Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Ilias Giannakopoulos

PhD Program: Computational and Data Science and Engineering

Title of Thesis: Memory compression of the Galerkin volume integral equations and coil modeling for the electrical property mapping of biological tissue

Supervisor: Professor Maxim Fedorov

Date of Thesis Defense: 12 May 2020

Name of the Reviewer:

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:** BG **Bastien Guerin** **Date: 4/14/2020**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

GENERAL COMMENTS: I have read with great interest the thesis of Ilias, which describes in detail some important novel contributions to the field of computational electromagnetics (EM) with an particular emphasis on applications for magnetic resonance imaging (MRI, my field of specialization). The thesis is well written and presents clearly not only the methods developed by Ilias, but also the foundations upon which he built his work (EM theory and, especially, integral equation (IE) methods). For a reader like me, not specialist in IE methods, this was greatly appreciated! This work is very relevant for MRI, and I imagine for other areas (for example, the memory compression work using Tucker decomposition seems well suited to cell phone safety studies, which face similar concerns as MRI safety). It is now becoming clearer that fast safety computations for MRI are going to be essential for patient-specific evaluation of SAR and maybe even temperature. This is especially important as the main magnetic field (and therefore Larmor frequency) keeps increasing to improve the signal-to-noise ration but leads to greater energy deposition in the body (specific absorption rate problem) and non-uniform B1+. On this latter point, and although Ilias does not mention this explicitly in the thesis, it is likely that the fast computation methods presented here can help with the B1+ mitigation problem, for example by designing better coils for UHF applications or bypassing the B1+ mapping process (and calculating them instead). In other words, applications abound for Ilias' work on memory footprint reduction for SIE-VIE methods, and I am therefore confident that his work will receive a lot of interest.

The second part of the thesis is an application of Ilias' fast computation work, whereby the fast solver is used as the forward model (and derivative evaluation) for the so-called general Maxwell tomography (GMT) problem that aims to estimate the underlying permittivity and conductivity maps of a human being using as input 1) knowledge of Maxwell equations as encoded in the IE method and 2) measurement of an RF coil' B1+ maps. Ilias' work is a continuation of the initial idea by Serrales et al, and shows in simulation that GMT can work in principle using an 8-channel 7 Tesla MRI coil. The numerical results are good and it is comforting to see that the regularized method seems to work in principle in a human application (i.e., beyond the simple 4 compartment distribution modeled in Serrales et al). I was a bit disappointed not to see more experimental results however, given that some were presented in Serrales et al and that the coil actually exists. So one of my question for Ilias is: Why was this experimental evaluation not done? I don't suggest doing it for the defense (nor do I think this is a requirement for Ilias to graduate), but I sure would be curious to see how the method fares on a realistic physical phantom and/or a human head. Ilias elegantly shows that B1+ maps can in principle be used to estimate ε and σ, I expect the unavoidable (and likely large, i.e. 10-20%) discrepancies between simulated and measured B1+ maps to propagate into unavoidable and large ε and σ estimation errors. Even if this proves true, this would not necessarily be a death blow of the method, since it may be the case that a combination of e, s and possibly other parameters can be more easily estimated and yield adequate contrast in cancer and other diseases. In other words, the ultimate test of the method is not (in my mind) accurate estimation of ε and σ, but whether or not the method yields good and reliable image contrast in the presence of some disease. I would be interested in hearing Ilias' thought on this matter, maybe we'll have this opportunity at the actual defense. All in all, it is clear that Ilias' work is state-of-the-art and represents the best methodology available to date to estimate electrical properties from MRI measurements – and for this, I congratulate him.

In summary, Ilias' work is excellent and represents the state-of-the-art in both 1) fast computation of EM fields for biomedical applications and 2) estimation of electrical properties from MRI measurements. His peer-reviewed papers are of great quality and the work is eminently relevant. Therefore, I wholeheartedly recommend Ilias to go ahead with

his defense, which I look forward to attending. I also look forward to hearing his thoughts on the questions and comments listed above.

SPECIFIC COMMENTS: Below are some specific comments that may be good to discuss during the thesis defense:

- *LOW MEMORY FOOTPRINT*: The compression factors for the N and K operators are very impressive, even at GHz frequencies. It is impressive that you are able to fit the field computation problem for the entire human body model (head to foot) in a GPU, I feel that's an important result.
- *LMF*: I understand that you applied Tucker and CP compression to the PWL discretization problem, do the same results hold for the PWC discretization?

- *GMT*: How do you think the method would fare as the number of coils is increased? Would this help the conditioning of the method, and therefore help control noise better?
- *GMT*: In your paper you write "the combination of transmit and receive field information is sufficient to resolve fundamental indeterminacies related to absolute field phase". What do you mean by this?
- *GMT*: You also write "the memory required to store the N and K operators increases with the number of voxels and could rapidly become prohibitive even for modern GPU's." Is it possible to recontract only the brain? Would that improve the conditioning of the method and the speed?
- *GMT*: "In this work, we used the true EP of the head models to calibrate the current distribution on the coil conductors, which is used to compute the incident fields (see Eq. 11). This step consists of a surface-volume integral equation (VSIE) coupling, which was performed before the GMT optimization." I was a bit confused by this statement, this seems a bit circular… In reality, you don't know the currents. You do mention that in reality, one would have to estimate both the EP and the coil current. Is there enough information content in the B1+ map to achieve this though? As you point out, the recent development by Georgy would allow doing this quickly.
- *GMT*: Your point about the importance of initial guess is well taken. In practice, you could start with a FreeSurfer segmentation that would likely give you an excellent estimate of ε and σ. This could save you a lot of iterations and improve the chance of convergence to the true solution.

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*