Development of an EM Device for Cerebrovascular Diseases Imaging and Hardware Acceleration for Imaging Algorithms within the EMERALD Network

Development of an EM Device for Cerebrovascular Diseases Imaging and Hardware Acceleration for Imaging Algorithms within the EMERALD Network

D. O. Rodriguez Duarte[1], M. A. Mansoori[1], J. A. Tobon Vasquez[1], G. Turvani[1], M. R. Casu[1], F. Vipiana[1]
[1] Dept. Electronics and Telecommunications, Politecnico di Torino, DET-POLITO, Torino, Italy,
{david.rodriguez, jorge.tobon, giovanna.turvani, mario.casu, francesca.vipiana}@polito.it

***Abstract*—This paper is presenting the first months of research activities within the Marie Skłodowska-Curie Innovative Training Network "EMERALD" developed by the Politecnico di Torino group. Our research work is related to the development of an electromagnetic device for cerebrovascular diseases imaging and to the hardware acceleration of the implemented imaging algorithms via field-programmable gate arrays or application-specific integrated circuits coupled with regular multicore central processing units and even graphics processing units.**

***Index Terms*—microwave imaging, stroke imaging, antennas, embedded systems, hardware accelerator, field-programmable gate array.**

I. Introduction

EMERALD (ElectroMagnetic imaging for a novel genERation of medicAL Devices) is the coherent action of European engineering groups involved in electromagnetic (EM) technology for medical imaging to form a cohort of highly-skilled researchers capable of accelerating the translation of this technology for medical diagnostics devices "from research bench to patient bedside".

EM imaging can bring unique contributions to a number of clinical applications, complementarily to the current well-proven imaging modalities, such as X-Ray imaging, ultrasound and magnetic resonance imaging. At microwave frequencies, EM imaging exhibits favorable penetration depths that allow imaging tissues deeper in the human body as compared to other emerging modalities (e.g. optical techniques), it is completely harmless since the involved waves are non-ionizing and used in very low doses, and the EM technology is economically sustainable, due to the progress in mobile industry and microwave devices in recent years.

Within the EMERALD action, our research activities are concentrated on the development of an EM device for cerebrovascular diseases imaging and to the hardware acceleration of the implemented imaging algorithms, as summarized in the following sections.

II. EM Device for Cerebrovascular Diseases Imaging

Cerebrovascular diseases represent one of the major clinical challenges nowadays, both owing to their pervasiveness and the fact that current imaging modalities are not viable for repeated operation. For instance, continuous post-event monitoring of stroke would improve the effectiveness of treatments, but cannot be performed with actual imaging modalities. As another example, mobile and low-cost modalities would allow a better management of traumatic events, such as hematoma, which is currently an unmet clinical need.

To fill this gap, we are developing a prototype of a mobile device for imaging cerebrovascular diseases, such as stroke, hemorrhage and hematoma. The device is formed by 24 antennas working in the frequency band 0.8-1.2 GHz (centered at 1 GHz), as theoretically studied in [1]. The antennas are connected to the vector network analyzer via a 2X24 switching matrix realized with electromechanical coaxial switches [2]. In this way, each antenna can act as transmitter or receiver according to the selected path in the switching matrix. As shown in Fig. 1, the antennas will be placed around the upper part of the human head, through a 3D-printed plastic support, and immersed in a coupling medium with dielectric constant ε_r=18.5 and conductivity σ=0.2 S/m. The coupling medium dielectric properties as well as the working frequency band have been chosen in order to guarantee the best trade-off between wave penetration inside the head and imaging resolution [3][4].

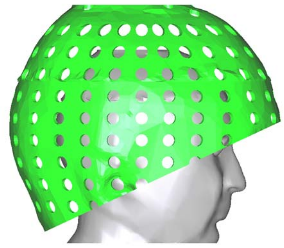

Fig. 1. Plastic support for the antennas placed around the head.

The designed antennas, shown in Fig. 2, are printed on a FR4 dielectric slab with ε_r=4.3, thickness equal to 1.6 mm, and size 48 X 30 mm. The antenna is printed on one side of the dielectric slab, while on the other side there is the ground plane and the coaxial cable. The simulated behavior of the designed antenna is reported in Fig. 3, where the $|S_{11}|$ is shown when the antenna is in free space and when instead it is immersed in the chosen coupling medium. It is evident that the antenna is very well matched within the device working frequency 0.8-1.2 GHz once immersed in the chosen coupling medium, as highlighted in Fig. 3.

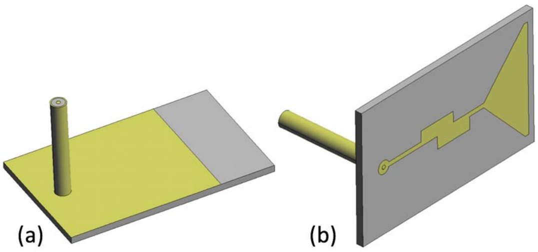

Fig. 2. Designed antenna geometry

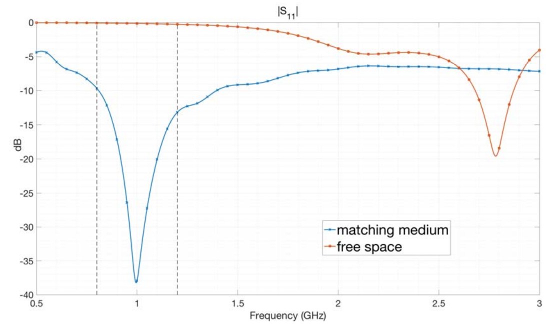

Fig. 3. Amplitude of the S11 (dB) of the designed antenna in free space (red line with circle marks) and immersed in the chosen matching medium (blu line with cross markers).

III. Hardware Accelerators for Microwave Imaging

Algorithms used in microwave (MI) imaging for biomedical applications range from the ones used in solvers for electromagnetic simulations, where antennas interact with human tissues and coupling media, to those used directly in the field, either in a laboratory setting or a clinical scenario, where images are reconstructed from data acquired typically using a vector network analyzer. What the vast majority of these algorithms have in common is complexity, which ultimately leads to excessive execution time on standard hardware.

Our research activity aims at reducing the execution time of MI algorithms by means of specialized hardware accelerators. These accelerators can be implemented in Field-Programmable Gate Arrays (FPGAs) or Application-Specific Integrated Circuits (ASICs) coupled with regular multicore Central Processing Units (CPUs) and even Graphics Processing Units (GPUs).

We believe that the best strategy to attain this goal is not designing a specific accelerator to tackle each and every MI problem, but rather identifying a class of algorithm "kernels" that are recurrent in these algorithms. These kernels can then be implemented in hardware and invoked from a host CPU whenever the associated code functions require them. To identify the kernels, we are collecting and analyzing existing MI software codes developed by the members of the EMERALD network. The profiling of the code will reveal which of these kernels actually require acceleration.

The MI algorithms very often deal with large datasets. Therefore, one of the main challenges is moving a large amount of data from the CPU's memory to the accelerators and not letting the transfer time undermine the potential speed-up. This requires not only the application of best hardware design practices, but also the definition of new design methodologies and formal approaches, which will also be tackled in this research project.

We acquired an extensive expertise in this research field over the years, working primarily on the acceleration of MI algorithms for breast cancer detection [5]-[9] and recently for brain stroke monitoring [10]. For example, Fig. 4 illustrates an accelerator for brain stroke monitoring implemented in a Zynq SoC. The accelerator is invoked by the ARM dual-core CPU. The non-blocking FIFOs enable the overlap of data transfer and computation, hence reaching the maximum acceleration.

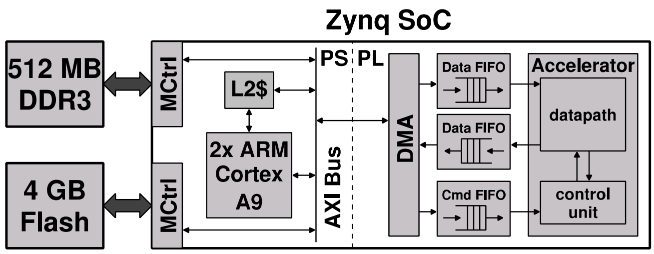

Fig. 4. Block diagram of an accelerator for brain stroke monitoring implemented in a Zynq SoC.

IV. Conclusions and Perspectives

This paper has illustrated the first months of research activities of the Politecnico di Torino group within the EMERALD action. The next steps of our research activities, that will be presented at the conference, will be the realization and experimental testing, via 3-D printed anthropomorphic phantoms, of the realized prototypal EM imaging device, as well as the classification of the kernels, recurrent in microwave imaging algorithms, that needs to be hardware accelerated.

Acknowledgment

This work was supported by the EMERALD project funded from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 764479.

References

[1] R. Scapaticci, J. Tobon, G. Bellizzi, F. Vipiana, L. Crocco, "Design and Numerical Characterization of a Low-Complexity Microwave Device for Brain Stroke Monitoring", *accepted for publication in IEEE Transactions on Antennas and Propagation*, 2018.

[2] J. A. Tobon Vasquez et al., "Ongoing Developments towards the Realization of a Microwave Device for Brain Stroke Monitoring",

IEEE International Symposium on Antennas and Propagation, Boston (MA, US), July 2018.

[3] R. Scapaticci, L. D. Donato, I. Catapano, and L. Crocco, “A feasibility study on Microwave Imaging for brain stroke monitoring,” *Progress in Electromagnetics Research B*, vol. 40, pp. 305–324, 2012.

[4] R. Scapaticci, M. Bjelogrlic, J. A. Tobon Vasquez, F. Vipiana, M. Mattes, and L. Crocco, *Emerging Electromagnetic Technologies for Brain Diseases Diagnostics, Monitoring and Therapy*. Springer int. pub., 2018, ch. 2. Microwave Technology for Brain Imaging and Monitoring: Physical Foundations, Potential and Limitations, pp. 7–35.

[5] M. R. Casu, F. Colonna, M. Crepaldi, D. Demarchi, M. Graziano, M. Zamboni, “UWB Microwave Imaging for Breast Cancer Detection: Many-core, GPU, or FPGA?,” *ACM Transactions on Embedded Computing Systems*, 2014, 13, 109:1–109:22. doi:10.1145/2530534.

[6] D. J. Pagliari, A. Pulimeno, M. Vacca, J. A. Tobon Vaquez, F. Vipiana, M. R. Casu, R. Solimene, L. P. Carloni, “A low-cost, fast, and accurate microwave imaging system for breast cancer detection,” *IEEE Biomedical Circuits and Systems Conference (BioCAS)*, 2015, pp. 1–4. doi:10.1109/BioCAS.2015.7348444.

[7] D. J. Pagliari, M. R. Casu, L. P. Carloni, “Acceleration of microwave imaging algorithms for breast cancer detection via High-Level Synthesis,” *2015 33rd IEEE International Conference on Computer Design (ICCD)*, 2015, pp. 475–478. doi:10.1109/ICCD.2015.7357152.

[8] M. R. Casu, M. Vacca, J. A. Tobon Vasquez, A. Pulimeno, I. Sarwar, R. Solimene, F. Vipiana, “A COTS-Based Microwave Imaging System for Breast-Cancer Detection,” *IEEE Transactions on Biomedical Circuits and Systems*, 2017, Vol. 11, pp. 804–814, doi:10.1109/TBCAS.2017.2703588.

[9] D. J. Pagliari, M. R. Casu, L. P. Carloni, “Accelerators for Breast Cancer Detection,” *ACM Trans. Embed. Comput. Syst.*, 2017, 16, 80:1–80:25. doi:10.1145/2983630.

[10] I. Sarwar, G. Turvani, M. R. Casu, J. A. Tobon, F. Vipiana, R. Scapaticci, and L. Crocco, “Low-Cost Low-Power Acceleration of a Microwave Imaging Algorithm for Brain Stroke Monitoring,” *submitted to Journal of Low Power Electronics and Applications (JLPEA)*, 2018.