Ph.D. position at Creatis

Team: Creatis – MYRIAD

Supervision: Denis Friboulet (Professor), Fabien Millioz (Associate professor), Damien Garcia (Researcher, Inserm)

How to apply: Send to the contacts below a resume, a cover letter and the grades/rankings of your last 2 years of studies (including the results of the 1st semester of the academic year 2020-2021).

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1. Title

Reconstruction of the Doppler velocity field in ultrasound imaging by deep learning

2. Context

The medical objective of this project is simultaneous imaging of the myocardial wall and blood dynamics for a comprehensive evaluation of cardiac function during an echocardiographic examination. In ultrasound imaging, duplex Doppler acquisitions allow the visualization of the anatomy of the explored tissues (B-mode imaging) and the blood velocities (Doppler imaging). As a result, the acquisition time must be shared between the anatomy and Doppler transmissions. This imaging modality is therefore limited in terms of acquisition rate: a reliable duplex image requires about 32 emissions for the anatomical part and 32 emissions for the Doppler part, which leads, at best, to acquisition rates of about 50 images/cardiac cycle [1]. This limitation proves to be very problematic for the study and monitoring of very rapid cardiac phenomena.

We have recently demonstrated that an approach based on deep convolutional networks can reduce by an order of magnitude the acquisition times devoted to the characterization of anatomical structures (B-Mode) using plane-wave [2] or diverging-wave [3] imaging.

With regard to the Doppler part of the acquisition, we have also shown the feasibility of reducing the number of emissions by a factor of about 2 using compressed sampling approaches [4, 5]. Unfortunately, these approaches do not allow a significant increase in the acquisition rate, because of the low compression factor and especially because they imply the resolution of an inverse problem, which does not yield computation times compatible with fast acquisitions.

3. Objective and methodology

In this context, the objective of this project is to develop, implement, and validate a deep neural network (DNN) approach for the reconstruction of the myocardial wall (B-mode) and blood flow (Doppler) from a very low number of emissions. Such an approach should allow obtaining high-quality echocardiographic images while reducing acquisition times by an order of magnitude (yielding more than 500 images per second).

A crucial element for the training of any DNN is the availability of massive and reliable reference data. Reference Doppler data cannot be obtained from physical acquisitions. Therefore, these reference data will be generated using the ultrasound image simulation approaches developed at Creatis for cardiac structures [6] and blood flow [7].

The key points to be addressed in this work will then be the following:

- Using the training set mentioned above, the adaptation of the convolutional network developed at Creatis for imaging [3] to Doppler estimation will be examined. In particular, the phase conservation properties of the network will have to be quantified.
- Based on these first results, a dynamic DNN approach will be developed to exploit the temporal redundancy inherent to image sequences and thus improve the quality of the estimation as well as the computation time. To integrate these temporal constraints in the reconstruction process, the Ph.D. student will examine the adaptation of architectures such as recurrent neural networks or temporal convolutional networks.

The approaches developed will be optimized and evaluated based on numerical simulations and experimental data acquired *in vitro* on phantoms with controlled motion. A validation phase on cardiac data acquired *in vivo* will be carried out at the end of the thesis. The software developments will be based on the PyTorch python library.

The validation of the project on *in vivo* data will be carried out in collaboration with a cardiologist from Toronto (O. Villemain). The ultrafast sequences, obtained with a Verasonics ultrasound scanner, will be evaluated on 10 volunteers [8].

4. Applicant's profile

A Master's in Machine Learning or Signal/Image Processing, showing a good knowledge and experience of deep neural networks, as well as excellent skills in programming, training, and testing such networks. Prior knowledge in ultrasound imaging is not a prerequisite, since the candidate will be trained in this field at Creatis. A background and interest in medical imaging and ultrasound imaging, in particular, will nevertheless be an asset.

5. References of the supervising team

[1] J. Faurie, M. Baudet, J. Porée, G. Cloutier, F. Tournoux, and D. Garcia, Coupling Myocardium and Vortex Dynamics in Diverging-Wave Echocardiography, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* 66 (3), 425-432, 2019.

[2] M. Gasse, F. Millioz, E. Roux, D. Garcia, H. Liebgott, and D. Friboulet, High-Quality Plane Wave Compounding using Convolutional Neural Networks, *IEEE Transactions on Ultrasonics, Ferroelectricity and Frequency Control,* 64 (10), 1637-1639, 2017.

[3] J. Lu, F. Millioz, D. Garcia, S. Salles, W. Liu, and D. Friboulet, Reconstruction for Diverging-Wave Imaging Using Deep Convolutional Neural Networks, *IEEE Transactions on Ultrasonics, Ferroelectricity and Frequency Control,* 67 (12), 2481-2492, 2020.

[4] O. Lorintiu, H. Liebgott, and D. Friboulet, Compressed sensing Doppler ultrasound reconstruction using block sparse Bayesian learning, *IEEE Transactions on Medical Imaging,* 35 (4), 978-987, 2016.

[5] J. Richy, D. Friboulet, A. Bernard, O. Bernard, and H. Liebgott, Blood Velocity Estimation Using Compressive Sensing, *IEEE Transactions on Medical Imaging,* 32 (11), 1979-1988, 2013.

[6] M. Alessandrini, B. Chakraborty, B. Heyde, O. Bernard, M. D. Craene, M. Sermesant, and J. D'Hooge, Realistic Vendor-Specific Synthetic Ultrasound Data for Quality Assurance of 2-D Speckle Tracking Echocardiography: Simulation Pipeline and Open Access Database, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* 65 (3), 411-422, 2018.

[7] K. C. Assi, E. Gay, C. Chnafa, S. Mendez, F. Nicoud, J. F. P. J. Abascal, P. Lantelme, F. Tournoux, and D. Garcia, Intraventricular vector flow mapping—a Doppler-based regularized problem with automatic model selection, *Physics in Medicine & Biology,* 62 (17), 7131-7147, 2017.

[8] P. Joos, J. Porée, H. Liebgott, D. Vray, M. Baudet, J. Faurie, F. Tournoux, G. Cloutier, B. Nicolas, and D. Garcia, High-Frame-Rate Speckle-Tracking Echocardiography, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* 65 (5), 720-728, 2018.