

A Platform to guide Catheter Ablation of Persistent Atrial Fibrillation using Dominant Frequency Mapping

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Abstract

Dominant frequency (DF) mapping has been widely used to study the pathophysiology of atrial fibrillation (AF). In this study, a DF mapping system was developed to guide catheter ablation on electro-physiology (EP) procedures of persistent AF patients. The proposed platform has an automated graphical user interface (GUI) that processes non-contact unipolar electrograms (EGMs) recorded simultaneously by St. Jude Ensite Velocity System and provides 3D representation of the left atrium with DF behaviours and phase analysis.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia in clinical practice, affecting 0.4% of the general population, and 5%-10% of those over 60 years old [1, 2]. However, the underlying pathophysiological mechanisms remain unclear [3, 4]. Recent work has shown that atrial sites hosting high DF might be important sites for the maintenance of AF [5]. In addition, targeting in maximal DF sites in the implementation of real-time DF mapping lead to elimination of left to right frequency gradients [6]. The spatio-temporal behaviour of DF sites was further investigated and recently has been shown to be largely temporally unstable, with transient episodes of stable DF for short segments, as well as a degree of re-appearance of DF activity over time [7]. In addition, organization index (OI) and Regularity index (RI) have been used in both basic and clinical to help in identifying possible AF arrhythmogenic sites [5, 7]. Recently, phase analysis has been shown as a promising additional tool to identify possible AF sites [8]. Therefore, these studies may lead the potential importance to access the DF and phase features during the EP procedures.

The main objective of this study was to design and develop a near-real time graphical user interface (GUI) that allows for DF mapping and for the DF spatio-temporal be-

haviour assessment persistent AF ablation procedures. The DF GUI has been developed to be used as an auxiliary tool with the time-based domain system to target atrial substrate in patients with persistent AF.

2. Method

5 persistent AF patients undergoing left atrium (LA) catheter ablation were enrolled. A high density non-contact balloon array (St. Jude Ensite Velocity System) was introduced transeptally in the LA. 2048 channels of unipolar EGMs (sampling frequency: 2034.5 Hz) were simultaneously acquired for 30 seconds. During the EP procedure, data were exported from the Ensite Velocity System and investigated on the DF mapping platform hosted by a user-oriented GUI developed in the MATLAB environment (R2013b, Mathworks, MA, USA), running on a high-specification laptop (Intel Core i7-4800MQ processor, 32Gb DDR3 RAM, 32Gb solid state drive).

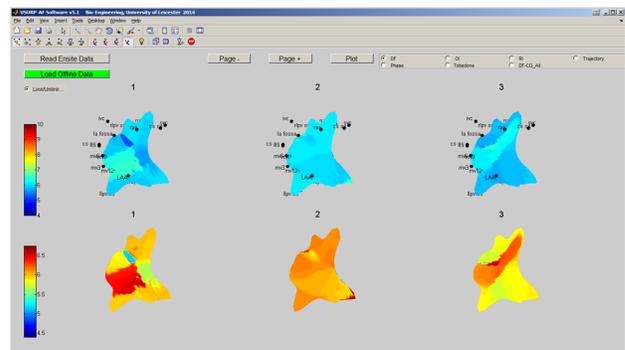


Figure 1. Screenshot of the main feature (DF plots) of the platform. The first row is sequence of DF maps with fixed colour range (4-10 Hz), while the second row is showing the same sequence of DF maps with adaptive colour range.

The data processing performed in the GUI (Figure 1) has been divided into the steps as illustrated in Figure 2. Each of the steps will be explained in the following subsections,

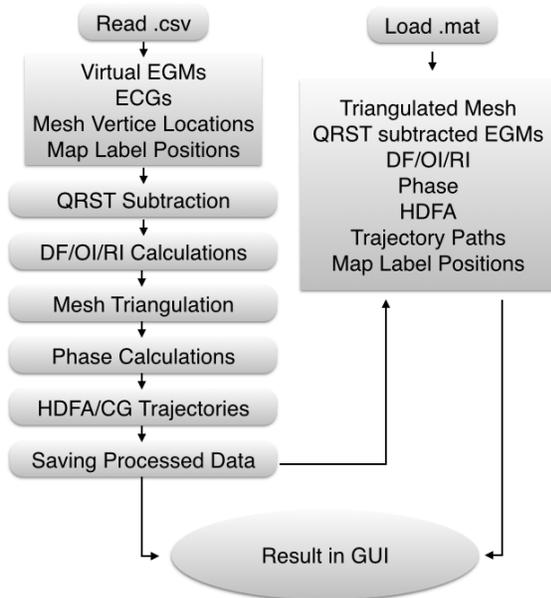


Figure 2. The flow chart of the System of data processing, including both on-line analysis (left) and off-line analysis (right).

and the processing time for each step was measured.

2.1. Platform Supported Files

The DF GUI (Figure 1) allows for on-line and off-line EP investigations, by reading either exported comma-separated data from Ensite Velocity System (.csv) or loading pre-saved Matlab format (.mat) by using the Read/Load buttons.

As illustrated by Figure 2: 2048 virtual EGMs with 30 seconds duration, mesh vertices and map labels locations and surface ECGs are read to the memory, during the on-line analysis. Processed data is read during off-line analysis, hence the following steps of data processing can be skipped.

2.2. QRST Subtraction

QRST subtraction (previously described in [9]) of all 2048 virtual EGMs was performed to remove the effect of ventricular far field. The user is allowed to select the ECG lead, where a QRS onset and T end segmentation will be performed and projected to the intra-cardiac signals after coherent delay adjustment. Then, the raw EGMs are replaced by the atrial EGMs, stored in memory.

2.3. DF Calculation

Fast Fourier transform (FFT) was performed on all 2048 atrial EGMs (after QRST subtraction) with Hamming win-

dow and zero padding factor of 5, resulting in a frequency step of 0.05 Hz. DF was defined as the frequency peak from 4 Hz to 10 Hz of the power spectrum, and DF calculation was performed on 4 seconds windows with 50% (2 seconds) overlap. [7]

Regularity Index (RI) was defined as the ratio of area of the DF peak and the total area of the power spectrum. [5]

Organisation Index (OI) was defined as the ratio of area of the DF peak and all the harmonics (up to 20 Hz) and the total area of the power spectrum. [2]

2.4. High DF cloud and Trajectory of Centres of gravity (CG)

High DF areas (HDFA) were defined as regions with DF between the maximum DF and 0.25 Hz below during each time window. For each high DF area, the centre of gravity (CG) was found and the trajectory of the shorted path from the previous CG was also calculated. [7]

2.5. Mesh Triangulation

The locations of 2048 (64×32) virtual electrodes provided by the system can be easily manipulated to form a mesh of rectangles. Nevertheless, this type of mesh would result in steep CG trajectories. The atrium was therefore re-meshed to obtain a triangular structure in order to obtain smoother CG trajectories.

2.6. Phase Calculation

The phase of each channel was generated as the inverse tangent of the imaginary part of the Hilbert transform of the virtual EGMs [10]. Thus, the each sample of the EGM phase was limited between $-\pi$ and $+\pi$.

2.7. Saving Data for Off-line Analysis

The processed data, which includes the measured DFs, trajectories, phase, CGs, labels positions, vertices and triangulations, was saved in .mat file for future off-line analysis (Figure 2).

3. Result

The proposed tool has a user-oriented interface, which can be easily operated by the clinicians. The DF GUI has embedded the following main features: Load/read data; map type selection; time window selection; rotation control.

3.1. Load/Read Data

The Read/Load buttons on the left upper corner of the main window are used as the analysis type selection. If

the user clicks on one of the buttons, a file selection window will pop up. The Read button is used during on-line investigations, while the Load button is used during off-line analyses. Once the data files are selected, the button is changed to red showing the tool is processing the data and will turn green when ready to show the results.

3.2. Map type panel

On the right upper corner of the main page, a group of buttons were designed to allow the user to change the type of parameters showing on the 3D mesh. One of these buttons can be active, showing the current status of the plots, accordingly:

(i) DF: By default, the button is set to DF, where a group of sub-plots (2×3) are shown in the axis. Note that the first 3 plots (first row) are 3 continuous windows of DF plots with the fixed colour code range (4 Hz -10 Hz), while the second row shows the adaptive colour code range, which ranges from the minimum to the maximum of the three maps. This provides a more detailed look of the landscapes and contours of the DF maps.

(ii) OI/RI: Once the user changes the button to OI/RI, the 3 plots in the second row will change to OI/RI of the same time window in adaptive colour code range.

(iii) Phase: Like the previous options, the phase can also be shown in second row as 3 plots (Figure 3). In order to representing the phase, a slider was designed to play the phase movie in 3D. Pause and play back are available in this section, the play speed can also be changed by entering an integer number in the right lower corner as frames per step.

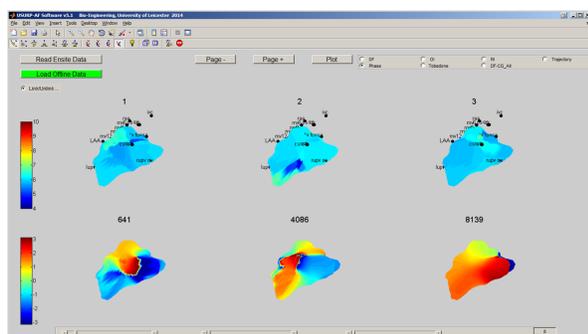


Figure 3. DF (upper graphs) and Phase animation plots (lower graphs), here the sliders at the bottom can be used to control phase plot movie as described.

(iv) Trajectory of CGs: Once the trajectory radio button is selected, 2 large plots of only the High DF clouds and CG of the first time window are shown. The 'Next' button can be operated to change the current window and all the CGs and trajectories/paths of how the CGs travel in on the 3D mesh. As shown in Figure 4, the red area refers to the

current high DF cloud(s), where the CG is the white dot with black edge in the middle of the cloud. The magenta dots represents the previous CGs and the white dash line is the shorted path between CGs on the mesh.

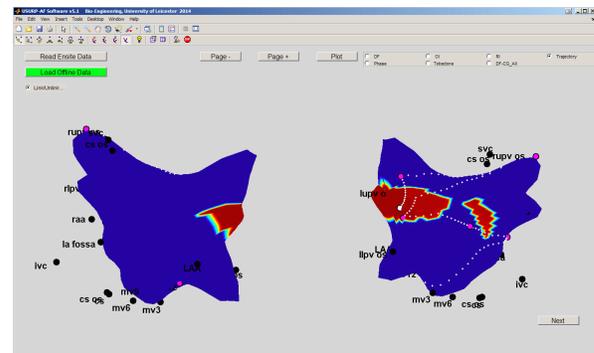


Figure 4. Trajectory of CGs and current High DF cloud

(v) Summary of CGs: The tool allows to shown one larger plot of the CG dots on the mesh as a summary of the CGs clustering (Figure 5). In this section, the virtual EGMs of interested can be accessed by selecting the nodes on the mesh. As shown in Figure 5, the EGM signal is from the white circle on the heart mesh.

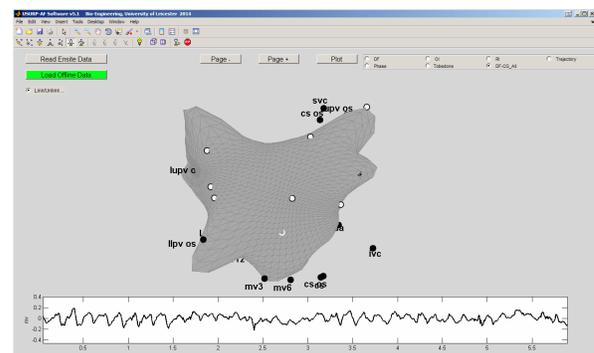


Figure 5. Trajectory of CGs and current High DF cloud

3.3. Window Selection

The 'Page+' and 'Page-' buttons allow the user to go forward and backwards by three windows per step(or the number of windows available if fewer than three at beginning or the end of the segment). The 'Plot' button is functioning like a 'reset' or 'force to plot', which can be used when a reset of starting window is needed in the CG trajectory plot.

3.4. Rotation Control and Labels

The Link/Unlink button on the left upper corner is designed to link and unlink the rotation with all six plots.

Thus, the user can rotate the plots together or individually by ticking and un-ticking the radio button.

As seen in Figure 1 3 4 and 5, the software also allows to show the location references (position labels) and names created in Ensite Velocity system during the EP study.

3.5. Processing Time

A processing time test was performed on the data on 30 second data of each patient. The overall platform processing time (mean \pm SD) per module for the 5 patients is shown on Figure 6 (total processing time 10.4 ± 1.5 min).

It can be seen from Figure 6 that the main module causing the variation of the processing time between patients is the QRST subtraction. This is due to different heart-rate, as fewer or more QRST segments are included in the pattern. A strong correlation between the heart rate and QRST subtraction time has been noticed.

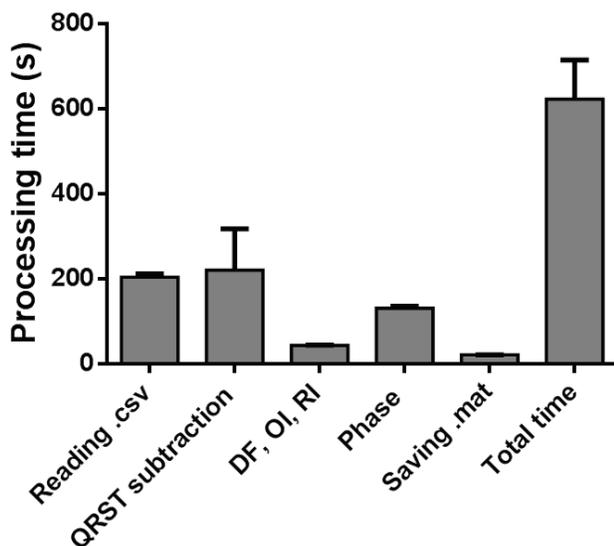


Figure 6. The processing time of the key modules

4. Conclusion

The proposed DF mapping platform is a fully automated GUI that provides 3D representation of the left atrium with the DF behaviour during the EP procedure with commercial available mapping system (St. Jude Ensite Velocity). This DF GUI has been successfully used to guide catheter ablation on EP procedures in 5 persistent AF patients and the clinical outcomes are currently being assessed.

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