EUROPEAN MECHANICS SOCIETY

The Euromech Colloquium 650 – Addressing Challenges in Applied Mechanics through Artificial Intelligence Applications, 27 – 29 August 2025, Belgrade, Serbia

Physics informed neural network for estimation of physiological models

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I. INTRODUCTION

Here are the One of the most important tasks in biomedical signal processing is related to assisting clinical decision making by health care providers. To achieve this goal, we often utilize inverse models in which a vast amount of information that is available from physiological measurements (electroencephalography, electrocardiography, ultrasound, magnetic resonance imaging, etc.) is reduced to much smaller, but still meaningful, set of parameters.

Depending on the phenomenon of interests the size of data may vary significantly thus affecting what kind of machine learning / artificial neural network techniques are applicable. In the case of limited amount of data (e.g. large patient-to-patient variability) we often need to utilize physics based models in order to compensate for the lack of big data sets.

To this purpose we demonstrate applicability of the proposed technique on two clinical application in which physics based models are utilized to estimate unknown physiological parameters. First, we demonstrate applicability of physics informed neural network for estimation of the electrical activity of the neonatal cortex using neural networks and finite-element-model of infant skull. Then we demonstrate the applicability of the proposed approach to estimating electromechanical properties of the heart using electrocardiography and tagged magnetic resonance imaging technique.

We evaluate the performance of the proposed techniques for various scenarios for both simulated and real data measurements.

II. FORWARD MODEL

The electro-mechanical activity in human body is modelled adequately using a set of partial differential equations (PDEs) with a particular set of boundary conditions defined by various physical constraints (e.g. intraventricular pressure is used to model boundary stress in elasto-dynamic equations). In addition, depending on the resolution level (micro-, meso- or macroscopic) various electro-mechanic and mechano-electric feedback mechanism may need to be included.

Furthermore, the actual complexity of realistically shaped geometries of organs requires that forward models are obtained by finite-element solvers (e.g. COMSOL ANSYS, etc.)

III. INVERSE MODELS FOR CORTICAL ACTIVITY

Using our previously proposed cortical activity model, we model the cortical activity using 256 dipoles placed on the cortical surface. Due to the fact that the geometry is inherently irregular the solution of these equations can only be obtained by using a numerical method such as finite-element method.

We use realistic geometry of the 9 months old infant obtained at The University Children Hospital, University of Belgrade, Serbia. MRI images consisted of 110 axial MR slices with 256x256 size and field of view of 240 mm.

The segmentation and meshing was done using software packages Slicer and Meshlabs that were then imported as STL files in COMSOL finite-element solver.

IV INVERSE MODELS FOR ELECTROMECHNICAL ACTIVITY OF THE HEART

We model the electro-mechanical activity of the heart using elasto-dynamic equations in which the elasticity modules are defined using electro-mechanical feedback model that assumes functional dependence between the stiffness of the heart muscle and Ca+2 ionic currents. The corresponding model accounts for intraventricular pressure by incorporating it as a boundary conditions.

The inverse model is defined using tagged magnetic resonance images that enable calculation of the corresponding strain (deformation) and intraventricular pressure (stress). The solution of these inverse models is computationally intensive due to a mesh size and physics informed neural networks (PINN) provide potentially fast solution with a desired level of accuracy.

V REFERENCES

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