A Toolkit for Forward/Inverse Problems in Electrocardiography within the SCIRun Problem Solving Environment

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INTRODUCTION

Computational modeling of bioelectric fields often requires the examination of system-specific forward and inverse problems [1,2] in order to non-invasively analyze physiological events that are otherwise inaccessible or unethical to explore. Solutions to such problems require a common set of components, each of which are customized or optimized for the particular problem formulation. Bioelectric activity begins from a source, which is defined to suit the specific goals of the problem. For example when the clinical mission is to identify focal activation in the brain, one or more current dipoles is a suitable source.

Each type of source requires an approximation in mathematical and then numerical form that can generate the associated voltages on the surface of the body. If the goal is to recover the source from body surface potentials, the solution strategy must include appropriate numerical techniques that can incorporate constraints and recover useful solutions, even when the problem is poorly posed and hence numerically ill conditioned. Creating complete software solutions to such problems is a daunting undertaking, and in order to make such tools more accessible to a broad array of researchers, the Center for Integrative Biomedical Computing (CIBC) has compiled a forward/inverse toolkit.

The goal of the toolkit is to create a generalized software environment based on the open-source SCIRun system [4,5], to aid researchers in constructing, executing, and visualizing such computational models. A key feature of our approach is that, rather than requiring custom code for all its functionality, SCIRun is able to link compatible and complementary software packages through a bidirectional MATLAB interface while supporting the development of additional C++ modules. SCIRun also supports many file formats and can thus import and export data and results with such packages as ECGSIM [3], CHASTE [6], and CARP [7].

TOOLKIT

SCIRun
- General purpose problem-solving environment
- Component-based, visual programming paradigm
- Linkable, purpose-specific modules
- Interactive modification
- Externally compatible data formats

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Forward/Inverse Toolkit paradigm
- Provides a diverse array of modules and data types for bioelectric field problems
- Provides sample networks and data sets with which to explore toolkit functionality

CASE STUDIES

Simulation of Cardiac Defibrillation

Goal: simulate the electric fields from an implantable cardiac defibrillator (ICD) in order to minimize required shock strength

- Generate patient-specific mesh (CIBC Software: Seg3D, Cleaver, and BioMesh3D)
- Place implantable defibrillator and electrodes
- Solve for shock potentials in the heart
- Analyze torso/cardiac potentials
- Adjust shock strength
- Iterate to determine optimal device placement

Solution to ECG Inverse Problem

Goal: find cardiac potentials or activation times based on thoracic geometry and a time series of body-surface ECGs

- Generate cardiac and torso meshes (CIBC Software: Seg3D, Cleaver, and BioMesh3D)
- Apply physiological constraints
- Create a simplified assumption of cardiac potentials (dipoles, monopoles, activation times)
- Iteratively adjust solution
- Determine solutions that best reproduce observed torso surface potentials

DISCUSSION

We have augmented the SCIRun problem solving environment with a set of modules, sample networks, and data sets to address a wide range of bioelectric field problems as they arise in clinical medicine and electrophysiology research. SCIRun provides an excellent framework because it is easily extended through the creation of dedicated C++ modules and, more flexibly, through an interface to MATLAB. We have used this framework to implement a comprehensive set of source models, numerical approximations of their bioelectric potentials, and source localization/construction methods to estimate the sources from body-surface potentials. The case studies provided are just examples of a range of applications that biomedical scientists and engineers have carried out (and continue to develop) using SCIRun with the toolkit. The CIBC makes all the associated software available under a very liberal open source license and provides documentation, tutorials, workshops, and individual assistance to others wishing to take advantage of this environment.

REFERENCES