Report on PhD thesis of Maxime Sermesant

By Derek Hill, May 2003

Maxime Sermesant's thesis addresses the highly topical and innovative area of electromechanical models of the heart, and the use of these models for image analysis and simulation.

Cardiac imaging has improved dramatically in the last few years. Ultrasound has increased in frame rate and resolution, and 3D imaging has been introduced. Cardiac MR has become a proven research tool and is sufficiently robust and reliable to be entering routine clinical use, and cardiac CT is beginning to show great potential. This progress in image acquisition provides ever increasing amounts of data about cardiac anatomy and function from the huge numbers of patients with cardiovascular disease. It also increases the need for reliable analysis tools in order extract the relevant information. Furthermore, innovative treatments making use of electrophysiological techniques (eg: RF ablation, bi-ventricular pacing and implanted defibrillators) make it important to improve the understanding of the relationship between ECG signals and cardiac motion derived from images. It is widely acknowledged that models are essential if these research challenges are to be tackled successfully. Maxime's thesis is an important contribution in this area. In the first part of his thesis, he demonstrates how an electromechanical model of the heart can be built from image-derived information, and how such a model can be used to simulate normal and pathological hearts. In the second part of the thesis, Maxime shows the potential of his cardiac models to assist in image analysis tasks such as segmentation of time series of images. The results in this thesis are an important contribution to the field. However, just as importantly, Maxime's work demonstrates the huge potential of these approaches and is likely to encourage many other researchers to take his work further.

Introduction : Chapters 1 and 2.

Chapter 1 introduces the clinical motivation for the thesis, and explains the links between models and images, and the way in which models can help in tasks as diverse as understanding pathology and segmenting images.

Chapter 2 gives anatomical and physiological background to the heart which is necessary to understand the rest of the thesis.

Premiere Partie : Chapters 3 – 5.

Chapter 3 focuses on modelling cardiac anatomy. Key aspects are the orientation of the muscle fibres, and the anatomical regions of interest. This chapter describes how these sources of information about heart structure can be incorporated into a suitable mesh for the application of finite element methods, and the way in which locations in the mesh and image voxels can be related.

Chapter 4 begins with a review of models of the electrical activity in the heart, and explains the choice of a macroscopic rather than cellular model for the work in the thesis. He then describes how such a model can be implemented on his heart mesh, describes the numerics, and then describes some validation experiments. These validation experiments are extremely useful to the reader, as they demonstrate that the model can generate plausible results, as compared with the classic work of Durrer with isolated human hearts, the highly invasive canine experiments carried out at Johns Hopkins, and pathologies. Although no true "gold standard" comparison is possible, the results certainly look reasonable. There are many opportunities for further work highlighted, including simulating external ECG recordings, and incorporating additional data in the model.

Chapter 5 describes the electromechanical coupling of model. The chapter begins with some anatomy and physiology, then describes the choice of mechanical model appropriate for the project. The numerical details of the implementation are described, and then results from the model are shown. The simulation of physiological signals in both normal and abnormal hearts is then used to demonstrate the capability of the system. He model is clearly not perfect: for example the movies show less apical shortening than is normally seen using imaging, but the results are very impressive and clearly advance the state-of-the art. The work described in this chapter is just the beginning of what can be done with this model. There is enormous scope for further simulations, and validation for both normal and pathological situations. The mechanical properties used could be improved – and ideally would be obtained from images.

Deuxieme Partie : Chapters 6 – 9

Chapter 6 gives a brief introduction to three important cardiac imaging modalites: ultrasound, MRI and SPECT. In some places the descriptions are, perhaps, overly simplified, but since the physics of acquisition is not critical to the thesis, this is of minor importance.

Chapter 7 describes a pre-processing step, using anisotropic diffusion. The innovation here is the use of diffusion in 4D rather than just over spatial dimension as is more common. Various options for handling the temporal direction are discussed, and some results obtained from ultrasound images are shown. It is not quite clear how important this chapter is to subsequent results in the thesis.

Chapter 8 describes how a biomechanical (rather than electromechanical) model can be used to assist in image segmentation. The use of the biomechanical model is analogous to the use of more traditional deformable models, but with the advantage that the internal energy terms are much more realistic. This chapter does not focus on the heart alone, but shows the potential of this generic technology on brain images. The main results, however, are for segmentation of temporal sequences of cardiac images from MRI and SPECT. The results show the potential of this approach. There is considerable scope to extend this study to larger numbers of test images, other types of images (the cardiac MR images shown look rather out-dated), and to compare this approach to alternative analysis techniques in widespread use. There is also the question of how pathology should be handled in this approach, which would benefit from additional research. This type of segmentation approach is going to become increasing important in image analysis over the next few years.

Chapter 9 sees the return of the electro-mechanical model, this time for image analysis. This chapter is relatively brief, but the results look extremely promising: it appears that the use of electrical as well as mechanical constraints provide improved segmentation. Unfortunately, synchronised ECG was not available along side the images, and introducing this sort of information, which is now becoming available, would open up additional possibilities for this technique.

Chapter 10

The conclusions of the thesis emphasise the contribution of the thesis, and also the limitations of the work. The candidate correctly highlights the issues of inter-individual variability, and the need for additional validation.

Conclusions

This thesis represents a large body of work. It is well presented, and very interesting to read. The work is highly innovative in several areas, and will encourage other researchers to take Maxime's ideas forward themselves. This thesis is ready to be defended orally.