Summary of project results

The results from the project can be divided into the following major 5 subprojects (and 2 bonus subprojects):

1. Method development for 3D time resolved phase contrast magnetic resonance imaging (PhD2, PhD3, P2, P3, P9, P12). Here we have focused on the necessary method development of the time resolved three dimensional phase contrast magnetic imaging technique pioneered in Linköping by Wigström (PhD3). Several important improvements were also made in Thunberg (PhD2), where we focused on artefact reduction and image improvement.

2. Non-invasive mapping of the blood flow in the heart and the aorta (PhD1, P1, P6, P10). Here we did our pioneering work on mapping the 4D behaviour of the blood flow through the heart. Special emphasis was put on the left atrium (Fyrenius Licentiate Thesis) and for visualization purposes new tools for automatic feature detection was developed by Heiberg (PhD1). These new tools, based on four dimensional quadrature filters, were subsequently used in the segmentation of the left ventricle for further strain/strain-rate imaging (see 4 below) and wall shear stress imaging (see 5 below).

3. Pressure mapping in the heart (P5, P7). Using the measured velocity data and the Navier-Stokes equations we were able to compute the pressure inside the human heart completely non-invasive by solving a Poisson equation in the measured pressure gradients and thus estimate the pressure field. This was a focus in Ebbers thesis (PhD4).

4. Strain and strain-rate imaging (P4, P8, CP3, CP13, CP15). From the velocity data measured we were able to compute the strain rate (being the symmetric part of the tensor formed by taking the Jacobian of the velocity vector). This new technique was pioneered by Selskog (Lic1). Using the segmentation tools by Heiberg the left ventricular wall was segmented and strain and strain-rate visualized. Continuing work with strain imaging requires the possibility to track individual points (Lagrange view instead of the Euler view used for strain-rate imaging). This has been explored in a collaboration with Stanford University (CP13, CP15)

5. Wall shear stress estimating using MRI and CFD (CP7-12, CP16-19). Using all possible information (geometry and velocity) it is possible to construct individual models of the human aorta for estimation of wall shear stress. This requires all the tools from the above: very accurate MRI techniques for both arterial wall delineation and automatic segmentation, accurate velocity measurements and robust computational fluid dynamics. At the end of the project we are at a point where this is possible (after the end of the project there have been further improvement of the methodology). Patient specific models for diagnosis, intervention planning and follow-up are now a reality!

During the course the work two more areas of research were initiated:

6. Optimization in medicine (P11, P13, CP1, CP2). In order to understand the complex structure of arterial trees, an new optimization technique was developed. These methods
have been used for constructing arterial trees as well as to determine parameters in constitutive equations (Stålhand’s Licentiate Thesis)

7. Neuro-mechanical networks for bio-inspired robotics (CP4-CP6). Together with Profs Klarbring and Krus we have initiated a new and exciting field of research into bio-inspired robotics. The project fall in the category “high-risk, high potential impact” and is currently funded by SSF/ProViking.

The project has produced 4 PhDs, one LicEng (and three additional Licentiate’s Theses in projects closely associated with CENIIT 99.11) as well as 14 journal publications, 19 conference papers and 35 conference abstracts.

Degrees resulting from the project

The project has resulted in four PhD theses and one licentiate thesis


Additionally there have been three licentiates theses where MK has been assistant supervisor.

- Johan Lundvall, 2004: Reconstruction of velocity data using adjoint optimization (Licentiate thesis)
- Jonas Stålhand, 2003: Modelling the passive mechanical properties of arteries. (Licentiate thesis) PhD planned for June 2005

Matts Karlsson was promoted to full professor in 2002 and appointed professor and division chairman in 2003.

MSc projects

- Anders Rönnbrant: Implementing a visualization tool for myocardial strain tensors, LITH-IMT/BMS20-EX--05/403--SE
- Petter Dyverfeldt: Estimation of Turbulence using Magnetic Resonance Imaging, LITH-IMT/BMS20-EX--04/378--SE
- Henrik Haraldsson: Quantification and Visualization of Shift in Cardiac Situs, LiU-IMT-EX-357
- Katarina Kindberg: Regional Kinematics of the Heart, LITH-IMT/BMS20-EX--03/354--SE
- Nicklas Törnblom: Surface Curvature Estimation and CFD Simulations in Human Abdominal Aortae, LITH-IKP-EX--05/2258—SE
- Fredrik Norling and Fredrik Sundberg: Computational modelling and optimization of arterial tree networks, LITH-IMT/BMS20-EX--05/390—SE
- Andreas Sigfridsson: Hybrid visualization of tensor fields in medical image data, LiU-IMT-EX-313, 2002
- Magnus Lundberg: Two Dimensional Myocardial Strain Rate Estimated from Phase Contrast Magnetic Resonance Imaging Data, LiU-IMT-EX-350, 2003
- Svante Hellzén: Pressure Computation from Magnetic Resonance Velocity Data, LiU-IMT-EX-291, 2000
- Pernilla Björklund: Time-resolved three-dimensional reconstruction of the mitral annulus from echocardiography, LiU-IMT-EX-280, 1999
Staff

The project has funded the research of Matts Karlsson, professor, chairman at Division of Biomedical Modelling and Simulation, Department of Biomedical Engineering as well as partly funded Tino Ebbers, PhD, assistant professor, Department of Medicine and Care, Lars Wigström, PhD, currently doing a post-doc at Lucas Center for Magnetic Resonance Imaging and Spectroscopy Research at Stanford University and Einar Brandt, PhD, currently performing post-doc research at Lund University Hospital. The research group also consists of Per Thunberg, PhD, research leader at Department of Biomedical Engineering, Örebro University Hospital and Jonas Stålhand, PhD, research assistant at Division of Mechanics. Several PhD-students have been partly funded by the project: Johan Lundvall, PhD-student at Department of Mathematics, Johan Svensson, PhD-student at Department of Mechanical Engineering and Roland Gårdhagen, PhD-student at Department of Mechanical Engineering. The group also consists of Katarina Kindberg, PhD-student at Division of Biomedical Modelling and Simulation, Department of Biomedical Engineering and Henrik Haraldsson, PhD-student at Division of Biomedical Modelling and Simulation, Department of Biomedical Engineering as well as Mattias Sillén, Industry PhD student and Pernilla Selskog, MSEE, LicEng, currently with SAAB Avionics in Jönköping.

Industrial contacts and cooperation

The industrial contacts within the CENIIT-project has been focused to two quite different areas:

- Collaboration with vendors of medical imaging systems, in particular Philips and GE Medical systems for MRI scanners and Siemens for CT scanners. These contacts have been made through the recently established Center for Medical Image Science and Visualization (CMIV), a joint research collaboration between the Institute of Technology, the University Hospital and industry. The work within the CENIIT project has been important for its establishment.
- Collaboration with software companies (codes for computational fluid dynamics, e.g., Fluent and CFD++), FOI/FFA with their code EDGE as well as SAAB Aircraft in Linköping (users of and developers for EDGE).

The project has collaborated extensively with former CENIIT project holders and completely new research areas have been established: Anders Klarbring (topology optimization in medicine) and Anders Klarbring and Petter Kruus (Neuromechanical networks for bio-inspired robotics). We were also collaborating extensively with Joakim Pettersson.

Establishment of a new division

The funding from the the CENIIT project has been instrumental for the formation of the new division Biomedical Modelling and Simulation at Department of Biomedical Engineering. Matts Karlsson is the founding chairman of the division. The research at the division of biomedical modelling and simulation includes the vast area from traditional basic physiology to advanced clinical applications. Presently, one focus is the biofluid mechanics of the heart and the greater vessels, another the mechanics of the myocardium. In biomedical modelling and simulation we are using tools from mathematics, mechanics and physics in order to analyse structure and function of complex biological systems. The advanced model development is based on high quality measurements. Currently, non-invasive measurement techniques are utilized combined with computer models for data assimilation. The rapid development in computers enables the development of inividually based models for advanced
diagnosis, intervention planning and follow-up. The research area is cross-disciplinary and presently we are participating in the development of Center for Medical Image Science and Visualization (CMIV), a joint effort between the University and the University Hospital. The division has a long standing research collaboration with the Department of Mechanical Engineering (IKP) and National Supercomputer Centre (NSC) at Linköpings universitet.

**Publications (journal papers)**


Publications (conference papers)


CP14. K. Kindberg and M. Karlsson: Mitral valve opening in the failing heart. In proceedings of 13th Nordic Baltic Conference, Biomedical Engineering and Medical Physics, Umeå, Sweden, 2005, 2p

CP15. K. Kindberg and M. Karlsson: Transmural myocardial strain distribution - theoretical results and in vivo data. In proceedings of 13th Nordic Baltic Conference, Biomedical Engineering and Medical Physics, Umeå, Sweden, 2005, 2p


Publications (conference abstracts)


CA2. AF Bolger, L Wigström, J Engvall, P Öhman, M Karlsson and B Wranne: Diastolic Function in LVH: Comparison of Doppler with Phase Contrast 3D MRI, Presented at American College of Cardiology (ACC), March 29 - April 1, Atlanta, USA, 1998.


CA27. P Selskog, E Heiberg, T Ebbers, L Wigström and M Karlsson: Kinematics of the Heart, Presentation at 4th World Congress Biomechanics, Calgary, Canada, 4-9 August, 2002


CA32. J Svensson, R Gårdhagen, T Länne and M Karlsson: Comparison of Wall Shear Stress Between Sifferent Segmentations of a Human Aorta with Coarctation and Aneurysm. Accepted for presentation at Svenskt Kardiovaskulärt Värmöte, 27-29 april, Malmö, Sweden, 2005

CA33. E Heiberg, L Wigström, M Carlsson and M Karlsson: Three dimensional Time Resolved Segmentation of the Left Ventricle, Accepted for presentation at International Society for Magnetic Resonance in Medicine 13th Scientific Meeting, South Beach, Florida, 7-13 May, 2005
