Project title: Electrocardiographic Imaging with Smart Mathematics

Project leader: Prof. Dr. Ir. R.L.M. Peeters

Function: Full professor, Research director, Vice-chair of the Department of Data Science and Knowledge Engineering

Collaborators: Dr. R.L. Westra; Dr. P. Bonizzi; Dr. J.M.H. Karel; Dr. E.N. Smirnov; Dr. Ir. K. Driessens; Prof. Dr. P.G.A. Volders, MD; Dr. M.J.M. Cluitmans, MD.

Proposal (250 words):

Introduction: Electrocardiography (ECG) has been the main diagnostic tool for analyzing the functioning of the heart for over 100 years. It uses 12 electrodes to record and display 1D electrical signals, measured on the patient's body, reflecting what happens on the heart. A new technique, developed in the last 25 years, is electrocardiographic imaging (ECGI). This technique uses a vest with about 200 electrodes and is now slowly finding its way into clinical practice. By solving the "inverse problem of electrocardiography", the 200 recorded signals are used to compute a 3D visualization of electrical activity on the heart, and to create movies of electrical propagation. This allows for more advanced diagnosis and better mechanistic understanding. Currently, this technique is expensive and requires CT or MRI-scans to build a sufficiently accurate patient-specific model.

Hypothesis and Objectives: The goal of this project is to develop a combination of mathematical and machine learning techniques ("smart mathematics"!), which makes ECGI work ***without scans*** sufficiently well. Reconstructions are nowadays computed by solving an ill-posed and underdetermined linear system of equations A X = B, using regularization and sparse estimation to obtain meaningful results for X. The matrix A is normally computed from scans. In this project, however, the goal is to compute both A and X only from B, by further regularization and additional use of deep learning.

Setting and Methods: The team involved has a strong track record on ECGI, with several completed joint PhD projects. It consists of a successful collaboration of cardiologists and applied mathematicians and engineers. It is state-of-the-art equipped, internationally recognized and received several awards. In this project, the team's expertise is extended with deep learning and transfer learning to further improve solution techniques for the ill-posed system A X = B. Both patient data and simulation data are abundantly available.

Impact: Without scans, the ECGI technique will become cheap and available to many. With sufficient accuracy, it can serve as a pre-diagnostic tool, to help refer patients-at-risk to further examination by specialists. The smart mathematics techniques developed in this project can be further deployed in other applications as well. The impact upon success is therefore high, both to society and to science.

Requirements candidate: Highly motivated student with good English communication skills and proactive and resolute attitude. Background (M.Sc.) in: applied mathematics, physics, computer science or engineering. Excellent programming skills. Basic knowledge in machine learning. Strong interest in applications in medicine.

Keywords: Linear system solving, Machine learning, Deep learning, Pattern recognition, Inverse problems, Signal processing, Imaging, Medical applications, ECGI.

Top 5 selected publications:

1. M.J.M. Cluitmans, R.L.M. Peeters, R.L. Westra, P.G.A. Volders, (2015), Noninvasive reconstruction of cardiac electrical activity: update on current methods, applications and challenges, *Netherlands Heart Journal* 23 (6), 301-311.
2. M.J.M. Cluitmans, M. Clerx, N. Vandersickel, R.L.M. Peeters, P.G.A. Volders, R.L. Westra, (2017), Physiology-based Regularization of the Electrocardiographic Inverse Problem. *Medical & Biological Engineering & Computing* 55 (8), 1353-1365.
3. M.J.M. Cluitmans, P. Bonizzi, J.M.H. Karel, M. Das, B.L.J.H. Kietselaer, M.M.J. de Jong, F.W. Prinzen, R.L.M. Peeters, R.L. Westra, P.G.A. Volders, (2017), In Vivo Validation of Electrocardiographic Imaging, *JACC: Clinical Electrophysiology* 3 (3), 232-242.
4. S. Zhou, E.N. Smirnov, G. Schoenmakers, R. Peeters, (2017), Conformal decision-tree approach to instance transfer, *Annals of Mathematics and Artificial Intelligence* 81, 85-105
5. S. Zhou, E. Smirnov, G. Schoenmakers, K. Driessens, R. Peeters, (2017), Testing exchangeability for transfer decision, *Pattern Recognition Letters* 88, 64-71.