A New Scheme for Observation and Interpretation Atrial Fibrillation

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***Abstract*—Atrial Fibrillation (AF) is a prevalent cardiac arrhythmias in modern society. It is mainly classified into three types: paroxysmal AF, persistent AF and permanent AF. Most of AF is supposed to have more than one focus or some abnormal propagating paths. Surgical therapy has been applied to eliminate AF for almost two decades and radio frequency ablation is invented in order to efficiently deactivate the focus or cut off the abnormal propagating paths. Unfortunately, there is little effect to treatment persistent AF and permanent AF in the respect that their mechanisms are still unknown. Epicardial mapping is an important tool to investigate the cardiac arrhythmias. The purpose of our research is to develop such a system and its corresponding user interface, which depicts the electrical activity on the heart surface. In animal experiment, ten canine models are established by chronic rapid atrium pacing at a high frequency of 370-400 bpm, 128 electrodes are sutured to the exposed canine heart in three patterns: full heart, atrium only, ventricle only. 3D dynamic mapping is formed based on the sampled voltage signals on these electrodes. The isopotential mapping diagram is displayed on the user interface (UI) software as a continuous animation. This study brings forward a new scheme for observation and interpretation AF. By comparing the signal morphology on each channel and 3D whole heart isopotential mapping diagram, an approximate image of electrical activation propagation can be formed. So the implementation details of this scheme will be discussed in this study.**

Keywords-Atrial Fibrillation; epicardial mapping; DirectDraw; OpenGL; Interpolation; Multiple threads; strategy

I. INTRODUCTION

AF is a complex arrhythmia and divided into three types, paroxysmal AF, persistent AF and permanent AF. Persistent AF and permanent AF can extend to several weeks or 1-2 years. In WPW (one kind of AF), patient's ventricle beats more than 300 times per minutes. AF is usually the main causation of kidney embolism and brain embolism. Mapping is commonly used in electrophysiology study and clinical precision measurement. It can reflect the conduction process of depolarization on the whole cardiac surface in complex arrhythmia such as AF, and is commonly used in AF therapy of radiofrequency ablation, which is considered to be the only way to cure AF once for all. Epicardial mapping system described here is a kind of electrical mapping. Fig. 1 shows the interior vision of epicardial mapping system and its UI software designed by Fudan University, Electrophysiology and Pacing Lab [1]. 128 electrodes on 3-4 soft patches are sutured into the surface of atrium, ventricle or the whole heart when system works. The detected signals of 128 channels are transmitted to PC through USB port, and displayed in the UI software. In our epicardial mapping system, the sample frequency of each channel is 2KHz, the throughput rate of ADC on sample board is 400kHz for 12bits, and there is a 64K FIFO on the board. Video card on PC is GeForce Go 6800, which has 256MB VRAM. PC screen's resolution is 1920$\times$1200 when scrolling the waveform or rendering the 3D heart model.

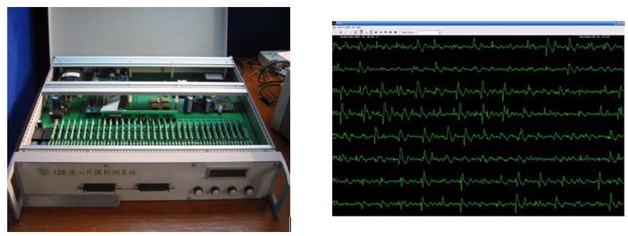

Fig. 1. Interior vision of 128 channel epicardial mapping system and UI software

II. METHODS

A. The architecture of UI software

UI software is functional depicted in Fig.2. The interface between UI and Epicardial mapping hardware is provided by sample card dynamic link library (DLL).

The whole software system can be divided into two parts: graphic user interface part (GUIP) and server provider part (SPP). GUIP contains UI frame packet, which inherits from Microsoft foundational class library (MFC). It supports document-view architecture [2], and constitutes the main frame of UI software. SPP is composed of follow classes: worker container and its children, interpolation worker and its children, DirectDraw interface, OpenGL interface and sample card DLL. Worker container is a virtual class, in which several unified thread interfaces are defined, such as resource distribution, resource reclamation, locking and releasing of multiple threads

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synchronization object et al. These interfaces should be rewritten in children of worker container. GUIP maintains an association with it. Through this association, polymorphism of interface could be implemented.

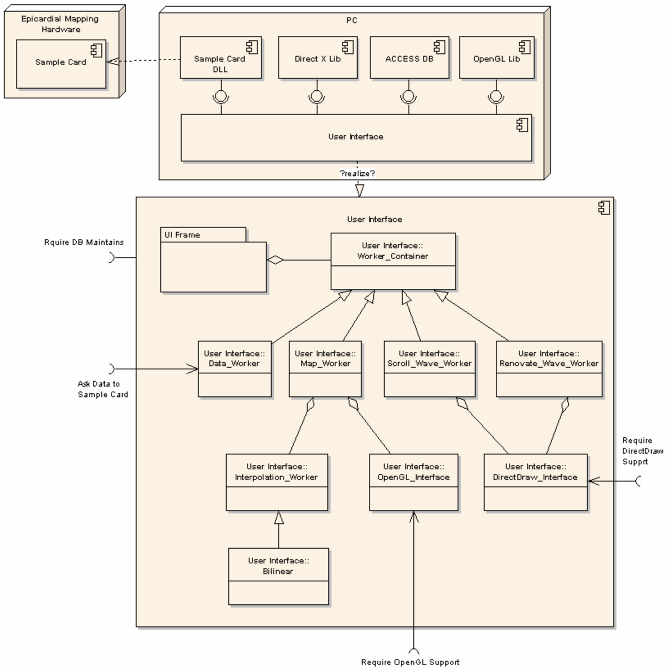

Fig.2 UI software architecture view

Each children of worker contain focus on several well intersected functions: data worker takes the responsibility of sample mission management, and file data base management; map worker uses assigned interpolation method to render a 3D heart model; scroll wave worker and renovate wave worker use DirectDraw technology to scroll or renovate wave smoothly on PC screen.

Besides the polymorphism, another shining point in architecture designation is the usage of a special design pattern, named "strategy", to implement a dynamic linkage between interpolation arithmetic and whole UI system. Map worker maintains an aggregation of interpolation arithmetic interface classes, which is also depicted in Fig.2. When GUIP asks map worker to do rendering tasks, it assigns special interpolation arithmetic by dynamically creating a concrete interpolation object, e.g. an implementation of bilinear class, which is a child of interpolation worker. Then GUIP stores the pointer of this object as an interpolation worker type and does all corresponding communications with this pointer. Profit from this design pattern, a designer could easily append a new interpolation method without rewriting the implementation function.

B. Wave scrooling and DirectDraw

In clinical usage, doctors use cardiogram to observe the patient's electrical activation in a cardiac cycle. The epicardial mapping system, introduced by this study, simulates the paper sliding activity of a cardiogram system on PC screen in order to make observer more comfortable. All signals scroll in a constrained velocity of 100mm/s when system polls each channel. Strenuous efforts are needed in developing this part of UI software for a well-maintained balance of each part must be taken into account. These parts include sampling task invoked by epicardial mapping hardware, wave-rendering task invoked by scroll wave worker and wave display task invoke by PC video card.

DirectDraw SDK is a set of API function developed by Microsoft Corporation [3]. It provides a faster and more efficient graphic engine than 32bits GDI does. Designer can use it to operate VRAM in video card directly. In this study, two main functional subsets of DirectDraw SDK, double buffer and field synchronization, are introduced in graphic interface's designation. Two buffers are created in the VRAM as GUIP is initializing, one is called primary surface, the other is called offscreen surface. The renovation operation acting on offscreen surface is invoked by a special synchronization event, which is initiated in kernel space and signaled by sampling task. After renovation is finished, scroll wave worker will be suspended pending the coming of field synchronization signal provided by PC video card. This signal awakes the scroll wave worker, which ask DirectDraw interface to duplicate offscreen surface to primary surface immediately. By this means, wave can scroll very smoothly on PC screen. This method is depicted in Fig.3. It is worthy to mention that a well-designed renovation routine in DirectDraw interface and a precise calculation for data buffer's size in data worker will remarkable improve this scheme's performance.

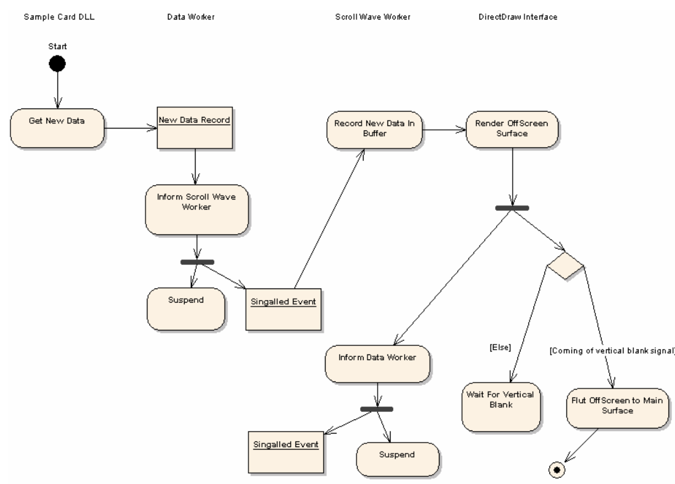

Fig.3 The activation view of one cycle in wave scrolling operation

C. 3D whole heart isopotential mapping and OpenGL

In order to depict the electrical activation's propagation on the surface of epicardium in a cardiac cycle, this system brings forward a new display mechanism named "isopotential diagram", which essentially has the same representation as contour map. Firstly, three broad-brush 3D models are created by using 3DMax and stored in corresponding text files with the extension .ase. Such kind of file contains all necessary information to depict a 3D model, e.g. the number of mesh and vertex. Map worker, mentioned in former paragraph, gets these parameters in the initialization phase and invokes OpenGL interface to display a 3D model in UI software with electrode on it. Fig. 4 shows the result of this stage.

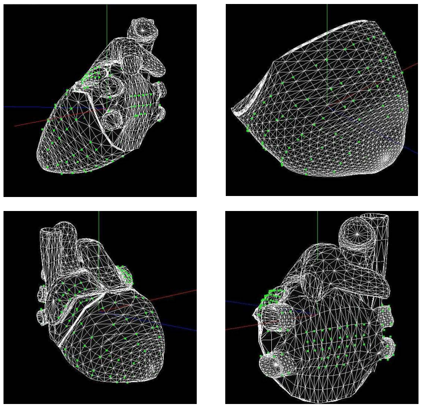

Fig. 4 Initialized 3D models
(top-left is atrium model,
top-right is ventricle model,
bottom-left and bottom-right are heart model)

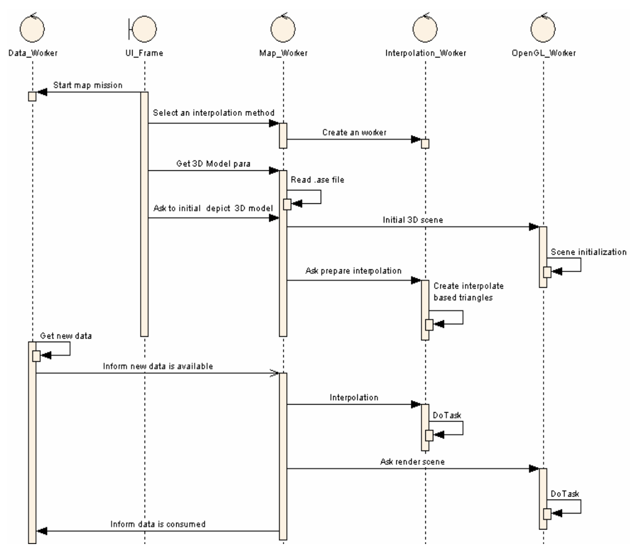

Fig.5 The sequence view of one cycle in
3D isopotential mapping operation

OpenGL is an industry standard for high performance graphics display. It is designed as a streamlined, hardware-independent interface to be implemented on many different hardware platforms [4]. OpenGL interface class defines a set of operation, which invokes API function in OpenGL Lib to do all render tasks in 3D isopotentioal mapping. The sequence view of 3D isopotential mapping is depicted in Fig. 5.

D. Interpolation arithmetic in 3D mapping

In a cardiac cycle, isopotential map could be formed by assigning different colors to different regions of heart model. The vertexes on a certain region, which has the same color, must have the same voltage value. In order to get voltage value on each vertex of 3D model, an appropriate interpolation method is needed. This arithmetic should confine to following rules which are abstracted from experiment experience:

- The electrode on each patch is regularly ranged.
- The voltage field on heart is not "smooth everywhere" in a cardiac cycle. That is to say, the grads of voltage on a certain direction is not continuous everywhere. So interpolation method should refer to both geographical relationship and voltage relationship, not only geographical relationship.
- The voltage vectors on vertexes and their adjacent electrodes in a cardiac cycle have very little difference. That is to say, both of them approximately have the same value and the same direction at a certain time. So the closer to the vertex the adjacent electrode is, the more positively correlated their voltage vectors are.

According to these rules some regular interpolation methods are abnegated and an adaptive one is set up. Those methods used in fitting and approximating could not be used in this system, for example, nonlinear regression analysis [5] and rational B-Spline surface fitting [6]. These methods stop estimating when the estimation error reaches a given threshold, but the interpolation method used in this system must be an 'exact one'. Fortunately, there are some efficient 'exact' interpolation methods, such as Kriging interpolation. Kriging interpolation is mainly used in geography information system. It covers the whole experiment area, so as to give better global predictions than the low-order polynomial regression [7]. Kriging interpolation uses co-variances between the known nodes and covariances between known and unknown nodes to establish a serious of linear equations for denoting predicted value on unknown nodes. In this system, there would be 128 independent variables in these equations. It might take a lot of time to get vertex's voltage each time. In one word Kriging would not be used here.

In this system, electrode pacing is supposed to be close enough that the propagating waveform's morphology doesn't changes between in two adjacent electrodes [8]. Further more, electrodes are supposed to be parallel to the advancing wavefront. So, bilinear interpolation technique is finally used. The calculation is composed of following two steps:

- Find the closest electrode and another two to form an interpolation-based triangle as showed in Fig. 6. The closest electrode is marked as 0^{th} little black square, which is besieged by other eight electrodes. The other two selected electrodes form two smallest angles (φ_0, φ_1) with 0^{th} electrode and vertex.
- Calculate voltage on vertex by using equation (1). In this equation V_v stands for the voltage on vertex, $V_{1,2,3}$ stands for the voltage on each electrode selected in former step, $S_{1,2,3}$ stands for the distance between vertex and these electrodes.

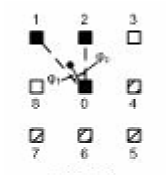

Fig.6 Find the interpolation based triangle

$$V_v = \frac{V_1 S_2 S_3 + V_2 S_1 S_3 + V_3 S_1 S_2}{S_1 S_2 + S_1 S_3 + S_2 S_3} \quad (1)$$

TABLE I shows the average cost of this interpolation method.

TABLE I. Arithmetic's time cost

	Sum of Vertexes	Sum of Faces	Interpolation time (us)
Atrium	3136	6234	12
Ventricle	2539	5072	12
Heart	2932	5828	12

III. RESULTS

Fig.7 to Fig.8 demonstrates the outline of user interface software.

Fig.7 Sampling window of user interface software (wave scrolls smoothly from right to left)

IV. CONCLUSION

This study brings forward a new scheme for observation and interpretation AF. By comparing the signal morphology on each channel and 3D whole heart isopotential mapping diagram, an approximate image of electrical activation propagation can be formed. This scheme was proved to be feasible in animal experiments.

In further investigation, the characters of AF will be abstracted by frequency domain analysis, statistical analysis and nonlinear dynamic analysis. Based on these characters, a classifier may be introduced into this system, to automatically distinguish AF and sinus rhythm.

Fig.8 3D model mapping windows of user interface software (Top-right windows shows two abnormal activation positions in current cardiac cycle, one in right ventricle, another in left atrium)

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