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Interactive visualization of cardiac anatomy and atrial excitation for medical diagnosis and research

Abstract: State of the art biomedical engineering allows for acquiring enormous amounts of intracardiac data to aid diagnosis and treatment of cardiac arrhythmias. Modern catheters, which are used to acquire electrical information from within the heart, are capable of recording up to 64 channels simultaneously. The software available for data analysis, however, does not provide adequate performance to neither analyze nor visualize the acquired information in an appropriate manner. We present a software package that facilitates interdisciplinary collaborations between engineers and physicians to address open questions about pathophysiological mechanisms using data from everyday electrophysiological studies. Therefore, a package has been compiled that enables algorithm development using MATLAB and subsequent visualization using the VTK C++ class libraries. The resulting application KaPAVIE, which is presented in this paper, is designed to meet the requirements from the clinical side and has been successfully applied in the clinical environment.

Keywords: visualization; atrial fibrillation; local activation time; medical imaging; intracardiac electrogram; diagnostic software

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1 Introduction

Atrial fibrillation (AFib) is a cardiovascular disease and therefore constitutes one of the most frequent causes of death in the western world. The mechanisms behind AFib are not yet sufficiently understood [1].

To investigate and treat these arrhythmias, electrophysiological (EP) studies are conducted. Catheters are inserted into the heart in a minimally invasive fashion to acquire EP data. Up to 64 poles record intracardiac electrograms (EGMs), which accumulates to thousands of measurements in the course of a few minutes [4]. The acquired EP data can potentially be used for further analysis to improve the understanding of the underlying pathophysiological mechanisms [3].

In recent work, EP data was analyzed and evaluated with novel data to approach common clinical questions [5] [6] [2]. Other research groups presented visualization software for similar problem sets, but with a very specific and narrow field of application [7].

Our proposed software framework delivers a novel and more universally applicable method to facilitate interdisciplinary communication of clinical expectations and technical inputs provided by engineers. By visualizing the EP data and results of analytical algorithms of the data in an interactive platform, both engineers and clinicians can express their perspectives more easily. The engineer’s desire to produce diagnostically relevant information in the form of descriptive visualizations can be better met by instantly applying the clinician’s judgement of the helpfulness of the data.

In many research facilities, the industry standard for data analysis is MATLAB. However, a common method to provide highly adjustable visualizations is to utilize the powerful C++ class libraries from the Visualization Toolkit (VTK) by Kitware [9]. With our current implementation of an interactive visualization platform, KaPAVIE (Karlsruhe Platform for Analysis and Visualization of Intracardiac Electrograms), we aimed for combining the best of both worlds.

2 Clinical requirements

2.1 Clinical data acquisition

The acquired data from EP studies comprises the atrial anatomy, given as a triangulated surface mesh, the position of all catheters and their electrodes continuously recorded in segments and the electrograms (EGMs) acquired from each electrode. Recordings from different sites along the atrial wall can be acquired during sequential mapping, in which synchronization can be performed us-
Clinical visualization standards

First requirement of clinical usage is the ability to comfortably visualize the raw clinical data. Thus physicians need to be provided with this type of familiar signals if the automatic analysis recommends a certain region for closer surveillance. Atrial anatomy has to be visualized in 3D, together with the position of measurement nodes. These can be either all points of a sequential map or the current electrode positions of multiple catheters. Intracardiac EGMs should be visualized if the user chooses an electrode via mouse click and displayed synchronously to both the surface ECG and the intracardiac reference to aid diagnosis. It should be possible to scale the EGM since the signals may cover two orders of magnitude. Furthermore, it is necessary to visually link both EGMs and measurement positions to aid geometrical understanding of a given situation. With respect to decision support and algorithm development, the results of signal analysis need to be visualized. This comprises both static and dynamic features of the signals and the atrial surface regions, respectively. Colour maps and value ranges need to be adjustable depending on the type of data visualized. Well-known parameters in clinical use already have commonly used colour maps which are to be utilized here as well. For time dynamic data, speed of visualization should be adjustable. An indicator should link the currently displayed time stamp of the three-dimensional animation and the two-dimensional signal plot.

3 Software implementation

3.1 Biomedical signal processing and analysis

Analysis of clinical EP data affected both geometrical and EGM specific tasks. Geometrical analysis focused on the position of measurement electrodes, their spatial stability over time and the amount of atrial surface covered by the multiple measurements. Goal of signal analysis was to extract diagnostically relevant features from the intracardiac EGMs. Signal processing and analysis was done via MATLAB (MATLAB version R2014b) [10]. MATLAB source code was optimized so that the data for visualization could be generated reliably in about 2 minutes. Once data analysis and processing was finished, the resulting 3D geometry along with the processed EGMs and surface maps were saved and exported to a file format that was compatible with the visualization environment. Geometrical data was saved as a polygonal mesh. Data was saved in binary format to optimize hard drive usage for the large amount of clinical data. The workflow established to acquire and visualize the EP data is briefly illustrated in fig. 1.
expected by the clinicians. A plugin to include an existing 
VTK Qt render window was used to visualize the 3D ge-
ometry of the atria and their respective surface data maps. 
EGMs were plotted using the open source plugin QCustom-
plot [11], licensed under the GPL.

3.3 Visualization pipeline

Using the algorithms of the VTK C++ software library (VTK 
version 6.1.0), the visualization of the 3D geometry was im-
plemented by using a VTK visualization pipeline and dis-
played in a VTK render widget. The data provided com-
prised three VTP files (atrial geometry, surface maps and 
EGM information) and one XML file for data specific set-
ings such as color maps and opacity. Once the user se-
lected an appropriate set of files, the geometrical polygo-
nal data that was defined by point and cell coordinates was 
loaded via the visualization pipeline. The well-established 
VTK procedure to input data was used, which includes 
reading the data and converting it into a data object, which 
then could be associated with a mapper. The mapper con-
verts the geometrical data object to a “tangible” object, 
which is then assigned to an actor. The actor serves the 
purpose of adjusting visible properties of the geometry 
such as coloring, size and rendering method. The actor is 
added to a renderer, which is associated with certain in-
teraction styles such as selecting actors and translating 
and rotating of the geometry. The spatial locations of the 
catheter measurement points were represented by spheri-
cal polygons which could be selected by the user to display 
the corresponding EGM plots. A customized interaction 
mode was implemented so that the measurement nodes 
could be selected via mouse click. Selection is visualized 
by coloring and enlarging the radii of the spherical poly-
gons.

3.4 Deployment

In order to promote usability for engineers and physicians, 
one of the main aspects considered during development 
was to support as many platforms as possible. Open source 
frameworks like Qt and VTK were chosen to develop the 
software so that it can be compiled and executed in differ-
ent operating systems, namely Microsoft Windows, Macin-
tosh OS X and most Linux distributions.

The software does not need any manual configura-
tions or changes on system settings in order to function 
properly. It can easily be executed in a common way di-
rectly in the installation directory. On Macintosh OS X the 
software was bundled into a single application (*.app) 
package and can thereby be easily transferred between dif-
f erent systems by moving the package like native Macin-
tosh software. For goal number one of the project, namely 
visualization of analysis results, no additional software is 
required on the used computer. If the complete analysis 
workflow is to be performed using KaPAVIE, a preinstalled 
MATLAB version is required on the system due to license 
limitations. Most scientific institutions who will bene-
fit from an improved interdisciplinary communication in a 
research environment, however, are expected to already 
own a license for this application.

4 Clinical application

The GUI application was designed so that the user can in-
teractively choose the preferred data representation. The 
user can choose an arbitrary number of measurement 
points and display their respective EGMs comparatively in 
the plotting widget. This allows the clinician to associate 
EGM data and 3D surface signals. The plotting widget can 
be adjusted to fit certain resolutions of the time axis (mea-
sured in [mm/sec]) common in clinical practice. Clinicians 
are familiar with these specific resolutions and can there-
fore more intuitively relate to the plotted EGMs. EGM am-
plitudes can be normalized for qualitative analysis, dis-
played with their original magnitude or arbitrarily scaled 
by the user for a close-up look. Normalization is especially 
useful when displaying data that varies over the order of 
two magnitudes. The plotting widget can also display a 
scale bar that shows the quantitative amplitudes of a se-
lected graph. This ensures quantitative context even when 
scaled to arbitrary units.

Coloring of the EGM graphs is either matched to the 
color of the 3D node representation or can be chosen to 
uniformly represent all EGMs with one color. Fitted col-
oring is best applied when visualizing measuring points from different regions of the intracardiac surface, whereas uniform EGM graph coloring is useful when displaying measuring nodes close to each other. The user can choose a desired surface data representation, e.g. LAT map, activity map, coverage map and others, depending on which maps are available for the data set at hand. This allows for comparison to evaluate diagnostic value of the different data representations.

Animations like an energy movie or electrical activity distributions can be played in synchrony with the respective EGM plots. Displaying EGM plots during visualization is important because EGMs are the trusted form of diagnostic information for clinicians. Animation speed can be adjusted as the user desires. Animation loops can be played between arbitrary points in time. This gives the user a variety of options to analyze specific time spans of the EP data visualization as well as the aforementioned association of EGMs and 3D visualization not only in space but also in time. Furthermore, the user is given the possibility to adjust the visualization to his or her desire such as the line width of the EGM plots. For demonstrative purposes, video sequences of the visualization can be exported.

The software platform KaPAVIE was successfully applied in the clinical environment of two institutions. Data from ablation procedures of atrial flutter and atrial fibrillation was analyzed retrospectively, with all patients providing informed consent. EGM information of up to 128 channels was successfully analyzed, acquired by multiple catheter types like standard 4 pole ablation catheters, 20 pole double loop spiral catheters and two 64 pole basket catheters during simultaneous biatrial mapping. Several algorithms were implemented in MATLAB and applied to extract diagnostically relevant features of the recorded EGMs.

5 Conclusion

In this contribution, we presented a new software platform for the analysis and visualization of intracardiac mapping data. A strong collaboration between engineers and physicians is necessary in the field of biomedical engineering to understand the mechanisms behind atrial arrhythmias. Our platform should enable engineers to develop novel algorithms in the common and widely spread MATLAB environment. In the communication between engineers and physicians, extensive visualization plays and important role: It allows engineers to grasp the ideas emerging from clinical practice, discuss the outcomes of data analysis with physicians and ultimately enables physicians to use the results for diagnosis and improved treatment. This platform should be the basis for future development of algorithms which hopefully will aid in diagnosis and treatment of cardiac arrhythmias.

Author’s Statement
Conflict of interest: Authors state no conflict of interest.

Material and Methods: Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

References
MathWorks, Inc., Natick, Massachusetts, United States.

[11] Eichhammer, E.: QCustomPlot Qt C++ widget for plotting and
data visualization. URL: http://www.qcustomplot.com