COMBINED FINITE ELEMENT METHOD AND MACHINE LEARNING TOWARD THE ANALYSIS OF MYOCARDIAL ISCHEMIA

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Abstract:

This study combines Finite Element Method (FEM) and machine learning (ML) with the aim to i) computationally simulate myocardial ischemia and, afterwards, ii) automatically detect and localize its presence. The computed tomography (CT) images are used to create a simplified 3D FE heart-torso model. A 3D FE model of the heart is segmented into 17 zones, enabling the simulation of both normal and ischemic cardiac beats in different zones and the creation of a virtual database which is further used for ML approach. Several classifiers are trained and tested using the virtual database to detect and localize ischemic beats based on the body surface potentials map (BSPM). If the ECG signal is classified as ischemic at the first stage ML model, potentials are processed by the second stage, which predicts the location of the ischemic area in one of the heart's segments. The proposed approach presents an improved solution which can facilitate daily clinical practice and enable timely treatment planning in future.

Keywords: myocardial ischemia, finite element method, machine learning

1. Introduction

Myocardial ischemia is one of the most common causes of death, presenting a restriction in the blood supply to heart tissue due to a partial or complete blockage of a coronary artery under atherosclerosis [1]. It is usually diagnosed by analysing ST deviations in patient's ECGs, but there is a strong evidence in clinical practice that ischemic regions cannot be localized using 12-lead electrocardiogram (ECG). In the last years, different computational methods have been developed to simulate heart's function and generation of body surface potential maps (BSPMs), as well as inversely model the cardiac activities (i.e., ECGs). With the aim to facilitate clinical application of computational solutions, the presented study combines two approaches - Finite Element Method (FEM) and Machine Learning (ML) alleviating limitations of their separate usage. The first step includes the creation of virtual database of normal and ischemic cardiac beats employing FEM, while the second step covers the localisation of detected ischemic cardiac beats using ML.

2. Materials and method

In order to perform FE simulations of normal and ischemic cardiac beats, a simplified 3D FE heart-torso model is created using Computed Tomography (CT) images. Torso is assumed to be completely homogeneous, while 3D FE model of the heart is segmented into 17 zones [2], enabling the simulation of ischemic and non-ischemic cardiac beats in different zones. Normal and ischemic beats are simulated by applying adequate values of electrical potentials within the heart, which propagates to the body surface. In this way, the virtual measurements are stored into the database which consists of 1700 instances (850 ischemic patients and 850 non-ischemic patients). Several classifiers are trained and tested using the virtual database to detect and localize ischemic cardiac beats based on the BSPM. If the ECG signal is classified as ischemic at the first stage ML model, potentials are processed by the second stage, which predicts the location of the ischemic area in one of the heart's segments. We analysed our dataset with two approaches for model automation: Bayesian model selection with Auto-WEKA tool [3] and caret package in R [4].

3. Results and Conclusions

In the detection of cardiac ischemia (the first phase model), Random forest model applied on the test set returned the best classification accuracy (94.7%), while the other methods achieved somewhat lower accuracy (from 93.2% to 93.8%). The second phase model determined the correct location of cardiac ischemia with 89% accuracy and it was, surprisingly, the linear discriminant analysis (LDA) which turned out to be the best classifier, taking into account that almost 10% of the testing set are misclassified with the first stage classifier. Other ensemble-based classifiers (mars, xgbT, xgbL, gbm, and rf) achieved somewhat lower classification accuracy. It can be said that the results of the second phase modelling are satisfying and allow successful practical application of the proposed system.

In summary, this study reported the investigation of myocardial ischemic detection and localisation employing FEM and ML approach, integrating the bidomain heart model with the monodomain torso model. It presents an improved solution which can facilitate daily clinical practice and enable timely treatment planning in the future. More complex models and simulations, as well as finer calculations of electrical potentials, will be in focus of our further studies.

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