Experimental Mechanics of Fluids and Materials

Project leader: Tino Ebbers
Project period: 2009-2015

Summary

Traditional experimental fluid dynamics (XFD) techniques for measuring the velocity in a point (Laser Doppler Anemometry, LDA) or in a plane (Particle Image Velocimetry, PIV) are relatively time consuming and restricted to specific phantom designs. A new technique which is emerging as a valuable tool for the analysis of fluid dynamics is magnetic resonance imaging. Originally, this technique allowed for the measurement of the mean velocity in a small volume element, similar to PIV and LDA but within a shorter measurement time and with less limitation in terms of phantom design. Recently, the MRI technique has been extended to the measurement of the distribution of the velocities within the volume element, which allows for the quantification of for example turbulence intensity. Additionally, magnetic resonance imaging has the ability to measure displacement. This allows for experimental three-dimensional three-directional assessment of the deformation of soft materials. These new kinds of data open a new world with possibilities and challenges related to measurements, post processing and visualization.

Main Scientific Results

- An efficient MRI technique for time-resolved three-dimensional three-directional velocity measurements with spiral k-space sampling has successfully been implemented and evaluation.

- A generalized MRI framework for the quantification of any moment of arbitrary velocity distributions has been developed. This framework is based on the fact that moments in the function domain (velocity space) correspond to differentials in the Fourier transform domain (k(v)-space). Based on this framework, we developed a technique to assess turbulent kinetic energy in the beating heart and different flow models.

- A prototype of a MRI-based industrial water tunnel has been developed and tested. The prototype allows three-dimensional assessment of velocity and turbulent kinetic of different flow phenomena.

- A semi-automatic approach for quantification and visualization of ventricular blood flow has been developed. This technique has lead to new insights into left ventricular and right ventricular blood flow in health and disease.
An automatic registration-based assessment of 4D flow MRI data has been developed. It allows automatic analysis of 4D flow MRI data in the large vessels. The segmentation allows for automatic analysis and visualization of cardiovascular 4D flow MRI data, and in depth studies of blood flow using CFD simulations.

A promising approach to included wall motion in CFD simulations of vascular blood has been developed. This approach circumvents all assumptions associated by fluid-structure interaction approaches by directly measuring the wall motion with MRI, and then prescribing the extracted wall motion directly in a numerical solver. Additional computational cost of this approach is only 17%, compared to a rigid wall simulation.

A novel technique for assessment of heart muscle deformation has been developed. This technique allows for three-dimensional three-direction measurement of tissue displacement.

We have developed a novel approach for quantification of the T1 and T2 MRI relaxation times in the heart muscle. T1 and T2 has shown to provide important information in cardiac diagnostics, but available methods generally demand a long breath hold to measure either T1 or T2 in a single 2D slice. Using an improved pulse sequence and a novel data analysis based on iterative simulation of the relaxation, we are able to map T1 and T2 simultaneously in 3D volume covering the whole left ventricular myocardium within a single breath hold of 15 heartbeats.

**Degrees and promotions**

2010 Tino Ebbers (PI) Associate Professor (lektor)
2011 Tino Ebbers (PI) Professor

**Master projects**

2009 Aidin Arbabi, “Investigating the Feasibility of Using PC-MRI Velocity Data to Estimate the Wall Shear Stress”
2012 Emre Kus “Estimation and visualization of relative pressure fields in the human heart from time resolved MRI flow data”
2014 Mattias Perkiö, “Assessment of Regional Pulse Wave Velocity in the Aorta by Using 4D Flow MRI”
2014 Catarina Tidbeck “Quantification of left ventricular blood flow using phase contrast magnetic resonance imaging”

**Bachelor project work**

2013 Richard Hellsberg, Simon Åkerblad, Tamara Kljajic, Tina Nikko “Development of a water tunnel system – for Implementation in MRI Scanners” LiU-IEI-RR-13/00172-SE

**Funded Staff**

Initially, the seed funding has been used to cover part of the financing of the PI. When this part could be covered by other external funding, the CENIIT funding has mainly used
as seed financing for new promising projects. Therefore, during the course of this project, several persons have been partly or fully financed by this CENIIT project.
- Petter Dyverfeldt, PhD postdoc
- Jörg Schminder, MSc, PhD student
- Jonas Lantz, PhD postdoc
- Magnus Andersson, MSc PhD student
In several cases, this seed funding has resulted in promising preliminary results, which facilitated continuation of the project using funding from other external funding agencies.

Cooperation with industry
Within the course of this project, collaborations have been build up with industrial as well as clinical partners. The main industrial partners have been Philips Health Care considering development of new MRI acquisition strategies and Synthetic MRI considering T1 and T2 analysis of heart muscle tissue.

Contacts with other CENIIT projects
None

New Research Group
The PI has currently his own research group consisting of 1 research engineer, 3 PhD students, and 4 postdocs financed through external funding from the European Research council, the Swedish Research Council, and the Knut and Alice Wallenberg Foundation. The majority of the projects are direct continuations of the CENIIT project.

Publications
Refereed Journal Articles


**Refereed Conference contribution**

44. Lantz J, Carlhäll, CJ, Ebbers T. Quantification of Helical Flow Patterns in Left Ventricles of Healthy Subjects and Patients with Dilated Cardiomyopathy. 2015 Summer Biomechanics, Bioengineering and Biotransport Conference. Salt Lake City, USA; 2015


