Guy's, King's
and St. Thomas'
Faculty of Life Sciences and Medicine
School of Biomedical Engineering
and Imaging Sciences

KING'S College LONDON

University of London

Mrs. Monika Zabranska
CVUT - FJFI
Brehova 7
115 19 Praha 1 -
Czech Republic

Professor Alistair Young, PhD
Professor in Cardiovascular Data Analytics and AI
Biomedical Engineering
King's College London
5th Floor, Becket House
1 Lambeth Palace Rd, London SE1 7EH
Tel. 020 784 89513, Fax 020 718 85442
email alistair.young@kcl.ac.uk

7-March-2023

Re: Kateřina ŠKARDOVÁ PhD Thesis Report on "Numerical and machine learning methods for medical image processing "

This Thesis develops new methods for image registration, image enhancement and tissue parameter estimation based on medical imaging data. These methods are applied to open problems in the field of cardiology, specifically the estimation of heart motion and tissue properties in patients with heart disease, evaluated using clinical magnetic resonance imaging examinations. The Thesis is organised into seven Chapters:

Chapter 1 describes the motivation and structure of the Thesis. The focus is on methods for motion correction, feature tracking, deblurring and tissue parameter estimation. The later is posed as an inverse problem, based on a mathematical model of the system.

Chapter 2 describes a method for non-rigid registration of T1 mapping images for the quantification for tissue T1 and extracellular volume parameters. The myocardium is segmented using a level set contour evolution approach, and the resulting binary images are transformed into a signed distance map. This is used to register the source and target images. This method avoids the problem of changing image contrast over the acquisition. The registration is solved using the optical flow, resulting in a set of non-linear equations which are solved by steepest descent. Results are compared to registration of the images themselves using a mutual information similarity metric.

Chapter 3 presents a proof of principal of a model-based registration procedure using synthetic tagged images. The process was applied to simulations of simple shear using an existing finite element solver.

Chapter 4 applies a model based registration method to MRI cine images in a patient group (tetralogy of Fallot). Ventricular torsion was found to be different in the Fallot group compared with healthy volunteers.

Chapter 5 describes a method for deblurring images by solving the inverse heat equation using an adjoint formulation. The method was applied to a standard image from the computer vision literature.

Chapter 6 proposes a two-stage approach to the estimation of T1 relaxation time from MOLLI MRI image acquisitions. A neural network was trained using synthetic relaxation curves generated from a Bloch equation simulator. In first stage this is applied to get an initial solution. In the second stage, the initial solution is refined by numerical optimization. The method was tested in a set of phantom experiments at 1.5T and 3T as well as 15 human scans.

The Conclusions chapter (Chapter 7) synthesizes these results and summarizes the current state of the art. Future extensions of the current methods are recommended including different numerical optimization methods.

In summary, this thesis represents original and novel work which advances the field by combining mathematical models with clinical data for the analysis and evaluation of cardiac disease from medical images. The topics are up to date and the goals of the thesis have been broadly achieved. The methods show promise for discovery of disease mechanisms in important patient groups who require extensive follow-up and multiple examinations and interventions.

In conclusion I recommend that the thesis deserves to be defended at an oral defence.

Questions for the candidate include

1. In Chapter 2, for the signed distance map registration method, the SDM will change as the source object is deformed. Is the SDM adapted during the optimization? If not, is there a way of adapting the SDM to ensure exact matching?
2. In chapter 3 are the model and deformation 2D? For a real heart, would a 2D image of a 3D deformation satisfy eqn 3.16?

3. In Chapter 4 is the apex and base rotation shown in Figure 4.7 a patient or a control? I would expect the base rotation to be opposite to the apex at end-systole?
4. In Chapter 5, would this model of blurring be realistic in MRI? How could the method be adapted in the case of the MRI imaging process?
5. In Chapter 6, would a method which considers a neighbourhood of voxels be able to achieve improved results?

Yours sincerely

Professor Alistair Young, PhD