PhD subject title: Biomechanically constrained motion estimation of the heart from standard cine-MRI data.

Research Unit: CREATIS (Director: BEUF Olivier), MYRIAD team
PhD supervisor: Dr CLARYSSE Patrick (DR CNRS)
PhD co-supervisor: Prof. LIU Wanyu (Shanghai University)

Context and Scientific field:
Motion estimation and quantification of the left ventricle is very important for the diagnosis and prognosis of cardiac diseases. Medical imaging techniques with notably 4D echocardiography and Magnetic Resonance Imaging (MRI) are the most used in clinical practice to assess the cardiac function. MRI proposes several alternatives for the quantification of cardiac motion with notably, tagged magnetic resonance images (Tagged-MRI), cine magnetic resonance images (Cine-MRI), Displacement Encoding with Stimulated Echoes (DENSE). Tagged-MRI is still considered as a reference for motion quantification, but partially loses the information of the original image due to the addition of the markers; moreover, it is not part of the clinical protocol to limit examination duration. Cine-MRI retains all the anatomical information and is routinely used. Because of similar gray levels and scarce feature points, Cine-MRI based motion assessment remains challenging and motivates research developments. Relative homogeneous intensity content within the myocardial wall and proximity with exterior structures make the dense motion field estimation problem complex. Optical flow (OF) is one of the major motion estimation method class in computer vision. But it has been relatively less experimented in cardiac MRI since the initial works [Amartu and Vesselle, 1993] probably because of the limits of the initial approach. Some improvements have relaunched its interest with for instance coupling intensity and its gradients [Wang, et al., 2019], and introducing additional features in the OF process like local phase, orientation and amplitude [Gao, et al., 2016]. The displacement field calculated on this basis is the prior step to the assessment of myocardial strains that are one of the determinant factors in heart diseases evaluation, and therefore has both important scientific and clinical values.
Keywords: motion estimation, heart motion, optical flow, biomechanical constraint, Cine-MRI.

Objective of the thesis:
In this thesis, we will investigate how biomechanical constraints can be integrated within the optical flow framework to improve the realism and accuracy of estimated spatiotemporal motion fields from Cine-MRI within a clinical compatible time. Interest of recent Artificial Neural Network (ANN) based methods will also be studied in the motion estimation task [Ilg, et al., 2017], [Evain, et al., 2020] or to segment the left ventricle from the Cine-MRI image sequence, thereby allowing improved optical flow assessment at the frontiers and significantly reducing the amount of calculation. The proposed approach will be evaluated against alternatives with notably registration-based methods, Feature Tracking (FT) approaches and the reference Tagged-MRI.

Scientific challenge:
On the medical point of view, the proposed approach should allow the improved cardiac kinetics assessment from standard Cine-MRI acquisitions, prospectively but also retrospectively. On the technical side, a new tailored method will be introduced adapted to Cine-MRI but that could be applied to echocardiography and Dynamic Computed Tomography.

Research program and proposed scientific approach:
The PhD student will first study the literature on the subject from both the medical and methodological perspectives, and constitute a database composed of synthetic and clinical data (0-6m). He will then design his/her own approach (year 2) that will be evaluated during the last 12 months.

Scientific supervision:

- **Description of the supervising committee:**

Name	Lab / Team	Scientific expertise	Rate (%)
CLARYSSE Patrick	CREATIS / MYRIAD	Medical image analysis	50
LIU Wanyu	Shanghai Univ.	Statistical analysis of medical data	50

- **Integration within the laboratory(ies)**: 100% CREATIS, MYRIAD team

Financing of the thesis: CSC application for the UT/INSA CSC program

Profile of the candidate (prerequisites): The candidate will have an educational background in computer science, particularly in numerical aspects such as image processing and analysis, machine learning, mathematical modeling, scientific programming (C++, Python, MATLAB).

Objectives of valorization of research work: The research work will be promoted through publications in journals of the field (Medical Image Analysis, IEEE Trans Biomedical Engineering, Medical Image Analysis...).

Skills that will be developed during the PhD:
- Deepening of knowledge in medical data analysis and modeling
- Acquisition of knowledge in physio-pathology and cardiovascular imaging
- Interaction in a multidisciplinary environment

Professional prospects after the doctorate: The professional perspectives of this subject are both academic (research and higher education) and industrial. The fields of activity concerned are data analysis (image processing, statistics) and scientific programming for biomedical applications but not exclusively.

Bibliographical references on the subject of the thesis:

[Amartu and Vesselle, 1993] S. C. Amartu and H. J. Vesselle, "A new approach to study cardiac motion: The optical flow of cine MR images," *Magnetic Resonance in Medicine*, vol. 29, no. 1, pp. 59-67, 1993.

[Wang, et al., 2019] L. Wang, P. Clarysse, Z. Liu, B. Gao, W. Liu, P. Croisille, and P. Delachartre, "A gradient-based optical-flow cardiac motion estimation method for cine and tagged MR images," *Med Image Anal*, vol. 57, pp. 136-148, 2019.

[Gao, et al., 2016] B. Gao, W. Liu, L. Wang, Z. Liu, P. Croisille, P. Delachartre, and P. Clarysse, "Estimation of cardiac motion in cine-MRI sequences by correlation transform optical flow of monogenic features distance," *Phys Med Biol*, vol. 61, no. 24, pp. 8640-8663, 2016.

[Ilg, et al., 2017] E. Ilg, N. Mayer, T. Saikia, M. Keuper, A. Dosovitskiy, and T. Brox, "FlowNet 2.0: Evolution of Optical Flow Estimation With Deep Networks," (eds), *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2017.

[Evain, et al., 2020] E. Evain, K. Faraz, T. Grenier, D. Garcia, M. D. Craene, and O. Bernard, "A Pilot Study on Convolutional Neural Networks for Motion Estimation From Ultrasound Images," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 67, no. 12, pp. 2565-2573, 2020.