSD) is used to isolate ECG segments with abnormal RR interval, which can be a result of either PAF or other arrhythmias. As an efficient time-domain method, computation of RMSSD greatly reduces the total computational time. RMSSD is a common method to estimate beat-to-beat variability [8]. For a normal episode, the beat-to-beat variation of ECG signal is lesser than abnormal episodes so RMSSD will be smaller. RMSSD is calculated based on equation below:

$$\chi_{RMSSD} = \sqrt{\frac{1}{n} \sum_{i=1}^n \chi_i^2} = \sqrt{\frac{\chi_1^2 + \chi_2^2 + \dots + \chi_n^2}{n}}$$

The results of ECG signal of a patient which shows HRV parameters like mean RR, SDNN, SDANN, rMSSD, pNN50 of a patient before onset of PAF (24 hrs, 1 hrs, 15-20 min) is shown in Table 1.

Table 1: Changes in HRV Parameters before onset of PAF [9]

Parameter	24 hour	1 hour	15-20 min
RR interval, ms	897±13	916±15	925±16
SDNN, ms	120±4	80±3	65±4
SDANN, ms	99±3	51±3	27±2
rMSSD, ms	29±1	30±1	30±1
pNN50, %	8±1	16±7	10±1
Parameter	10-15 min	5-10 min	0-5 min
RR interval, ms	924±16	909±17	906±16
SDNN, ms	68±4	70±4	70±4
SDANN, ms	31±2	33±3	32±3
rMSSD, ms	31±2	31±1	31±2
pNN50, %	11±1	10±1	10±1

To determine the R-R interval behavior in atrial fibrillation, at least some correlation between the duration of a R-R interval is expected. The successive duration of R-R interval in PAF changes significantly, the same is shown in histogram before onset of PAF in Fig 2.

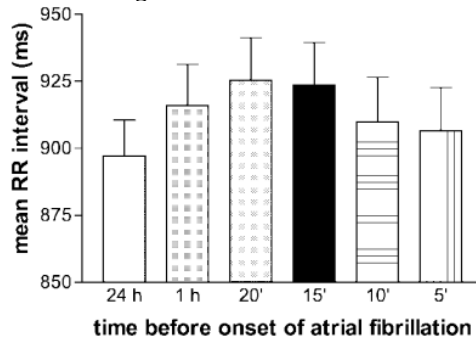


Figure 2. Histogram on Mean R-R interval changes v/s time before onset of PAF [9]

III. FREQUENCY DOMAIN ANALYSIS

The time domain analysis algorithms are reporting the results with good sensitivity and specificity while some time it is noticed that the ECG signal does not give distinguishable results. Atrial activation during PAF had for a long time been described as chaotic and random, with no discernable pattern. So the researches shifted their interest in Frequency domain analysis. It becomes evident that plotting signal in frequency domain is more differentiable than in time domain. HRV features in the frequency domain are analyzed in form of fast Fourier transforms, and the following parameters are generally calculated: very-low-frequency components (VLF; <0.04 Hz), low frequency components (LF; from 0.04 to 0.15 Hz), high-frequency components (HF; from 0.15 to 0.40 Hz), and the ratio of LF/HF. Histogram of HF and LF components are shown in Fig 3 before onset of PAF.

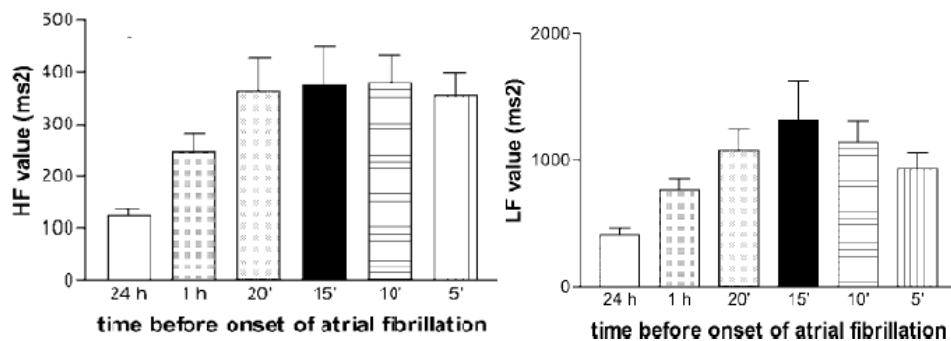


Figure 3: Histogram of HF components v/s time before PAF [9]

Power spectral Density (PSD) is the power of different frequency components in a signal. Normal ECG signal, its PSD and numerical representation of VLF, LF and HF is shown in Figure 4.

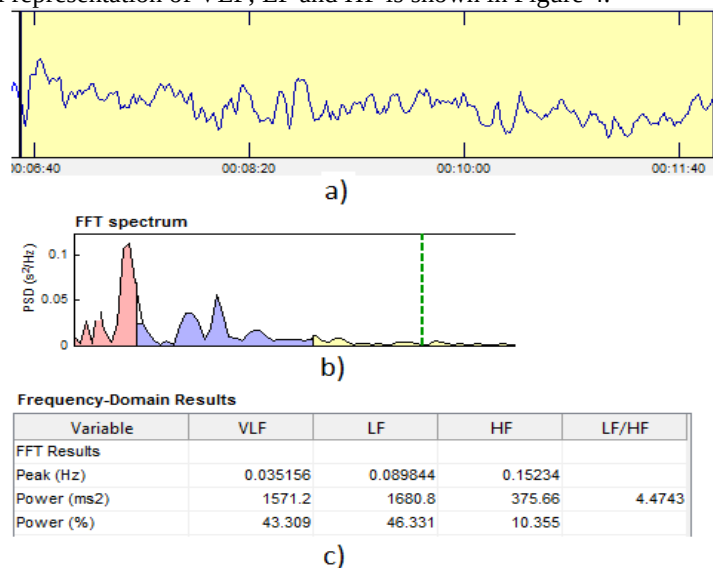


Figure 4: Frequency-Domain Analysis of ECG signal showing a) ECG signal b) FFT spectrum of ECG signal in (a). c) VLF, LF, HF frequency components weightage and % of power with LF/HF ratio

IV. NON LINEAR ANALYSIS

Non-Linear analysis is also found to be good measure of HRV. In non-linear analysis the analysis is not done w.r.t to time or frequency but according to parameters in HRV which are related to each other. In principle, these techniques have been shown to be powerful tools for characterization of various complex systems, so as in HRV measure this approach also is giving good results.

Poincare Plots is powerful analysis tool which falls in category of Non-Linear analysis. The Poincare plot is a two-dimensional scatter plot of each heartbeat interval plotted against the subsequent interval, and thus depicts the correlation between successive heartbeat intervals. In Poincare plots two adjacent RR intervals are compared on x and y axis. If we see RR intervals which are at same distance apart as compared to RR intervals which are not equidistant and we draw an ellipse across the line SD2 more points will lie outside that ellipse as compared to one which are equidistant. It is intuitive to assume that for a normal person who's having normal heart beat, all the points will lie along SD2. The Poincare plot is shown for irregular heart beat and regular heart beat is shown in figure 5 :

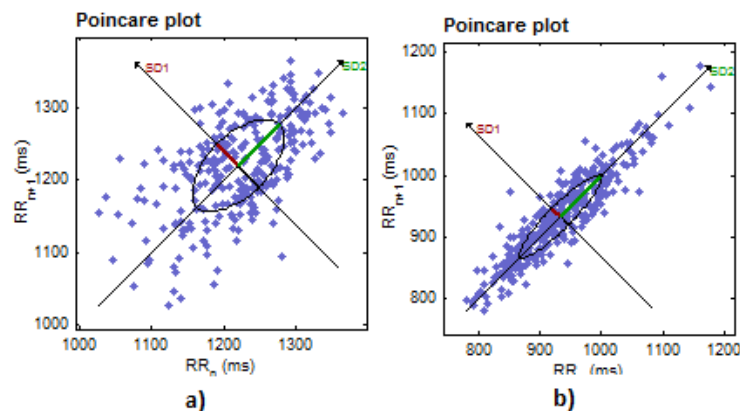


Figure 5: a) Poincare plot showing consecutive RR intervals, considerable points lying outside the ellipse depicting irregular RR intervals. b) Poincare plot showing consecutive RR intervals, considerable points lying inside the ellipse depicting regular RR intervals.

V. CONCLUSION

This paper has reviewed and categorizes the various studies that has been done for the analysis of Paroxysmal Atrial Fibrillation. All methods have their own merits and demerits. Considerable progress has been made in PAF detection throughout the years, but no promising method has been proposed yet. Even some scientists have developed softwares which generates a comprehensive report based on all three types of analysis. The data which compares the sensitivity and specificity is shown in table 2.

The main challenge to detect PAF is due to lack of precise characterization of ECG signal. Hence searching for better metrics to characterize the ECG signal for PAF detection is a future direction of work. With respect to the found results mentioned in table, nonlinear measures can be investigated further in future studies of heart rate variability in different cardiac diseases. The successful treatment of these measures may result in a better understanding of the nature of HRV.

Table 2: Performance analysis of various approaches

Approach	Sensitivity (%)	Specificity (%)
Time Domain Analysis	90	95
Frequency Domain	43.0	99.3
Non-Linear Analysis	91.5	96.9

REFERENCES

- [1] "Report of working group on Disease Burden for 12th Five Year Plan 2012-2017", Planning Commission, Government of India.
- [2] "National Cardiovascular Disease Database Report 2014 Ministry of Health & Family Welfare", Government of India and World Health Organization.
- [3] Madhavan SR et al, "Epidemiology of Sudden Cardiac Death in Rural South India" Indian Pacing and Electrophysiology Journal (ISSN 0972-6292), 11 (4): 93-102 (2011)
- [4] D. Nagaraja, G. Gururaj, N. Girish, Samhita Panda, A.K. Roy, G.R.K. Sarma & R. Srinivasa "Feasibility study of stroke surveillance: Data from Bangalore, India" Indian J Med Res 130, pp 396-403, October 2009.
- [5] "Health and Economic Burdens of Stroke and Atrial Fibrillation". Pfizer Incorporation, May 2014.
- [6] Denis Jabaudon, Juan Sztajzel, Katia Sievert, Theodor Landis, Roman Sztajzel, "Usefulness of Ambulatory 7-Day ECG Monitoring for the Detection of Atrial Fibrillation and Flutter After Acute Stroke and Transient Ischemic Attack". In American Heart Association Journal, Pages 1647-1651, May 2004.
- [7] Desok Kim, Jae-Hyeong Park and Jun Hyung Kim. "Development of Computer Aided Prediction Technology for Paroxysmal Atrial Fibrillation in Mobile Healthcare, Cardiac Arrhythmias" - New Considerations .pages 515-535, February 2012.
- [8] A. H. M. Zaidul Karim and Md. Meganur Rhaman. "Identification of Atrial Fibrillation (AFIB) of Heart Using Robust

- Statistical Tools and Approximate Entropy Method". International Journal of Computer and Information Technology (IJCIT) 2011.
- [9] Marco Bettoni, MD; Marc Zimmermann, MD, FESC "Autonomic Tone Variations Before the Onset of Paroxysmal Atrial Fibrillation". Circulation is published by the American Heart Association. Pages 2753-2759, May 2002

BIBLIOGRAPHY OF AUTHORS



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