**Title:** CT-based heart digital twin can improve estimation of vectorcardiographic derived positions of the electrical activity

**Authors:** Michał Szafarczyk, Krzysztof Malinowski, Sandra Zarychta, Julia Kolasa, Klaudia Proniewska, Peter van Dam

Center for Digital Medicine and Robotics, Jagiellonian University Medical College, Krakow, Poland

Laboratory of Functional and Virtual Medical 3D Imaging – 3D-FM, Department of Diagnostic Imaging, University Hospital in Krakow, Krakow, Poland

**Introduction**

The electrocardiogram (ECG) is one of the oldest electrical measurements of the human body and provides instant information on the cardiac function as well as mechanical or structural changes in the heart. The vectorcardiogram is a related tool that represents electric activity as the direction of a vector and the average cardiac anatomical location of activation over time [1].

**Description of the problem**

Although ECG contains information on heart anatomy as waveforms are majorly determined by the 3D shape of the heart in relation to the electrodes, creation of the average cardiac anatomical location of activation is based on underlying assumptions on the heart model and orientation as well as torso model and electrode placement. Contrary to ECG which is patient-specific, remaining models (heart, torso, electrodes) are generic.

Providing personalized, patient specific heart, torso and electrode placement models can facilitate estimation of the average cardiac anatomical location of activation and further improve its diagnostic performance in detection of abnormal ECGs. One readily available source of such information can be Computed Tomography (CT) scans.

**Related work**

It has been shown that vectorcardiographic derived positions of the electrical activity (PathECG) as well as waveforms (WaveECG) can be used in rapid identification of ECG abnormalities [2][3].

Digital twin technology has proven to be a great approach for many tasks in the medical field [6]. On top of that, it’s a way in which medicine becomes more personalized and patient oriented.

Medical imaging data, besides being by itself a modality very useful for diagnostics, has also been shown to be a great tool for enhancing other diagnostic methods. MRI and CT scans have already been used in generating more accurate 3D heart models for electrophysiological simulations [7], creating highly personalized heart models for SCD risk assessment [8] or generating reconstructions of aortic valve for calcification quantification [9].

**Solution of the problem**

Estimated from CT:

- chest depth and width at position heart (to estimate chest dimensions)

- estimate heart position and orientation

These parameters can then be used by CineECG to adapt the torso and heart model to compute a more patient specific PathECG [4][5].

**Conclusions and future work**

This research presented a novel method of injecting additional patient-specific information to the creation of vectorcardiogram-derived PathECG based on CT scans. However, only chest dimensions and heart position and orientation were used. The presented method will be further improved to develop a full patient specific heart and torso model including actual lead placement in order to maximize the diagnostic performance of methods using PathECG to identify ECG abnormalities.

**Acknowledgment**

This work was supported by the grant and project “Interactive TEAching of Medical 3D cardiac anatomy supported by Mixed Reality (iTeam 3D-MR),” agreement number 2023-1-PL01-KA220-HED-000159314, Erasmus + Program, Strategic Partnerships (Key Action 2).

**References**

1. van Oosterom A, Oostendorp TF, van Dam PM. Potential applications of the new ECGSIM. J Electrocardiol. 2011;44:577-583. doi: 10.1016/j.jelectrocard.2011.05.006
2. E. Pociask, K. P. Malinowski, M. J. Mortada, K. K. Proniewska and P. M. van Dam, Automatic Classification Normal ECGs Based on Normal PathECG and WaveECG Features, 2023 Computing in Cardiology (CinC), Atlanta, GA, USA, 2023, pp. 1-4, doi: 10.22489/CinC.2023.216.
3. P Van Dam, K Malinowski, K K Proniewska, 121 year after Einthoven: show me the normal ECG?, European Heart Journal, Volume 45, Issue Supplement\_1, October 2024, ehae666.3435, https://doi.org/10.1093/eurheartj/ehae666.3435
4. Dam PMv, Locati ET, Ciconte G, Borrelli V, Heilbron F, Santinelli V, Vicedomini G, Monasky MM, Micaglio E, Giannelli L, et al. Novel CineECG Derived From Standard 12-Lead ECG Enables Right Ventricle Outflow Tract Localization of Electrical Substrate in Patients With Brugada Syndrome. Circulation: Arrhythmia and Electrophysiology. 2020;13:e008524. doi: doi:10.1161/CIRCEP.120.008524
5. van Dam PM, Boonstra M, Locati ET, Loh P. The relation of 12 lead ECG to the cardiac anatomy: The normal CineECG. Journal of Electrocardiology. 2021;69:67-74. doi: <https://doi.org/10.1016/j.jelectrocard.2021.07.014>
6. [Feng Zhao](https://arxiv.org/search/physics?searchtype=author&query=Zhao,+F), [Yizhou Wu](https://arxiv.org/search/physics?searchtype=author&query=Wu,+Y), [Mingzhe Hu](https://arxiv.org/search/physics?searchtype=author&query=Hu,+M), [Chih-Wei Chang](https://arxiv.org/search/physics?searchtype=author&query=Chang,+C), [Ruirui Liu](https://arxiv.org/search/physics?searchtype=author&query=Liu,+R), [Richard Qiu](https://arxiv.org/search/physics?searchtype=author&query=Qiu,+R), [Xiaofeng Yang.](https://arxiv.org/search/physics?searchtype=author&query=Yang,+X)Current Progress of Digital Twin Construction Using Medical Imaging, 2024, doi: https://doi.org/10.48550/arXiv.2411.08173
7. Banerjee A, Camps J, Zacur E, Andrews C M, Rudy Y, Choudhury R P, Rodriguez B and Grau V 2021 A completely automated pipeline for 3D reconstruction of human heart from 2D cine magnetic resonance slices Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 379
8. Loewe A, Martínez Díaz P, Nagel C and Sánchez J 2022 Innovative Treatment Strategies for Clinical Electrophysiology, ed T Jadczyk, et al. (Singapore: Springer Nature Singapore) pp 111-34
9. Rouhollahi A, Willi J N, Haltmeier S, Mehrtash A, Straughan R, Javadikasgari H, Brown J, Itoh A, de la Cruz K I, Aikawa E, Edelman E R and Nezami F R 2023 CardioVision: A fully automated deep learning package for medical image segmentation and reconstruction generating digital twins for patients with aortic stenosis Comput Med Imaging Graph 109 102289