UNIVERSITY OF SZEGED
FACULTY OF SCIENCE AND INFORMATICS

INSTITUTE OF INFORMATICS

6720 S Z E G E D
Árpád tér 2.
6701 P.O. Box: 652.

Review Report on the PhD Thesis of
Zeyu Wang
entitled
GPU-Accelerated Signal Decomposition for Efficient EEG Processing: Methods and Applications

The Candidate's submitted doctoral thesis addresses the area of signal processing. The Candidate proposed advanced signal decomposition methods exploiting high-performance GPU-based parallel computing, in order to enhance the efficiency and effectiveness of EEG analysis. The topic is relevant, and the Candidate's contributions to the field are satisfactory.

The thesis is organized into seven chapters, written in 87 pages altogether, furthermore, figures, tables and algorithm snippets enrich the work. The thesis is well written and easy to follow. The presentation quality of the thesis has been improved compared to the previous version submitted for the pre-defense, only a small number of grammatical issues remained.

In the first part of the thesis, in Chapter 1, the Candidate introduces the readers into the topic of the dissertation and states the motivation and the research goals of the work. First the long history of EEG signal processing is detailed, then the latest advances of HPC and GPU developments are mentioned. As the main motivation, it is emphasised that modern neuroscience research relies on large-scale EEG datasets, and their processing needs advanced algorithms using GPUs and deep learning models.

In Chapter 2, the Candidate elaborates the development history of signal decomposition, naming various application fields, highlighting its advantages and the challenges. The most important signal decomposition methods are also introduced here, including frequency decomposition and spatial decomposition.

Chapter 3 presents the first contribution of the dissertation, which is a massively parallel GPU implementation of the ICEEMDAN algorithm used for precise time-frequency analysis of non-stationary EEG signals. In Section 3.1, some related parallel implementations have been mentioned for the EMD algorithm.

Chapter 4 presents the second contribution of the thesis, which is an efficient GPU implementation of the Multivariate Empirical Mode Decomposition (MEMD) method in CUDA. The relevant related works are introduced in Section 4.1, and Section 4.3 presents and details the achieved results.

Chapter 5 presents the last, third contribution of the dissertation. It introduces an Independent Component Analysis (ICA) prototype implementation using tensor cores for speeding up the EEG spatial decomposition. It has achieved a significant speedup with improved GPU memory throughput compared to a MATLAB implementation. The Candidate's implementation managed to achieve a higher performance using a shared memory buffer.

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Chapter 6 presents a summary of the dissertation, highlighting possible future works. Finally, Chapter 7 closes the dissertation by listing the main thesis points containing the contributions.

Concerning the thesis booklet, it has still remained a bit longer than usual. In the booklet the essences of the thesis points have been highlighted by italics text at the beginning of the sections, which provide a nice, condensed overview of the achieved results. Unfortunately, these versions have not been synchronized with the thesis point statements in the dissertation. Finally, a minor comment that the numbering of the own publications and the literature references are overlapping, it would have been better to use different notations (e.g. [P1], [P2], ...).

After this general overview, I would like to address the Candidate's dissertation with the following direct questions:

- What were the main differences in the properties of the synthetic and real datasets used to evaluate the proposed implementation, shown in Chapter 4?
- Would a larger computing infrastructure help in gaining additional research results?
- The Candidate stated that "achieving real-time EEG processing on wearable, low-power portable devices is an ongoing challenge". Would the proposed solutions be usable in such real-time settings? What modifications would be needed, if not?

Concerning the Candidate's publication record, the thesis is based on six publications, the Candidate published his work mainly in workshop or conference proceedings, and has a Q1 (Sensors) and a Q2 (Journal of Computational Science) journal publications as well. It is also positive that the source code of the algorithm implementations are publicly available.

As a summary, the thesis represents a great deal of work and meets the requirements laid down for the degree of Ph.D. I appreciate the Candidate expertise in the field, and after answering my remaining questions satisfactorily, I can accept his contributions. Based on the above, I recommend organizing the public defense of this thesis. In case of a successful defense procedure, I recommend awarding the Ph.D. degree to the Candidate.

Szeged, 2025.07.01.

Dr. habil. Attila Kertész
associate professor
Software Engineering Department
Institute of Informatics
University of Szeged