33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Atrial Fibrillation Source Identification

Raja Sarath Chandra Prasad Vaizurs[1], Ravi Sankar[1], Fabio Leonelli[2],
[1]Department of Electrical Engineering, College of Engineering, University of South Florida,
[2]Division of Internal Medicine, Division of Cardiology, College of Health, University of South Florida.

***Abstract*—Atrial Fibrillation, a common arrhythmia accompanied by an increased morbidity and mortality remains difficult to treat either with medications or invasive procedures. Targeted destruction of atrial fibrillation triggers offers the best hope for permanent resolution of the arrhythmia. In this work, identification of atrial triggers is based on the analysis of complex endocardial recordings. Here, we propose a novel algorithm to detect the source of atrial fibrillation by classifying the signals originating from the four pulmonary veins in the left atrium.**

I. INTRODUCTION

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice. Potential consequences of AF range from mild symptoms such as fatigue and palpitations to severe complications including stroke and congestive heart failure. Given the increase in life expectancy and the strong relationship existing between aging and AF, the number of patients affected by this condition are predicted to become over 15 million by the year 2050 [1]. The natural history of AF is to progress from a few episodes to a permanent form. This behavior is best explained by the presence of fast discharging foci inducing AF. Artificial pacing is a constant rapid rate stimulation inducing electrophysiological changes on the rest of the atrial tissue. Because of this, the tissue is able to sustain multiple reentrant arrhythmia coalescing at the same time (perpetuators). This mechanistic hypothesis also explains why it is difficult to restore long term sinus rhythm with medical therapy. At present, Radio Frequency Ablation (RFA) which is a catheter based destruction of arrhythmic tissue offers the best chance of abolition of AF and maintenance of sinus rhythm. Nevertheless, the success rate of the current treatments of AF is only 30-35%. Precise identification of tissue involved in the triggering or maintenance of AF remains elusive leading to larger tissue destruction and less than ideal procedural results.

Clinical observations regarding location of AF sources and propagation of fibrillatory activity have provided a fund of knowledge allowing researchers to focus on interpretation of recorded intracardiac electrograms from specific areas o the left atrium. Left to right atrium gradient of frequencies and the observation of dominant frequencies in the left atrium suggests a preferential origin of AF in the left atrium. Clinically, the AF is assumed to be originating from the pulmonary veins. Hence the main objective of this research is to characterize and classify the signals from the four pulmonary veins in the left atrium using frequency domain analysis and statistical pattern recognition techniques. The classification of AF signals obtained from the pulmonary veins was done based on dominant frequency, frequency distribution and normalized power.

This research was supported in part by the College of Engineering Interdisciplinary Scholarship Program. The work was done in collaboration with Dr. F. Leonelli, M.D., Director of USF Clinical Electrophysiology Training Program at USF College of Medicine and Cardio Electrophysiologist at the James A. Haley Veterans Hospital.

II. METHODOLOGY

The basic block diagram for identification of single source of AF is shown in Figure 1.

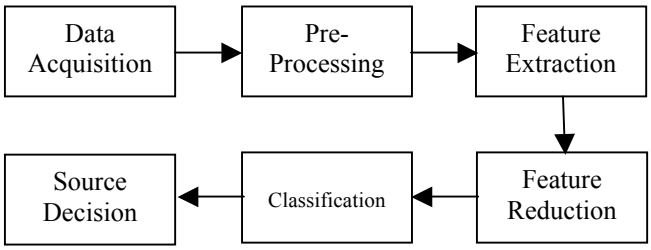

Fig. 1. Block Diagram for Identification of Single Source

A. Data Acquisition and Pre-Processing

Data was collected from patients referred to the Cardiology Arrhythmia Service at the James A Haley Veterans Medical Center Affairs for RFA of AF. During standard RFA procedure, a number of recording catheters are positioned inside the patient's heart. The catheter in the coronary sinus (a vein in the back of the heart running along the inferior border of the left atrium) will be selected for study data recording because of its stability as it has no movement during the heartbeat. Left atrium is divided arbitrarily in to right superior and inferior, left superior and inferior. By considering the left atrium into four segments, the focal activation of AF triggers was stimulated by artificially pacing the method at each of these segments. The AF data recorded from the coronary sinus was stored and analyzed offline. The AF signals acquired were sampled at frequency rate of 977 Hz by cardio lab in VA hospital. This study comprised of 18 patients with paroxysmal AF undergoing ablation.

The intracardiac signals measured by catheters contain much more atrial activity compared to that of ECG. This is because catheters collect the data much more closely from

each tissue. Hence, AF can be analyzed in a better way with intracardiac signals compared to ECG signal. The signals were normalized to zero mean and unit variance. Fig 2 shows the AF signal collected from the ECG and AF measured by catheters

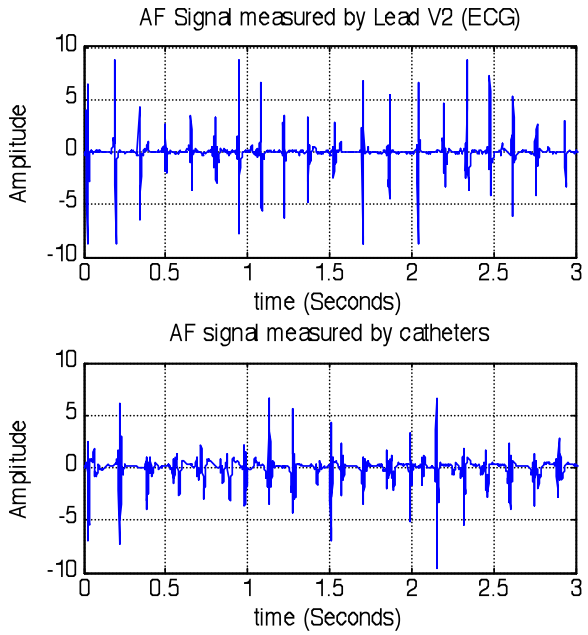

Fig. 2. AF signal as measured by ECG and Catheters

B. Feature Extraction

Feature extraction is a way of simplifying the amount of data required to describe a large set of data accurately. The features extracted for classifying the signals originated from each pulmonary vein are dominant frequency, frequency distribution and normalized power.

1. Dominant Frequency

The most common application of frequency domain analysis is finding the dominant frequency. Dominant frequency analysis is an effective way of estimating the atrial rate in AF. It is also used to detect rapid activations areas and changes in the rate [2]. The dominant frequency is defined as the frequency of the sinusoidal waveform with the highest amplitude. Currently, AF researchers believe that the dominant frequency of AF signal will be in the range of 4 to 9 Hz [3]. Dominant frequency is computed using the following steps [4].

- Band Pass Filter (Pass-band: 40-250 Hz)
- Rectification (Absolute Value)
- Fast Fourier Transform (FFT)
- Low Pass Filter (Cutoff frequency: 20 Hz)

The intracardiac activity collected from the Coronary Sinus (CS) is located between the left atrium and left ventricle. Hence, the sensors on catheters collect both the atrial activity and ventricular activity. Dominant frequency is calculated to find the atrial activation rate. In order to calculate the dominant frequency, ventricular activity must be removed. As the ventricular activity always has high amplitude compared to atrial activity, the signal can be clipped at certain amplitude to get the atrial activity. In general the amplitude of atrial activity is always expected to be below 2 mV. Figure 3a shows the dominant frequency with ventricular activity and Figure 3b shows the dominant frequency with ventricular activity clipped. Figures 4a and 4b show the dominant frequency in the left atrium and right atrium, respectively.

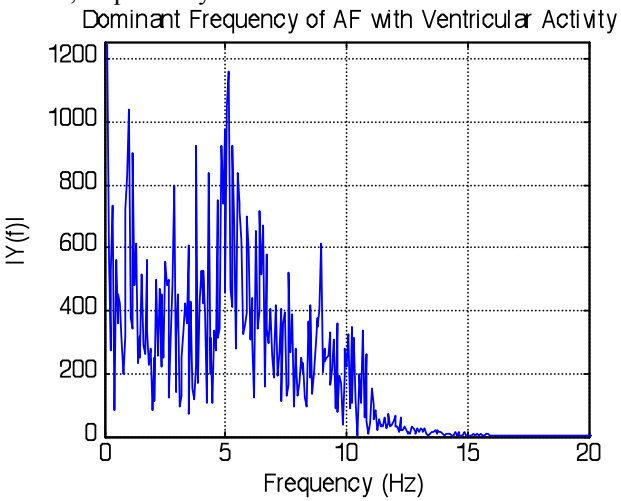

Fig. 3a. Dominant Frequency of AF with Ventricular activity

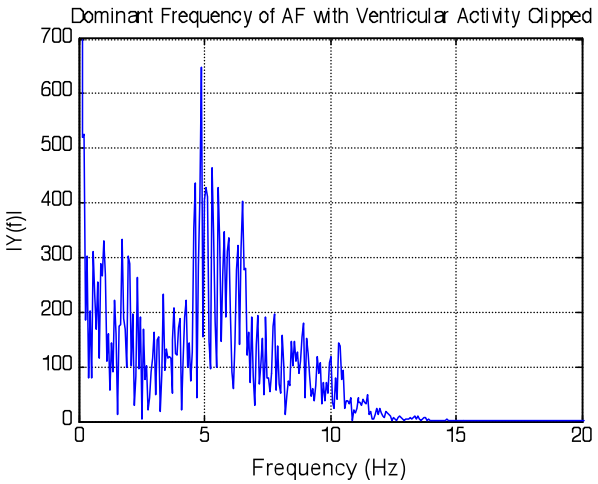

Fig. 3b. Dominant Frequency of AF with no Ventricular activity

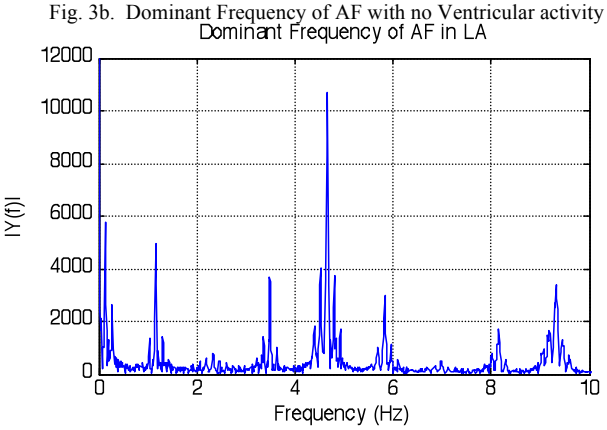

Fig. 4a. Dominant Frequency of AF in Left Atrium.

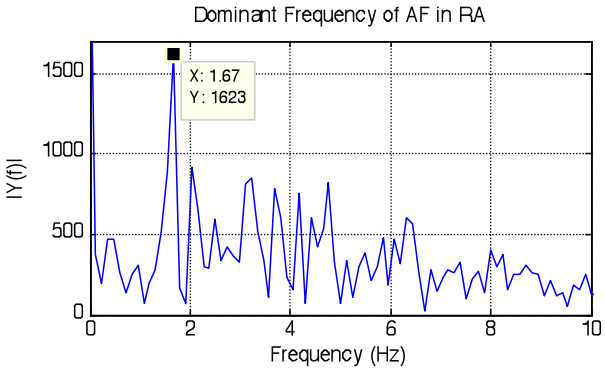

Fig. 4b. Dominant Frequency of AF in Right Atrium.

The dominant frequencies of a patient at right superior, right inferior, left superior, left inferior pulmonary veins were found to be 5.307, 4.293, 6.053, and 4.92Hz, respectively as illustrated in Figure 5. The mean and standard deviation of the dominant frequencies at the right superior, right inferior, left superior, left inferior pulmonary veins were found to be 5.2±0.21, 4.3±0.34, 5.9±0.15 and 4.8±0.2 Hz, respectively.

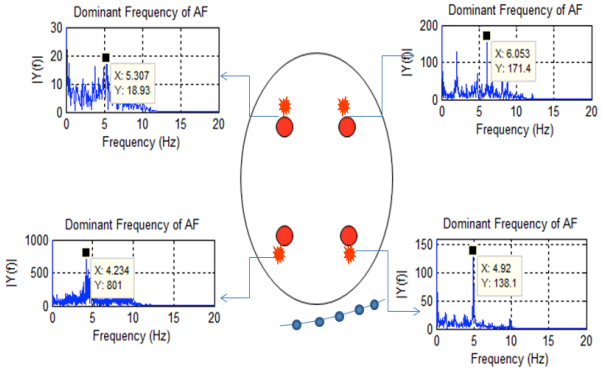

Fig. 5. Dominant Frequency at four pulmonary veins in a patient with spontaneous paroxysmal AF.

2. Frequency Distribution

A histogram is a graphical representation of data analysis for summarizing the distributional information of a variable. In this work, the AF signal was filtered using a band pass filter (pass-band: 40-250 Hz). The histogram of the filtered AF data was constructed with 100 bins. In AF, the atrial activity and ventricular activity was found to be in the ratio of 4:1. Hence this atrial activity can be found with the bins of highest amplitude on the histogram. From the histogram of the filtered signal, three features were selected for the classifying the signal originating four pulmonary veins. They are as follows:

- Frequency at which highest amplitude is obtained in Histogram.
- Frequency at which second highest amplitude is obtained in Histogram
- Frequency at which the amplitude is 20% of the highest amplitude.

Figure 6 shows the frequency distribution of a patient at right superior, right inferior, left superior, left inferior pulmonary veins.

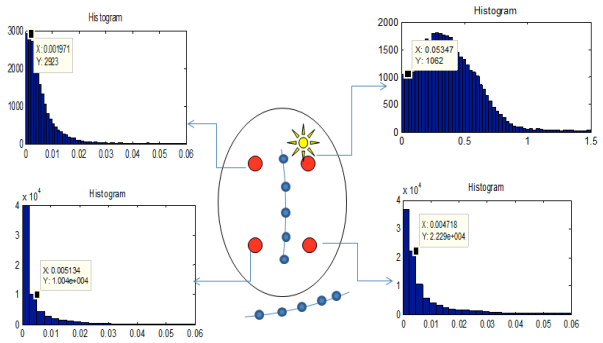

Fig. 6. Histogram of Band pass filtered AF signal at four pulmonary veins in a patient with spontaneous paroxysmal AF.

3. Normalized Power

This section explains how the normalized power was used to classify the AF signals obtained from the four pulmonary veins. An AF signal was stimulated with one of the pulmonary veins as focal activation point and collected at CS through catheter as explained in the data acquisition protocol. The feature for classifying AF signals was extracted by calculating the power loss as the signal travels from origin (stimulated pulmonary vein) to the destination or final point (catheter). The destination point was varied by moving the catheter to other pulmonary veins other than the stimulated pulmonary vein. Initially, power of the stimulated signal along with power of the signal captured at coronary sinus catheter was calculated. Further, the power loss of the signal as it travelled from stimulated pulmonary vein to catheter can be found by subtracting the power of signal at catheter from the power at the stimulated pulmonary vein. Then, the destination catheter is moved at other pulmonary veins to collect the signal at each pulmonary vein (other than the stimulated pulmonary vein). Hence, we can calculate the power at each pulmonary vein, and also the power loss of the signal. Further, each power loss obtained is normalized by the total power loss of the signal. This gives a set of four features.

For example, assume that the signal is stimulated at the right superior pulmonary vein (PV1). The power of the signal is calculated by measuring the average power under the power spectral density curve and assigned as P_1. This signal travels through the left atrium and is captured at CS catheter. Let the power of the component measured at CS catheter be P_{c1}. Power loss as the signal travelled from PV1 to CS catheter is calculated. This can be found by subtracting P_{c1} from P_1. Let the power loss be P_{L1}. The signal powers captured at other pulmonary veins as the signal travels from stimulated vein was also calculated as P_2, P_3, and P_4. Further, the power losses from these pulmonary veins to CS catheter were calculated as P_{L2}, P_{L3}, and P_{L4}. In real time, every person will not have same heart beat or stimulating energy. So the power loss is normalized as given by $P_{L1}/ (PL1_+ P_{L2+} P_{L3+} P_{L4})$. The power losses from right superior, right inferior, left superior, left inferior pulmonary veins to coronary sinus catheter were found to be 3.2, 4.3, 1.6, and 1 micro watts, respectively. This feature was found

to be different for all pulmonary veins.

C. Feature Reduction and Classification

The total feature set (f_1 to f_8 extracted from dominant frequency, frequency distribution and normalized power) was used to classify the signal originated from the four pulmonary veins. Apart from these features, some other features like mean, standard deviation of R-R (R is a part of ECG signal) intervals, and number of zero crossing points were extracted. These features were found to be same in all the four pulmonary signals, and hence these features were not applied to classification. Only features (f_1 to f_8) were applied to Principal Component Analysis (PCA). The first principal component contains nearly 52% of the variance. The first component and second component together achieved 74%. Further, as the principal components were added, the variance increased to 81%, 87%, 92%, 96%, 99% and 100%. Data compression can be made by discarding the last feature vector or last principal component. This can be achieved by losing only 1% of the variance. Hence considering the first seven principal components, Linear Discriminant Analysis (LDA) was applied to classify the AF signals obtained from the four pulmonary veins. The comparison of classification errors of LDA and Quadratic Discriminant Analysis (QDA) are shown in Table 1.

Table 1. Classification Error Comparison

Pulmonary Vein	Right Inferior	Right Superior	Left Inferior	Left Superior
Classification Error of LDA	8.1%	5.4%	7.6%	4.1%
Classification Error of QDA	12.5%	9.1%	13.0%	6.2%

III. Discussion

Among the 18 patients data recorded from VA hospital, features extracted from 10 patients were used to train the LDA and QDA models. While classifying the other 8 patients, LDA was found to have less classification error compared to that of QDA. The classification errors for both the left and right inferior veins were found to be high as the frequency distributions were similar. The algorithm was tested clinically on both stimulated and spontaneously generated AF and the source was correctly found based on AF data from 18 patients (verified by the participating cardiologist who treated the patients). Hence, a novel methodology to identify the source has been developed by classifying the signals originated from the four pulmonary veins. Potentially, AF is expected to have multiples sources triggering together producing a highly disorganized signal. This research work presents promising results that can be used in the future for developing an algorithm to identify multiple sources of AF.

IV. Conclusion And Future Work

In this work, we hypothesize that we are able to identify direction of AF activation wave front and therefore their anatomical location or site of activation for a single source. Extensive research has been carried out in the development of synchronous and asynchronous directional AF. Triggers at times isolated but more frequently multiple, create a substrate characterized by rapid discharging foci mostly localized in the four pulmonary veins. Breakdown of uniform conduction is frequently observed during these fast discharging rates and this adds to the complexity of the signal recorded endocardially. Hence, the understanding of the mechanism maintaining AF is far from complete. As time domain based recording do not allow us to advance our knowledge beyond a simple grasp of the seemingly chaotic nature of this arrhythmia, new tools are necessary to achieve the goal. Identification of potential initiating sources requires a decomposition of the complex AF signal into its basic triggers and an algorithm which provides information regarding their anatomical sites. In future, the initial signal of AF can be deconstructed to ascertain if the organized rhythm observed during ablation is identified as one of its components.

In the future, AF signal can be deconstructed to ascertain if the organized rhythm observed during ablation is identified as one of its components. Most of the ablations are performed during spontaneous or induced AF. As atrial tissue is ablated is to observe a reorganization of fibrillation into a more organized rhythm and finally, as ablation is directed to the sources of these rhythms return to sinus rhythm. Our hypothesis is that these rhythms are the triggers of AF. Their fast stimulation of atrial tissue or possibly the combination of two or more sources induce break down of regular activation into disorganized waves rendering the resultant signal of AF impossible to analyze into their initial components. These components are true initiator of AF and we speculate that, elimination of these sources will terminate the AF and potentially cure it.

References

[1] V. Fuster *et al*. "Acc/aha/esc 2006 guidelines for the management of patients with atrial fibrillation: a report of the American college of cardiology/American heart association task force on practice guidelines and the European society of cardiology committee for practice guidelines: developed in collaboration with the European heart rhythm association and heart rhythm society." *Circulation,* vol. 114, pp.257-354, 2006.

[2] A. Verma *et al*., "A prospective multicenter evaluation of ablating complex fractionated electrograms (CFEs) during atrial fibrillation (AF) identified by an automated mapping algorithm: acute effects on AF and efficacy as an adjuvant strategy," *Heart Rhythm*, vol.5, pp. 198-205, 2008.

[3] K. Ropella *et al*., "Effects of procainamide on intra-atrial electrograms during atrial fibrillation: Implications for detection algorithms," *Circulation*, vol. 77, pp. 1047–1054, 1988.

[4] G. Botteron and J. Smith, "A technique for measurement of the extent of spatial organization of atrial activation during atrial fibrillation in the intact human heart," *IEEE Trans Biomed Eng.*, vol. 42, no. 6, pp. 579–586, June 1995.