# Novel Method for Orientation-Independent Analysis in Equi-Spaced Multi-Electrode Arrays

Izan Segarra[1], Samuel Ruipérez-Campillo[1,2,3], Francisco Castells[1], José Millet[1]

[1] ITACA Institute, Universitat Politècnica de València, Spain
[2] Department of Medicine, Stanford University, Palo Alto, USA
[3] Bioengineering Department, University of California, Berkeley, USA

## Abstract

*The diagnosis and treatment of cardiac arrhythmias relies on catheter recordings, that may be inefficient because of the continued use of the bipolar processing and analysis techniques of traditional catheters, missing the potential of the novel matrix catheters. This results in the need of more processing of the signals and longer cardiac scans to obtain accurate information about the state of the tissue being analysed. This study proposes a new clique configuration to compute omnipolar EGM (oEGM) in multi-electrode array catheters to obtain parameters of interest in a more robust and accurate manner. Numerous simulations with varying input parameters are designed to emulate the propagation of electrical activity on the cardiac tissue surface captured by the catheter and characterise the differences between the classic method of omnipolar analysis (triangular clique) and our proposed new method (cross clique). The results show that the cross clique is more robust to variations in the direction of wave propagation, and more accurate in the estimation of the local activation time (LAT).*

## 1. Introduction

Exploration and diagnosis by means of catheters in electrophysiology laboratories benefits from reduced recurrence rates, which implies important economic and operational profits. This type of procedure increases knowledge in the management of certain arrhythmias such as atrial fibrillation (AF), atrial flutter (AFL) or ventricular tachycardias (VT), amongst others. Ablation, which is a common treatment for those, consists of a surgical procedure that burns or freezes some tissue creating a scar that breaks up the electrical signals responsible of the irregular heartbeats [1].

To identify and characterise the area that needs to be ablated, a multielectrode and an electroanatomic navigator are used to perform a 3D mapping of the heart chamber. Furthermore, the location of the device is essential as perpetuation mechanisms of slow conduction regions may reveal the ablation region for different diseases such as AFL [2, 3]. Another example is given by complex fractionated EGMs detected during substrate mapping during AF, that can reflect complex etiologies that need to be well defined [4]. Various flexible catheters with different geometric shapes have been developed hitherto to improve the exploration and mapping quality [5]. Although new probes have been developed, the most widely used recording modalities are unipolar recordings (uEGM) and bipolar recordings (bEGM). Nonetheless, uEGMs are sensitive to low-frequency noise, and bEGM strongly depends on the direction of the propagation wave [6].

Abbott's Advisor™ HD grid catheter is one of the most recently approved catheters for clinical use, consisting of 16 equally-spaced electrodes (4 mm centre-to-centre) in a 4x4 array with a stable spatial position for high-density cardiac tissue mapping. Furthermore, its configuration allows the study of omnipolar recordings (oEGM), which are independent of the direction of propagation of the electrochemical signal [7]. These features make it possible to characterise healthy or damaged (e.g. scarred) tissue.

The oEGM is calculated using the clique concept, which relies on an area consisting of 4 contiguous electrodes. The common procedure to construct a clique is by choosing 3 of the 4 electrodes to create a triangle (see figure 1). Nevertheless, this configuration implies some limitations. For instance, resulting geometric centre does not coincide with the geometric centre of the complete clique. Besides that, one electrode is used twice in the computations, and there are four possible configurations for the triangular clique.

We hypothesise that using 4 electrodes (see figure 1) will provide us with an oEGM with a better amplitude, orientation and more accurate local activation time (LAT), relying on the fact that using this configuration, the geometric centre coincides with the centre of the clique.

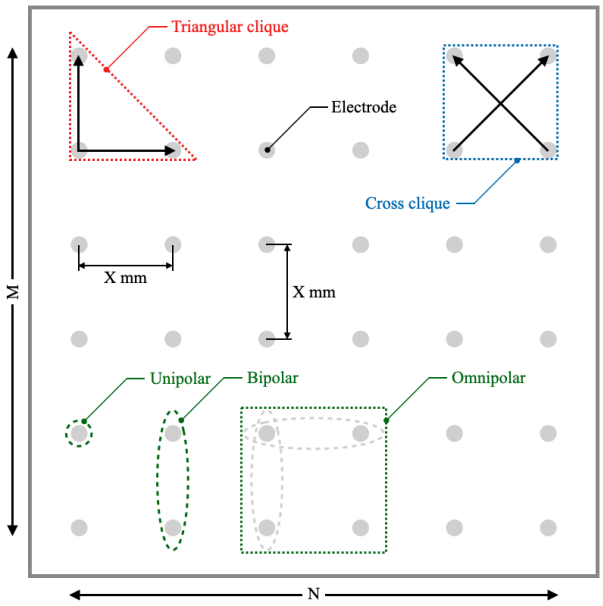


Figure 1. Scheme of a generic multi-electrode array of size MxN with inter-electrode distance of X mm on the vertical and horizontal axis. In the upper-left region of the figure, the traditional calculation of the oEGM is depicted in red - i.e., 3 electrodes conforming a triangular clique. In the upper-right section the new proposed method for computing the oEGM is illustrated in blue, using the 4 available electrodes, that is, the entire clique. For the sake of clarity, the unipolar, bipolar and omnipolar recordings are represented in green in the lower part of the figure.

## 2. Materials and Methods

### 2.1. Propagation Plane Generation

In order to test the efficacy of the proposed method, a flat wavefront and homogeneous propagation model has been designed by emulating the data captured by a 4x4 multi-electrode catheter (following the generic scheme of figure 1) on the cardiac surface. The propagation model has as input parameters the velocity, the angle, the inter-electrode distance, and a unipolar signal as a reference.

To test the performance of the 4 possible triangular cliques to use only one, we require a large population, so 1000 simulations were created with an interelectrode distance of 1 mm with uniform randomly generated velocity and propagation angles in the range [0.5-1 m/s] and [0 - 360 º].

### 2.2. Computing the bEGMs Loops

The unipolar signals are acquired by the *MapTech*© system, module used for the amplification, digitalisation and processing. Specifics for the analysis are the default of *PaceMap*© software.

The calculation of the bipolar signal from the unipolar one is performed as indicated by the arrows in Figure 1 for the triangular and cross clique.

Note that the use of only 3 electrodes in the first case (triangular) means that the abscissa and ordinate components are not aligned, leading to hindrances in the loop they form, and requiring of further signal treatment [8]. On the other hand, in the cross clique, as the centre coincides, the only parameter to be considered is that a rotation of 45º is needed to align the bipoles with the coordinate axis.

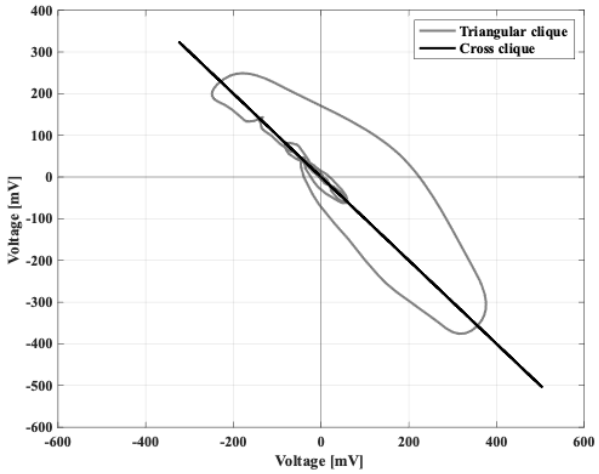


Figure 2. Resulting bEGM loop for each clique for a propagation angle of 315º and a conduction velocity of 0.5 m/s. The effect of the axis desynchronisation in the triangular clique is evident from the width of the loop, while the cross clique is almost a straight line with a larger amplitude.

### 2.3. Estimation of Propagation Angle and Computing the oEGMs

When transforming the bipolar loop depicted in Figure 2 from Cartesian to polar coordinates, the propagation angle ($\theta$) is found to be the angle whose distance between the radial coordinate ($\rho$) and the origin is maximum.

Since the oEGM is the bEGM in the direction of the propagation wave, having information this angle makes it possible to correct the direction to compute the oEGM. Analysing the abscissa and ordinate components of the oEGM, we can observe that one of them is close to zero (see figure 3). On the other hand, the other has maximum amplitude when following the propagation direction.

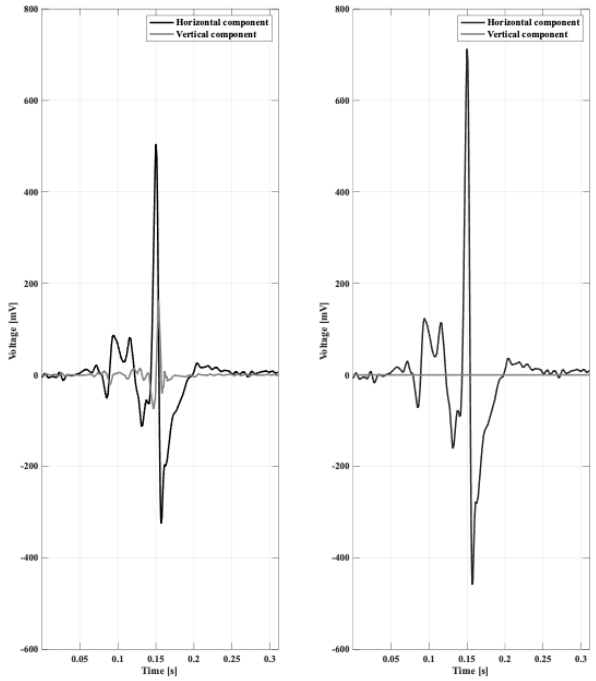


Figure 3. The left-hand side of the figure shows the oEGM components computed from the triangular clique. The right-hand side depicts the same information obtained with the cross-clique. Note that the amplitude is higher in the later case and that the perpendicular component to the propagation direction is negligible in the proposed method. The applied rotation has been accurate to show an error-free result in angle detection.

## 2.4. Estimation of Local Activation Time (LAT)

It is essential to have a suitable reference to compute the LAT in the bEGM to improve its sensitivity. The maximum negative slope of the uEGM is broadly used in literature [9], so it is used in this study as a reference. For the comparison to be sensible, it is germane to have a reference for each of the cliques since they do not share centre. Hence, the uEGM needs to be computed at the centre of the triangular clique and at the centre of the cross clique.

Each reference is compared with the maximum of its corresponding bEGM. Thus, it is possible to determine the error in the LAT estimation.

# 3. Results

The results of the 1000 simulations with varying input parameters show that, on average, the proposed clique configuration provides more accurate amplitude and LAT values than the triangular clique - commonly used in the literature to calculate the oEGM. This is because the proposed method is able to always detect the highest amplitude regardless of the direction of propagation. Additionally, a more accurate LAT estimation is obtained by taking as reference the LAT of the unipolar signal.

The traditional method captures an average amplitude of 600.36 ± 116.4 mV in the direction of waveform propagation, while the new method captures an average amplitude of 840.47 ± 160.09 mV (see figure 4A). On top of that, figure 4B illustrates how the detection is more accurate, decreasing the error from 207.50 ± 256.91 $\mu$s to 22.75 ± 29.43 $\mu$s.

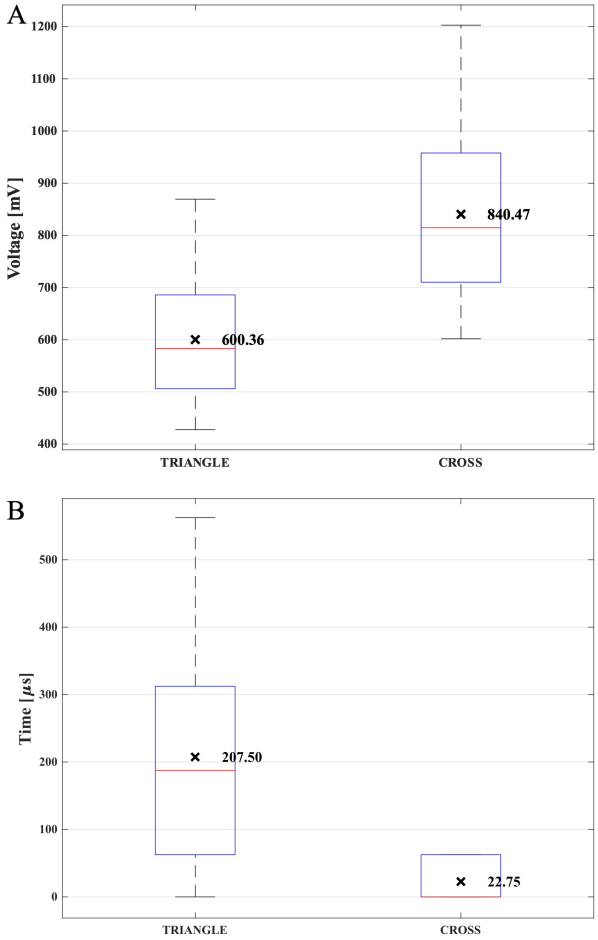


Figure 4. Amplitude and LAT box-and-whiskers plot. The median is indicated by a red horizontal line and the mean by a bold x. A: Amplitude. The cross clique has on average a 40% larger amplitude than the triangular clique. B: LAT. A smaller error is observed in the novel cross configuration.

Note that when applying automatic angle detection in the case of the traditional method, the desynchronisation of the components of the traditional model affect the results as the bEGM loop is widened. These results are summarised in table 1.

| Parameter | Triangular | Cross |
|---|---|---|
| Amplitude (mV) | 600.36 ± 116.4 | 840.47 ± 160.09 |
| LAT error ($\mu$s) | 207 ± 256.91 | 22.75 ±29.43 |
| LAT error* ($\mu$s) | 254.38 ± 257.21 | 20.69 ± 29.43 |
| Angle error* | 1.04 ± 0.80 ° | 0.75 ± 0.53 ° |

Table 1. Summary of the results of the parameterised simulations. The parameters marked with * have been calculated when the bEGM propagation angle estimation is activated, while the others have been calculated assuming an ideal angular estimation.

## 4. Discussion and Conclusions

New generation multi-electrode catheters such as the HD grid provide novel medical hardware tools for disease diagnosis and tissue damage localisation in the heart. Yet, novel processing techniques are needed to exploit these device's potential.

The oEGM is being discussed more often due to its improved performance in determining the parameters needed to localise the regions to be ablated amongst other tasks. The most common method in the literature for oEGM computaiton uses 3 electrodes, which results missing part of the potential of the catheter.

The proposed method, proves that it is possible to improve the performance in the detection of the parameters (amplitude and LAT) by oEGM in 3D electroanatomical systems, overcoming the limitations of other clique configurations.

## 5. Limitations and Future Directions

This study used a single unipolar morphology and an interelectrode distance of 1mm. Furthermore, the treatment of the omnipolar signal implies some assumptions such as locally flat wave propagation and a small interelectrode distance with respect to the electrophysiological characteristics [10]. This implies the need for a comprehensive study to identify the limits of the inter-electrode distance of medical devices to ensure the correct functioning of omnipolar technology. Furthermore, the physiological characteristics of each patient could be a determining factor when locating these limits. Future work involves performing this analysis in clinical signals and proving the improvement on the recordings in the clinical framework.

## Acknowledgments

This work was supported by PID2019-109547RB-I00 (National Research Program, Ministerio de Ciencia e Innovación, Spanish Government), CIBERCV CB16/11/00486 (Instituto de Salud Carlos III) and PROMETEOII/2014/037 (Generalitat Valenciana).

## References

[1] Lippi G, Sanchis-Gomar F, Cervellin G. Global epidemiology of atrial fibrillation: An increasing epidemic and public health challenge. International Journal of Stroke 2021;16. ISSN 17474949.

[2] Ruipérez-Campillo S, Castrejón S, Martínez M, Cervigón R, Meste O, Merino JL, Millet J, Castells F. Non-invasive characterisation of macroreentrant atrial tachycardia types from a vectorcardiographic approach with the slow conduction region as a cornerstone. Computer Methods and Programs in Biomedicine 2021;200. ISSN 18727565.

[3] Ruipérez-Campillo S, Castrejón S, Martínez M, Cervigón R, Meste O, Merino JL, Millet J, Castells F. Slow conduction regions as a valuable vectorcardiographic parameter for the non-invasive identification of atrial flutter types. In 2020 Computing in Cardiology. IEEE, 2020; 1–4.

[4] Narayan SM, Wright M, Derval N, Jadidi A, Forclaz A, Nault I, Miyazaki S, Sacher F, Bordachar P, Clémenty J, Jaïs P, Hasïsaguerre M, Hocini M. Classifying fractionated electrograms in human atrial fibrillation using monophasic action potentials and activation mapping: Evidence for localized drivers, rate acceleration, and nonlocal signal etiologies. Heart Rhythm 2011;8. ISSN 15475271.

[5] Maury P, Monteil B, Marty L, Duparc A, Mondoly P, Rollin A. Three-dimensional mapping in the electrophysiological laboratory, 2018.

[6] Magtibay K, Massé S, Asta J, Kusha M, Lai PF, Azam MA, Porta-Sanchez A, Haldar S, Malebranche D, Labos C, Deno DC, Nanthakumar K. Physiological assessment of ventricular myocardial voltage using omnipolar electrograms. Journal of the American Heart Association 2017;6. ISSN 20479980.

[7] Nguyen M, von Alvensleben JC, Runciman M, Collins KK. Advisor high-definition hd grid catheter for mapping accessory pathways in pediatrics. HeartRhythm Case Reports 2020;6. ISSN 22140271.

[8] Riccio J, Alcaine A, Rocher S, Martinez-Mateu L, Laranjo S, Saiz J, Laguna P, Martínez JP. Characterization of atrial propagation patterns and fibrotic substrate with a modified omnipolar electrogram strategy in multi-electrode arrays. Frontiers in Physiology 2021;12. ISSN 1664042X.

[9] Cantwell CD, Roney CH, Ng FS, Siggers JH, Sherwin SJ, Peters NS. Techniques for automated local activation time annotation and conduction velocity estimation in cardiac mapping. Computers in Biology and Medicine 2015;65. ISSN 18790534.

[10] Deno DC, Balachandran R, Morgan D, Ahmad F, Masse S, Nanthakumar K. Orientation-independent catheter-based characterization of myocardial activation. IEEE Transactions on Biomedical Engineering 2017;64. ISSN 15582531.

Adress of correspondence:

Izan Segarra - ITACA Institute Edificio 8G, Acceso B, 1ª planta, Universitat Politècnica de València, Camino de Vera S/N 46022 Valencia, Spain. izsegor@teleco.upv.es