

Strategic University Program on Computational Methods in Nonlinear Motion Control

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Objectives and results

The strategic university program (SUP) on Computational Method in Nonlinear Motion Control has from 2004 - 2009 investigated the design and analysis of nonlinear motion control systems based on computational methods. This has involved research on numerical optimization, computational hydrodynamics, finite element methods and nonlinear control theory. The new theory and methods have been demonstrated in motion control applications such as snake robotics, ships and offshore vehicle control, automotive vehicles active safety systems, formation control of satellites, and decompression of divers, amongst others.

The following production of results has led to the main objectives of the project being met, and in some cases exceeded:

- 9 PhD candidates have been fully financed by the project (6 have already received their PhD degree, 2 have set dates for their PhD defence in February 2010, and 1 is expected to defend his PhD thesis later in 2010). As agreed with NFR, the funding for 1 PhD student (there were originally 10) was transferred to funding of additional postdoc researcher positions.
- 7.5 person-years of post.doc. researcher training were made.
- 82 publications in highly recognized international journals (some of these are resulting from research partly financed by other parallel projects where the key personnel were involved).
- 3 books have been published based on project results.
- 13 book chapters (some of these are resulting from research partly financed by other parallel projects where the key personnel were involved).
- 245 publications in highly recognized international conferences (some of these are resulting from research partly financed by other parallel projects where the key personnel were involved).
- 3 workshops arranged with participation from industry and academia, one of them with strong international participation.
- 14 articles and interviews in media have been made.

Research activities and participants

The key researchers involved in the SUP have been

- Professor Tor Arne Johansen, Dept. Engr. Cybernetics, NTNU (project manager)

- Professor Olav Egeland, Dept. Engr. Cybernetics, NTNU (until 2008)
- Professor Thor I. Fossen, Dept. Engr. Cybernetics, NTNU, and Center for Ships and Offshore Structures, NTNU
- Professor J. Tommy Gravdahl, Dept. Engr. Cybernetics, NTNU
- Professor Kristin Y. Pettersen, Dept. Engr. Cybernetics, NTNU
- Professor Asgeir J. Sørensen, Dept. Marine Technology, NTNU
- Professor Ole Morten Aamo, Dept. Engr. Cybernetics, NTNU

The following main research activities have been the core of the project

- Aksel Andreas Transeth, *Modeling and Control of Snake Robot*, PhD thesis, 2008
- Even Børhaug, *Nonlinear Control and Synchronization of Mechanical Systems*, PhD thesis, 2008
- Luca Pivano, *Thrust Estimation and Control of Marine Propellers*, PhD thesis, 2008
- Johannes Tjønnås, *Nonlinear and Adaptive Dynamic Control Allocation*, PhD thesis, 2008
- Svein Hovland, *Model reduction and control in computational fluid dynamics*, PhD thesis, 2008
- Thomas Krogstad, *Attitude Synchronization in spacecraft formations*, PhD thesis, 2010
- Esten Ingar Grøtli, *Robust stability and control of spacecraft formations*, PhD thesis defence set for 10 February 2010
- Gullik Jensen, *Offshore Pipelaying Dynamics*, PhD defence set for 18 February 2010
- Christian Holden, *Parametric Roll Resonance Stabilization*, PhD defence planned 2010
- Tu Duc Nguyen (postdoc researcher), *Output feedback control for systems modeled by partial differential equations*
- Trong Dong Nguyen (postdoc researcher), *Hybrid positioning control of offshore vessels*
- Alexey Pavlov (postdoc researcher), *Controller and observer design for nonlinear systems*
- Feng Le (postdoc researcher), *Computational methods for optimal decompression of divers*
- Sui Dan (postdoc researcher), *Regularized Moving Horizon Estimation without Persistence of Excitation*
- Erik Kyrkjebø (postdoc researcher), *Coordinated formation control of marine vessels*

In addition, several PhD candidates and researchers have been associated with the SUP and received partial funding for expenses through the SUP project: Jørgen Spjøtvold, Håvard Fjær Grip, Hege Langjord, Erik Kyrkjebø, Pål Johan From, Associate Professor Alexandra Grancharova, and Adjunct Professor Bjørnar Vik. All project activities have been conducted at NTNU. The main collaborators have been:

- Center for Ships and Offshore Structures at NTNU
- SINTEF Applied Cybernetics, Trondheim

9 PhD students have been guest researchers with the following institutions, financed by the SUP:

- Massachusetts Institute of Technology, Cambridge
- University of California, Santa Barbara
- University of Washington, Pullman

- Daimler Research, Stuttgart
- Johns Hopkins University, Baltimore
- University of Rio de Janeiro
- Imperial College London
- University de Liege, Belgium
- University of California, Berkeley

Schedule, resources and further work

The project was originally planned for the five years 2004-2008. In order to account for the changed schedule of PhD students due to leaves and teaching assistant assignments, the project was extended to the end of 2009. As indicated above, 2 remaining PhD students have set dates for PhD defence in 2010, and the final remaining PhD student has good progress and is expected to finish in 2010.

The funding has been used to cover the expenses of salaries, equipment and experimental work, travel and visits, project management, meetings and workshops, and overhead to the university. The resources were sufficient, and all funding was used. The activities remaining in 2010 are financed by some of the charged overhead that were transferred by NTNU back to the project.

Dissemination, exploitation and impact

The results have been disseminated through international publications, media articles and interviews, with industry through workshops and direct interactions in projects, seminars, and the project's website <http://www.itk.ntnu.no/cmmc/>

Of the 16 persons that had PhD and postdoc positions fully financed by the project, 4 are now working in research/Sintef, 10 are working as researchers in companies in Norway, and 2 have temporary academic positions. We are pleased that so far four of the five persons recruited from abroad all have found permanent jobs in the Norwegian oil and gas business, and the fifth person is also looking to stay in Norway.

Several of the results have direct interest for product development and are considered for commercialization by Norwegian and international companies. This is in particular the case for the research on snake robotics, unmanned vehicle research, marine propeller control, parametric roll resonance stabilization, automotive vehicle motion estimation, and diving computers.

Many of the results forms the basis for further research in this area, and several new research projects have already been funded, including a new Strategic University Program on Control, Information and Communication Systems for Environmental and Safety Critical Systems managed by Professor Kristin Pettersen, and funded by the Research Council of Norway for 2009-2013. A Gemini center on Advanced Robotics, a robotics laboratory and a KMB in the same area has also resulted, and several applications for NFR and EU project funding based on ideas that evolved from the SUP project are currently under evaluation and preparation. Research on unmanned vehicles, robotics and computational control methods are gaining momentum boosted by this SUP.