

# Heart Geometry Generation and Signal Projection for Optical Panoramic and Electrical Mapping in Atrial Fibrillation

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## Abstract

*Abstract Atrial Fibrillation (AF) is a common and dangerous condition and have complex driven mechanisms not completely elucidated. For the better understanding of this condition, a panoramic optical and electrophysiologic mapping setup was created to investigate the AF mechanisms in isolated rabbit heart. The setup is composed by three high-frequency cameras, separated in 120° between them, two multielectrode arrays for contact mapping with 16 electrodes each, and a tank that simulate the torso, with 60 electrodes uniformly disposed, for non-invasive mapping. Langendorff system is used to perfuse the heart with Tyrode solution. Dye is administrated to obtaining the optical signals. A three-dimensional geometry was generated by rotating the heart, capturing 50 to 100 images along the 360°, then the images was semiautomatically segmented, and Radon Transformation was applied, then thresholding, generating a volume. From that, it was obtained a triangular mesh. The epicardium multi-electrode array (MEA) electrodes were manually located in the bidimensional maps, and both were inversely projected in the mesh vertices. For calibration, a triangular prism with 15 landmarks in each face, with known positions, was placed in the center of the tank, and a matrix was generated for transforming pixel-space in real-space coordinates. The method was applied in 7 experiments. The method was able to reconstruct the heart geometry with enough fidelity. The three-dimensional signals were consistent with the original two-dimensional maps.*

## 1. Introduction

Cardiovascular diseases are the main causes of death worldwide and among them, heart diseases are particularly important with an incidence rate of 4% of the Brazil population with a cost of 2% of GDP. Many of these patients can present abnormalities related to heart electrical conduction system, resulting in arrhythmic episodes [1]. Atrial fibril-

lation (AF) is the most common cardiac arrhythmia, affecting about 1% of the worldwide population [2].

Over the last decade, new technologies have been developed to improve the diagnosis and classification of arrhythmic mechanisms, in order to provide more effective treatments, and consequently, increase patients' quality of life [3]. The heart's electrical activity can be acquired by electrical and optical mapping (functional imaging). The electrical mapping typically comprises a set of electrodes in contact with the heart (endocardium or epicardium), termed invasive, or throughout electrodes spread in the body torso, for non-invasive measurement [4, 5].

These two distinct techniques are commonly referred to as body surface mapping or electrocardiographic imaging [3]. Optical mapping uses optical cameras to acquire changes in the emitted fluorescence from the bound to the cardiac cell membrane, correlated to the cell transmembrane voltage change [6]. These methods differ from each other in how electrical activity is acquired.

A common characteristic between the above methods is the need of a 3-dimensional (3D) geometry of the heart chamber(s) or torso and based on the electrical potentials recorded. These potentials are then overlaid onto the 3D geometry shell and color-coded to generate 3D mappings [5]. Clinicians can visualize and manipulate the maps to examine potential values, as well as other characteristics such activation frequency, wavefront time propagation, conduction velocity and phase. The tools are based on the representation of the intrinsic variables as color maps on an anatomically accurate 3D representation of the atrium.

This study aimed to re-create the 3D geometry of the heart into a Langendorff perfused isolated heart rabbit under AF. To solve this problem, a software was built in Python 3, allowing the three-dimensional analysis of the optical and electrophysiological signals acquired along the experiments, such as the heart geometry reconstruction, the optical signal projections, and the electrode location in the same geometry.

## 2. Methods

### 2.1. Experimental setup

This system works under constant pressure. A peristaltic pump (Gilson, Minipuls Evolution) pumps tyrode's solution (composition in mM: NaCl 128.2, NaHCO<sub>3</sub> 20.0, CaCl<sub>2</sub> 1.3, KCl 4.7, MgCl<sub>2</sub> 1.05, glucose 11.1, e NaH<sub>2</sub>PO<sub>4</sub> 1.19) to a reservoir tank where it is mixed with carbogen (95% O<sub>2</sub> and 5% CO<sub>2</sub>). The solution is passed through a heat exchanger connected to a thermal circulatory pump inside a digital water bath (7Lab, Brazil) filled with distilled water at 37°C. Finally, the solution passes through a bubble trap and then is supplied through the aorta of the rabbit heart. After staining heart with transmembrane sensitive fluorescent dye (Di-4-ANBDQPQ), the dye is excited using a custom assembled apparatus. The illumination system consists of three deep-red LEDs (650 nm, Luminus Devices Inc., USA) placed on a heatsink and LED light is collimated (Aspheric Condenser Lens, Thorlabs) and band-pass filtered (650/40 nm Thorlabs) before reaching the heart surface. The LED intensity is controlled with custom Labview GUI (version 21, National Instruments) which also controls the DC power supply (Programmable DC Power Supply, Tektronix Keithley, Taiwan).

The emitted fluorescence is passed through a long pass filter of 715 nm cut-on wavelength (BrightLine Long / Short pass Single-edge Filter, Semrock, USA) on each of the three cameras with C-mount lens (C-mount lens, Machine Vision C-Mount / Fujinon). The cameras are connected to a PC, and a sequence of images is acquired at 600 Hz at resolution of 1604 x 1100 pixels (Emergent Vision Technologies). Optical signals are conducted through an optical Fiber Cable to a fiber Transceiver (fiber Transceiver, Emergent Vision Technologies) and a Network Interface Card (Network Interface Card, Emergent Vision Technologies). The emission of heart fluorescence is acquired at 600 frames/s with a resolution of 1604 x 1100 pixels. A GUI in Labview (version 21, National Instruments) triggers the cameras, acquires images, and saves them onto a Desktop (TRX40 AORUS PRO, Gigabyte Technologie).

The experiment provides different kinds of data. Among them are three signals, been the invasive epicardial potentials, the non-invasive potentials around the tank, both acquired with OpenEphys software, and the optical signals from the three cameras, acquired with StreamPix software. Also, in each experiment, images from the heart are captured while rotating 360 degrees by a servo motor, using a graphical user interface (GUI) constructed on LabView. Finally, after the heart was removed from the setup, a calibration prism is coupled, and images are captured, also using StreamPix.

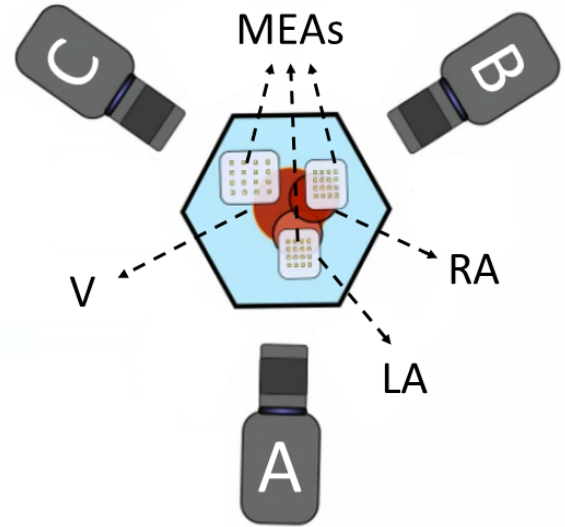


Figure 1. Cameras (A, B and C) and MEAs arrangement in the experimental setup. V: ventricles; LA: left atrium; RA: right atrium.

### 2.2. Calibration

The camera calibration is the process of find the relation between each pixel coordinate and the real world. For the real world coordinates, the reference is set in the center of the tank, where a calibration prism is positioned (Figure 2, top-left). The calibration prism consists in a white triangular prism with a height of 6 cm and a width of 3 cm for each lateral face. These faces contains a black grid of 5 by 3, with 1 cm between the lines, totaling 15 line crossings. For the calibration, at the end of every experiment, images are taken with the cameras, with each face of the prism turned to each camera. After the experiment, the images is used in the software to manually identify at least the 9 central crossings. Then, the software computes the calibration file for each camera, which consists in a transference matrix that converts the pixel space to the real space. This files are used later in the geometry construction and the optical data projection.

### 2.3. Heart geometry reconstruction

For the geometry reconstruction, in the final of the experiment, 101 pictures is obtained from the heart while it is rotated by a servo-motor in 363.6 degrees (the first and the last one is redundant for assurance). The pictures are loaded in the software, then a window with a segmentation tool is opened (Figure 2, top-right). The tool have a semi-automatic segmentation that applies thresholding, with a manually adjusted threshold, followed by morphological

operations (opening and closing) and the selection of the biggest connected component. The resulting region of interest (ROI) can be adjusted by manually adding or subtracting polygons.

After, a volume is created, that is, an array full of ones, shaped of  $w$  by  $w$  by  $h$ , been  $w$  the heart picture's width, and  $h$  the height. Following, for each ROI in respect to every angle, the ROI's contour is carved in the volume, then the volume is rotated by 3.6 degrees in the vertical axis. This generate an approximation of the real heart geometry, disregarding only concavities in the horizontal sections of the heart shape.

Then, a triangular mesh is obtained from the volume by using the following steps: a three-dimensional moving average of size 3 is applied to the volume, and the voxels with values below 24 and are contained in the original volume, is selected, keeping only the volume shell, or surface, minimizing the computational cost. Also, a moving average with a size of 7 is applied to the original volume, followed by a three-dimensional Sobel filter, computing an approximation of the volume gradient, which is then normalized. This gradient is, for every voxel, a vector pointed to the outside of the volume, that is, a normal vector in relation to the heart surface. The volume shell voxels coordinates, along with its respective normal vector, is used in the Poisson surface reconstruction algorithm for constructing triangular mesh from a point cloud [7].

## 2.4. Optical data projection

The optical data projection on the reconstructed geometry was also made through a GUI, and is computed as an inverse projection, where the geometry vertices are projected in the optical data and the data from the nearest pixel is assigned to each vertex. In order make this computation, a precise projection of the geometry on the optical data is required. For this the GUI was composed of three main windows that appears subsequently. The first one is used to select the optical signal files and its respective calibration files, along with tools to make corrections on the orientation of the camera images, rotation and flip, that should be used carefully (Figure 2, bottom). The next window allows to make fine corrections on the geometry position and orientation, comparing the image of the heart in the optical data with the projected silhouette of the geometry on each image. In the next window, the silhouettes can be minor adjusted to the images, to correct any possible error in the camera calibration. The, the inverse projection is performed and the information regarding the accurate geometry position, the projected signals and the relationship between the geometry and each camera data is saved in the computer for further analysis, and also for the electrode location, described in the next section. To validate the congruence of the projected signals (making a "san-

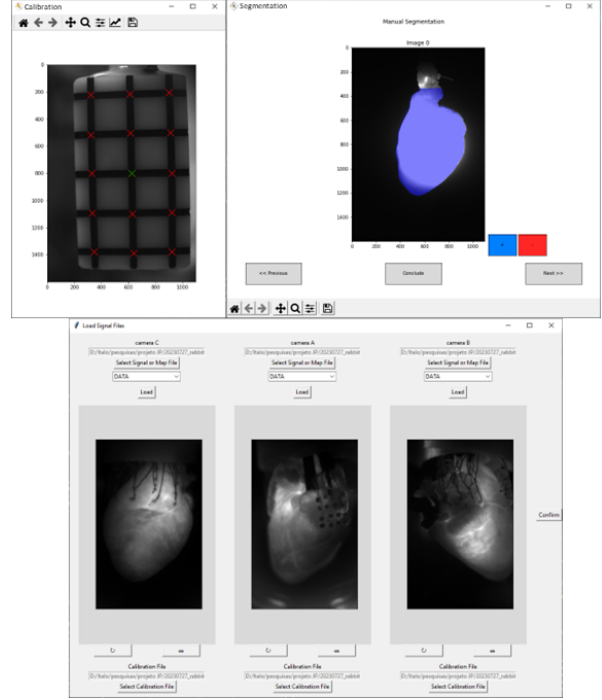


Figure 2. Three windows from the GUI. Top-left: Calibration window with the prism and the located landmarks; Top-right: Segmentation window, with the optical signal in gray-scale, the ROI in blue, with the buttons "+" and "-" to add and subtract polygons from de ROI; Botton: The load window, with the loaded signals from each camera and the selected calibration files.

ity check"), images with the letters "A", "B" and "C" was used (Figure 3).

## 2.5. Electrode location in geometry

The electrode location tool requires firstly the computation of the data projection. With this information, the electrodes can be manually located and ordered in the optical data, then the tool finds the vertex from the 3D geometry correspondent to this coordinate in the pixel space. The assigned vertex for each electrode was displayed in order to allow a qualitative evaluation of the algorithm performance.

## 3. Results and Discussion

The reconstruction of the heart geometry can be seen in Figure 3, the projections were consistent with the validation images displayed in the GUI, and also with the expected heart anatomy (as seen in Figure 1), that is, the camera A displayed most of the left atria, camera B displayed most of right atria, and camera C displayed most of the ventricles.

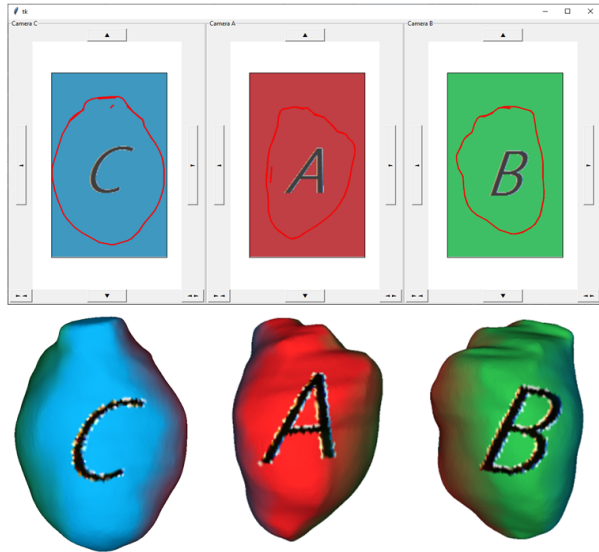


Figure 3. The validation of the data projection. Top: The validation data displayed for each camera in the second projection window (the fine adjustments); Bottom: the data already projected in the heart geometry, viewed in each camera perspective.

#### 4. Conclusions

Animal models has been of great importance to improve current knowledge of AF, including elucidating AF mechanisms, areas harbouring arrhythmogenic tissue, with the possibility of implementation of commercial systems. In this study, the re-create the 3D geometry of the heart into a Langendorff perfused isolated heart rabbit under AF was created allowing 3D mapping of the optical and electrical mappings.

#### Acknowledgments

This study is supported by grant no. #2018/25606-2, São Paulo Research foundation (FAPESP) and CNPq INCT INTERAS. call 58/2022. J.G. Siles-Paredes is supported by grant #2020/03601-9, FAPESP. I. Sandoval is supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

#### References

- [1] Tortora GJ, Derrickson B. Chapter 20 - The cardiovascular system: The heart. In: B Roesch, C Stone, editors. Principles of anatomy and physiology. 11th edition. John Wiley & Sons, Inc, 2006; .
- [2] Bollmann A, Lombardi F. Electrocardiology of atrial fibrillation: Current knowledge and future challenges. IEEE Engineering in Medicine and Biology Magazine 2006;25:15–23.

- [3] Salinet J, Molero R, Schlindwein FS, et al JK. Electrocardiographic imaging for atrial fibrillation: a perspective from computer models and animal experiments to clinical value. *Frontiers in Physiology* 2021;12:Art. no. 65013.
- [4] Rudy Y. Noninvasive electrocardiographic imaging of arrhythmogenic substrates in humans. *Substrates in Humans* 2013;112(5):863–874.
- [5] Júnior JLS, Oliveira GN, Vanheusden FJ, et al. JLDC. Visualization of intracardiac atrial electrograms of patients with atrial fibrillation using spectral analysis. *Computing in Science Engineering* 2013;15:79–87.
- [6] Qu F, Ripplinger CM, Nikolski VP, Grimm C, Efimov IR. Three-dimensional panoramic imaging of cardiac arrhythmias in rabbit heart. *Journal of biomedical optics* 2007; 12(4):Art. no. 44019.
- [7] Kazhdan M, Bolitho M, Hoppe H. Poisson surface reconstruction. *Symposium on Geometry Processing* 2006;61–70.

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