PhD Subject
3-D cardiac ultrasound: from morphological deep learning-based imaging to tissue characterization

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Context

The heart is a complex organ that performs the essential function of circulating blood in the human body. This function is crucial to life, and heart disease remains a fundamental cause of death in industrialized countries. The development of diagnostic tools or therapeutic methods requires a detailed understanding of the physiology of the heart: motion/deformation of the muscle, hemodynamics in the various cavities, electrical activation, etc. Moreover, since the heart consists of muscle fibers, it also looks relevant to try to image the local fibrous structure of the tissue as finely as possible to establish a link between this local structure and heart function and, more generally, with the development of the various pathologies.

Based on MRI imaging of the free diffusion of water in tissue, CREATIS is one of the world leaders in cardiac fiber imaging. This imaging type is very complex, primarily because of the rapid and significant movement of the heart during MRI acquisition. On the other hand, thanks to the emergence of ultra-fast ultrasound imaging by plane-wave, the first technique for imaging tissue structure by ultrasound has recently been developed [1-2]. Ultrasound has many advantages over MRI, including its much lower cost, portability, and, for our application, its high acquisition speed, particularly in ultra-fast imaging. However, regarding pure image quality, 3-D ultrasound is currently not at a clinical level, particularly when compared to 2-D cardiac ultrasound.

In the context of the ANR project DELTA, 3-D cardiac tissue imaging has to be improved for the morphological aspects (temporal imaging, region of interest identification…) and tissue characterization. A high-technological scanner will be available to perform 3-D US imaging without any constraints in the probe multiplexing. A specific acquisition pipeline for high-quality images and tissue anisotropy estimation must be proposed. The latter has already been partially developed in the laboratory [3] but should be validated in dedicated experimental environments, as proposed in this PhD project.

Objectives

To complete this PhD project, several aspects will have to be investigated:

1. High-quality US imaging: The PhD student must propose deep learning-based strategies to provide high-quality imaging in real-time 3-D US acquisition. Previous works have been proposed in 2D and may be a good starting point [5-6]. The pipeline validation will be conducted in collaboration with practitioners associated with the ANR project.
2. Coherence estimation: Based on the previous work conducted by the team, the anisotropy estimation must be implanted inside the new scanner and tested on dedicated phantom and *ex vivo* tissue. Utilizing a whole 3-D system will modify the overall quality of the coherence estimation, and dedicated optimisation will have to be proposed to access the best anisotropy map possible (local estimation + tractography).
3. Experimental acquisition: The complete pipeline will be validated on the PILoT platform. The performance of the total acquisition scheme will be evaluated using specific media. Moreover, depending on the acquisition strategy proposed earlier, the impact of the anisotropy estimation

must be quantified. In particular, the transmission of diverging waves instead of plane waves could impact the coherence pipeline. Depending on the advancement, deep learning strategies could also be implied to estimate the local tissue orientation to loop with "Coherence estimation" works.

4. Clinical validation: It will be carried out in collaboration with the Creatis MRI team (ANR partner), with which links already exist. Thanks to a clinical protocol already established, it will be possible to take part in various operations on pigs during open-heart surgery. In addition to the morphological heat imaging, it will be possible to measure the local orientation of the tissue using ultrasound and MRI. In addition, the team has expertise in ischemia creation and reperfusion. The value of ultrasound measurement can be assessed in the face of this clinical problem.

Maturity

Ultrasound is currently undergoing a veritable revolution. After ultrafast 2-D imaging, which is starting to become standard in research laboratories, ultrafast 3-D imaging is now emerging. In addition, the project will benefit from a recent 1024-channel scanner that allows both transmission and reception on the full 2-D array and the possibility to manufacture numerous *in vitro* and *in silico* test media. In addition, the acquisition system contains a dedicated GPU architecture that could allow the proposed network to be directly installed in real-time acquisitions.

Concerning the database and network generation, given the work of the previous Master's trainee and PhD students, several promising avenues have been identified to set up the learning base and the networks.

Profile/Skills

Student from a top engineering school (generalist or EEA profile), with skills in image and signal processing, ultrasound imaging, deep learning, mathematics. A commitment to experimentation is necessary for this project.

Application procedure

Please send a CV, cover letter, and M1&M2 transcripts to

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The PhD grant has already been obtained in the context of the ANR DELTA.

References

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