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Electromagnetic Modeling of Human Body Using High Performance Computing

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Abstract

Realistic simulation of electromagnetic wave propagation in the actual human body can expedite the investigation of the phenomenon of harvesting implanted devices using wireless powering coupled from external sources. The parallel electromagnetics code suite ACE3P developed at SLAC National Accelerator Laboratory is based on the finite element method for high fidelity accelerator simulation, which can be enhanced to model electromagnetic wave propagation in the human body. Starting with a CAD model of a human phantom that is characterized by a number of tissues, a finite element mesh representing the complex geometries of the individual tissues is built for simulation. Employing an optimal power source with a specific pattern of field distribution, the propagation and focusing of electromagnetic waves in the phantom has been demonstrated. Substantial speedup of the simulation is achieved by using multiple compute cores on supercomputers.

Keywords: Electromagnetics; High performance computing; human body

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1. Introduction

A novel mechanism to use wireless power transfer to charge tiny medical implanted devices deep inside the human body has recently been discovered by researchers in electrical engineering at Stanford University for its application to medicine [Kim et al. 2012, Kim et al. 2013, Ho et al. 2014]. The discovery serves to eliminate the bulky batteries that limit the usage of these medical devices, and could provide a new type of medicine by treating diseases with electronics rather than drugs. It will spawn a new generation of programmable micro implants – sensors to monitor vital functions deep inside the body; electrostimulators to change neural signals in the brain; and drug delivery systems to apply medicines directly to affected areas.

The method, termed midfield wireless powering, utilizes midfield excitation from a microwave power source to create a high-energy density region deep in tissue and making these power harvesting structures extremely small then allows optimal targeting of devices within the body. *Ex vivo* experiments have been carried out to evaluate the performance of midfield wireless powering schemes in complex tissue geometries by designing two configurations that simulate power transfer to devices in the left ventricle of the heart and the cortex region of the brain in a pig. The demonstrated performance characteristics far exceed requirements for advanced electronic functions, and should enable new generations of miniaturized bioelectronic devices to sense and correct biological activities with fine spatial and temporal resolution.

While midfield wireless powering has shown tremendous improvement over conventional wireless power transfer techniques, much theoretical and experimental work is required for the realization of an actual wireless implanted device embedded in the human body. Realistic simulation of electromagnetic wave propagation and interaction with different kinds of tissues in the human body can expedite the process of producing a safe device prototype for clinical trials. With current simulations performed on desktop computers with limited memory and CPU power, it is very time-consuming, if feasible at all, to model the large problem size arising from the disparate spatial scales associated with the complex geometries inside the human body. SLAC has been developing the parallel finite element electromagnetics simulation suite ACE3P [ACE3P] for accelerator modeling using high performance computing (HPC) [Ko et al. 2010, Ge et al. 2015]. ACE3P simulation capabilities can be enhanced to enable modeling electromagnetic wave propagation in human body. Computing on massively parallel computers, ACE3P will provide the needed power to tackle the computationally challenging problems in advancing this medical research area.

Supported by the US Department of Energy "Accelerator Stewardship Test Facility Pilot Program," [ASTFPP] ACE3P is applied to model electromagnetic wave propagation in human body for the investigation of midfield wireless powering. This enables collaborative research in high-fidelity simulation using high performance computing (HPC) that has leveraged the respective expertise at

- SLAC National Accelerator Laboratory – Electromagnetic simulation using the parallel finite element electromagnetic code suite ACE3P developed for high fidelity modeling of accelerator applications running on massively parallel computer platforms
- Stanford University – Pioneering research in midfield wireless powering for miniature implanted devices at the Department of Electrical Engineering
- Simmetrix Inc. [Simmetrix] – Enabling technology in handling of geometrical models and generation of high-quality unstructured meshes for complex geometries

Thus, this project involves the collaboration of a national laboratory, academia and industry, aiming to provide a leading edge simulation tool with advanced enabling technologies that can impact the progress of research in this medical application.

2. **Midfield Wireless Powering**

The mechanism of harvesting a medical implanted device from an external power source is shown in Fig. 1. The micro-implant proposed by Stanford is embedded within a certain depth (up to several cm) from the human body skin. A planar microwave power source, configured in a specified pattern represented by the current source, is placed closed to the body. The evanescent field generated from this source becomes propagating modes when interacting with