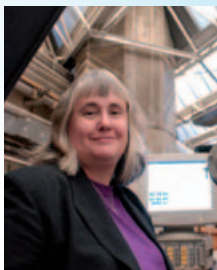




The Royal Academy  
of Engineering

## Distinguished Visiting Fellowship Scheme Case Study

# Higher-Order-Sliding-Mode (HOSM) Observers for State Estimation and Input Reconstruction in Non-linear Systems



**Host:**  
**University of Leicester**  
**Professor Sarah Spurgeon**  
Head of Department and  
Professor of Engineering



**Distinguished Visitor:**  
**Professor Yuri B Shtessel**  
Department of Electrical and  
Computer Engineering,  
The University of Alabama  
in Huntsville,  
USA



The problem of state estimation and input reconstruction in non-linear systems using higher-order-sliding-mode (HOSM) techniques for the system without or stable internal dynamics is studied in several research centres including University of Leicester and The University of Alabama in Huntsville. Professor Shtessel's visit to University of Leicester brought together the expertise at the universities of Leicester and Alabama to undertake a research project dedicated to developing HOSM observers for state estimation and input reconstruction in non-linear systems with unstable zero dynamics, as well as HOSM-based output tracking in nonlinear nonminimum phase causal systems.

Professor Shtessel is an international expert with over two hundred publications in the area of control engineering whose contributions to fundamental developments are supported by an extensive record of achievements in a number of areas of industrial applications with ongoing support from NASA. He has been working on a wide variety of research topics encompassing Nonlinear Nonminimum Phase Output Tracking on Sliding Modes with application to Flight and Space Vehicle Control.

Sarah Spurgeon heads an established research team of international repute. Work is largely concerned with the development of practically realisable nonlinear control strategies, which yield robust

performance in the presence of uncertainty and the design of robust condition monitoring schemes.

The visit provided an excellent opportunity to combine Professor Shtessel's theoretical background and applications experience with the expertise in and the activities of the Control and Instrumentation research group in the Department of Engineering as well as the wider space research activities at University of Leicester.

### Statement from the Host

*'The Royal Academy of Engineering Distinguished Visiting Fellowship scheme provided a unique opportunity to invite an international expert to the UK. Exposure to Professor Shtessel's theoretical and applications experience significantly enhanced the knowledge base of both my team and also of those working in related areas at other UK universities. The visit has resulted in the development of an exciting new research area, which builds upon the strengths and experience of both teams.'*

**Professor Sarah Spurgeon FEng**  
Head of Department



Professor Yuri Shtessel at University of Leicester

## Why a visit?

The overall purpose of the visit was to undertake a research project on state estimation and input reconstruction in nonlinear systems using HOSM techniques where the systems do not have stable internal dynamics.

The specific objectives were to:

- Undertake research on the application of HOSM to nonminimum phase systems by harnessing the synergy between the experience base of the Leicester team and Professor Shtessel.
- Apply the theoretical developments to practical aerospace control problems, including launch vehicle and satellite estimation and control problems.

## Visit outcomes

- The higher order sliding mode (HOSM)-based algorithms for state estimation, input reconstruction and output tracking control of nonlinear nonminimum phase causal systems were studied. A novel approach of implicitly numerically solving the unstable differential equation used for asymptotic estimation of the full state in nonminimum phase causal nonlinear systems was proposed. A manuscript titled 'HOSM observer for a class of nonminimum phase causal nonlinear MIMO systems,' by Yuri Shtessel, Simon Baev, Christopher Edwards, and Sarah Spurgeon was prepared for submission to a journal.
- Asymptotic output feedback tracking in a class of causal nonminimum phase uncertain nonlinear systems was addressed via sliding mode techniques. A manuscript titled 'Output feedback tracking in causal nonminimum-phase nonlinear systems using higher order sliding modes,' by Simon Baev, Yuri Shtessel, Christopher Edwards, and Sarah Spurgeon was prepared for submission to a journal.
- The paper titled 'Output feedback tracking in causal nonminimum-phase nonlinear systems using HOSM techniques,' by S. Baev, Y. Shtessel, C. Edwards and S. Spurgeon was presented at the 10th

## Statement from the Distinguished Visitor

*'I enjoyed the opportunity to work with the world leaders in sliding mode control, Drs. S. Spurgeon and C. Edwards, which was provided by The Royal Academy of Engineering Distinguished Visiting Fellowship. The daily discussions, seminars and presentations were very productive and allowed new results in Nonlinear Nonminimum Phase Output Tracking on Sliding Modes to be achieved. Two joint papers have been submitted to IEEE Transactions on Automatic Control and International Journal of Robust and Nonlinear Control. I hope to continue the cooperation with Drs. Spurgeon and Edwards by hosting them in Huntsville, AL, USA and also visiting them in the UK.'*

Professor Yuri Shtessel  
The University of Alabama in Huntsville,  
USA

International Workshop on Variable Structure Systems held in Antalya, Turkey and published in the Proceedings of the Workshop.

- A presentation titled 'Closed-Coupled Formation Flight Control Using Higher Order Sliding Modes,' was given at Department of Mechanical Engineering seminar, University of Bristol.
- A presentation titled 'Higher Order Sliding Mode Control with Application to Blood Glucose Level Regulation' was given at
  - IMA Systems and Control Theory Group seminar, London City University.
  - Department of Applied Mathematics seminar, University of Sheffield.

## Future links and collaboration

Plans are in place to continue the link and collaboration between University of Leicester and The University of Alabama in Huntsville. Whilst attending the IMA Systems and Control Theory Group seminar, for example, a new research direction involving applied adaptive nonlinear control germinated. The team are currently preparing a research funding application to move this new strand of research forward in the future.



Professor Sarah Spurgeon  
and Professor Yuri Shtessel  
at University of Leicester

## For further information please contact

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The scheme application form and guidance notes for applicants are available to download from The Academy's website:

<http://www.raeng.org.uk/research/researcher/dvfs/apply.htm>