Internship offer for 2nd-year MSc or 3rd-year engineering school students, with the possibility to continue with a doctoral thesis

Microbubble Localization using Deep Learning for Ultrasound Localization Microscopy (ULM)

Keywords: ULM, super-resolution, ultrasound, MB localization, deep learning, unfolding CNN.

1 Project Description

Ultrasound (US) imaging has gained increasing prominence in the field of medical practice, primarily owing to its properties including its non-invasive nature, non-ionizing radiation, cost-effectiveness, and user-friendliness. Employing plane wave techniques, US imaging is capable of achieving acquisition rates of up to 20kHz, thus facilitating proficient visualization and precise quantification of microvascular structures. This unique capability proves particularly invaluable in the detection of abrupt functional changes within the brain and in enhancing the sensitivity of blood flow assessment for improved filtration accuracy [1]. Nevertheless, the propagation of US waves encounters various physical phenomena, including diffraction and attenuation, which invariably impose constraints on spatial resolution. The recent introduction of **ultrasound localization microscopy (ULM)** has effectively addressed the inherent trade-off between spatial resolution and penetration depth, all the while maintaining heightened sensitivity [2]. This achievement is made possible by using both sparse microbubbles (MBs) and ultrafast imaging techniques. Traditionally, the ULM procedure comprises five pivotal stages: 1) data acquisition, 2) pre-processing (tissue filtering), 3) MB localization, 4) MB tracking, and 5) ULM image formation (rendering).

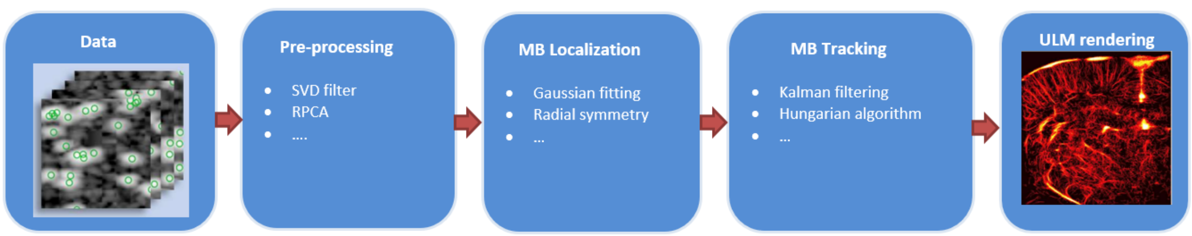

Figure 1: ULM pipeline in which some typical techniques are developed in each step [2].

While ULM has demonstrated its efficiency, it introduces **a novel trade-off** between **the precision of MB localization** and **data acquisition time** [3]. Employing a high dilution of MBs to achieve spatially sparse signals yields superior MB localization accuracy, albeit at the cost of extending data acquisition to ensure comprehensive perfusion of the entire vascular network under investigation. Conversely, a lower MB dilution permits more rapid acquisition by accommodating a greater number of vasculature perfusion events within a shorter time frame. However, this approach results in heightened signal overlap among MBs, leading to a higher incidence of spurious events and inaccurately reconstructed features. **Mitigating this trade-off** is a central focus of active research within the field of super-resolution ultrasound. Among these research efforts, deep learning (DL) solutions have garnered increasing attention for enhancing ULM imaging. They exhibit the potential to improve localization accuracy and streamline the time-intensive ULM processing pipeline, particularly when dealing with high concentrations of MBs. For instance, conventional convolutional neural network (CNN) architectures have been proposed to extract point target locations, representing MB centroids from B-mode images in the spatial domain [4]. Furthermore, a comprehensive CNN has been developed to process spatiotemporal US data, further enhancing localization confidence [5]. Despite their potential, these DL methods act as end-to-end **black-box engines** which indeed hinders their interpretability.

In this work, our focus will be on improving microbubble (MB) localization when MB signals from high-concentration contrast injections overlap. Unlike the aforementioned DL methods, we will particularly investigate model-driven DL approaches, i.e., unfolding CNN approaches [6], [7], to handle the interpretability of the entire network.

2 Project Objectives

The requested work consists of:

1. Review and get familiar with the primary references related to the existing codes.
2. Create training databases by simulating MB flow using real *in vivo* vascular data (e.g., [8]).
3. Improve the ULM performance by proposing an unfolding CNN-based MB localization.
4. Apply the developed algorithm to a diverse range of imaging scenarios, both in simulation and *in vivo*.

3 Required skills

- 2nd year of Msc and/or 3rd year of an engineering school,
- Strong background in signal and image processing, or applied mathematics,
- Proficiency in machine learning (ML) techniques, with a particular focus on CNN,
- Strong programming skills in either Matlab or Python,
- Proficiency in the English language,
- An interest in medical US imaging would be a plus, without requiring any prior knowledge.

4 Starting date

As soon as possible and no later than March 31, 2024.

5 Supervisors

This internship will be supervised by:

- Duong Hung Pham, IRIT/UPS, Toulouse, duong-hung.pham@irit.fr
- Denis Kouamé, IRIT/UPS, Toulouse, kouame@irit.fr

6 References

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