WIDE Kick-off Meeting

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Partner presentation of the

Automatic Control Laboratory
School of Electrical Engineering
KTH, Stockholm, Sweden

Attending the kick-off:

Mikael Johansson

<u>Henrik Sandberg</u>

Pablo Soldati

Bo Wahlberg

Outline

- About KTH
- About the Automatic Control Lab
- Contributions to WIDE
  - Distributed optimization
  - Wireless sensor networks
  - System identification
  - Model reduction

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Welcome to KTH

KTH, the Royal Institute of Technology
Excellence in Education, Research and Entrepreneurship

KTH
VETENSKAP
OCH KONST

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OF TECHNOLOGY

KTH in Stockholm

KTH was founded in 1827 and has remained the largest of Sweden's technical universities. Since 1917, activities have been housed in central Stockholm in beautiful buildings which are currently protected as being of special historical interest.

Associated colleges are found at various places in the Stockholm surroundings – Haninge, Södertälje, and Kista.

KTH co-operates with Stockholm University in Kista, the main Swedish resource centre of information technology, and in the AlbaNova Centre, with its departments of physics and biotechnology.

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Students 2007

- A total of approximately 17,000 programme students
- 338 KTH students travelling to other universities
- 1,057 foreign exchange students began their studies at KTH
- 1,105 international master’s students began their studies at KTH
- 1,434 active postgraduate students with a minimum of 50% activity

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Research 2007

NUMBERS OF PROFESSORS

- 259 professors
- 5 part-time consulting professors
- 202 associate professors

INTERNATIONALLY PUBLISHED MATERIALS

- 1,800 conference contributions (papers, etc.)

GROWTH AREAS IN FOCUS

- Biotechnology
- Material Science and Engineering
- Information Technology
- Energy and Environment

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Schools From January 2005

School of **Architecture and the Built Environment**
School of **Biotechnology**
School of **Computer Science and Communication**
School of **Electrical Engineering**
School of **Industrial Engineering and Management**
School of **Information and Communication Technology**
School of **Chemical Science and Engineering**
School of **Engineering Sciences**
School of **Technology and Health**
Scientific Information and Learning
KTH **Business Liaison**

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Automatic Control Lab

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- Belongs to School of Electrical Engineering

- 4 professors
- 1 associate professor
- 2 assistant professors
- 5 postdocs
- 16 Ph.D. students
- ~10 persons involved in WIDE

- Main areas of research
  Networked Embedded Systems
  Modeling and Estimation
  Systems Biology

Distributed optimization

Researchers: Björn Johansson, Mikael Johansson

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Research focus:

- Large-scale optimization, decomposition techniques
- Novel algorithms for distributed optimization
- Applications in networking, wireless systems and control

Sample application

"Distributed model-predictive consensus"

Agents should distributively agree on optimal "meeting point"

Each agent subject to linear dynamics and constraints

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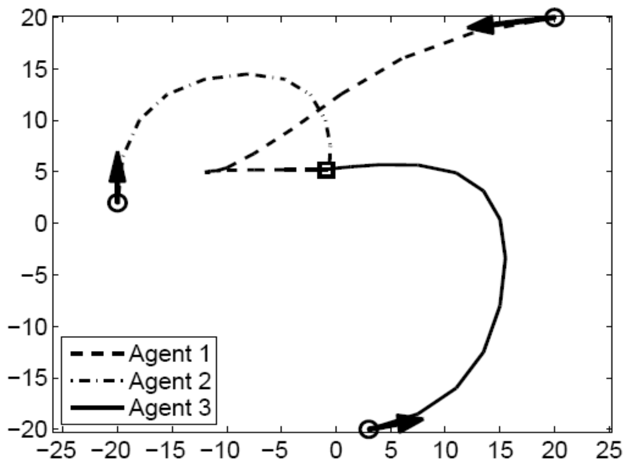
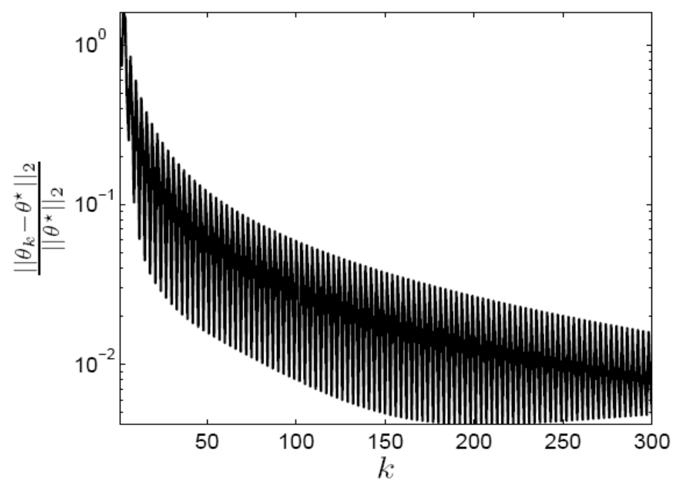
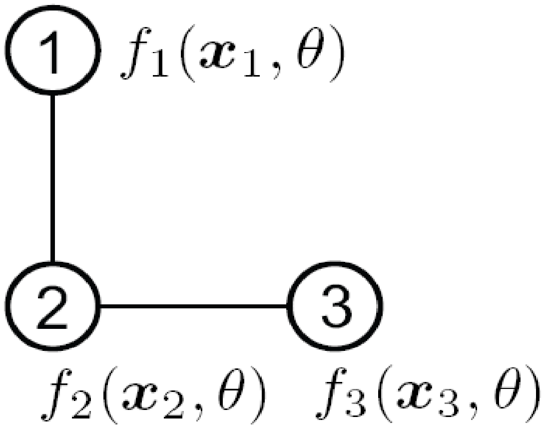




$$\begin{array}{ll} \text{minimize} & \sum_i \sum_t (x_i(t)-\theta)^T Q_i (x_i(t)-\theta) + u_i^T(t) R_i u_i(t) \\ \text{subject to} & x_i(t+1) = A_i x_i(t) + B_i u_i(t) \\ & x_i \in X_i, \qquad \theta \in \Theta \end{array}$$

A prototypical problem

$$\begin{array}{ll} \text{minimize} & \sum_i f_i(x_i; \theta) \\ \text{subject to} & x_i \in X_i, \;\; \theta \in \Theta \end{array}$$



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Each computational node associated with a cost function f_i, and local variables x_i

Can communicate with subset of “neighboring” nodes

Need to distributively agree on optimal global variables θ

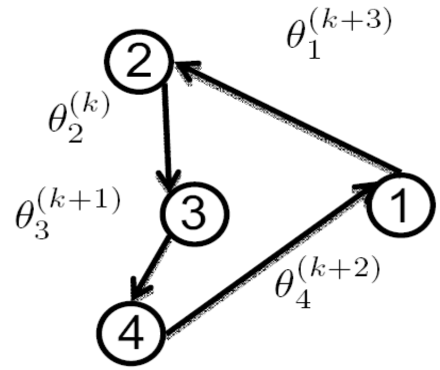
Results and research

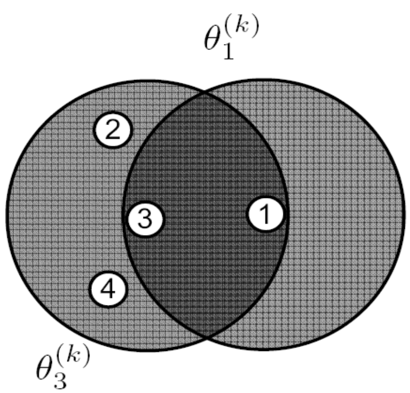
Theory:

New incremental subgradient methods based on peer-to-peer communication only

Novel combinations of subgradient and consensus algorithms

$$\begin{array}{ll} \text{minimize} & \sum_i f_i(x_i;\theta) \\ \text{subject to} & x_i \in X_i,\ \theta \in \Theta \end{array}$$





Evaluation:

Detailed simulations (ns2) + real WSN implementation (ongoing)

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Wireless sensor networks

Researchers: Henrik Sandberg, Pablo Soldati, Haibo Zhang, Mikael Johansson

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Research focus:

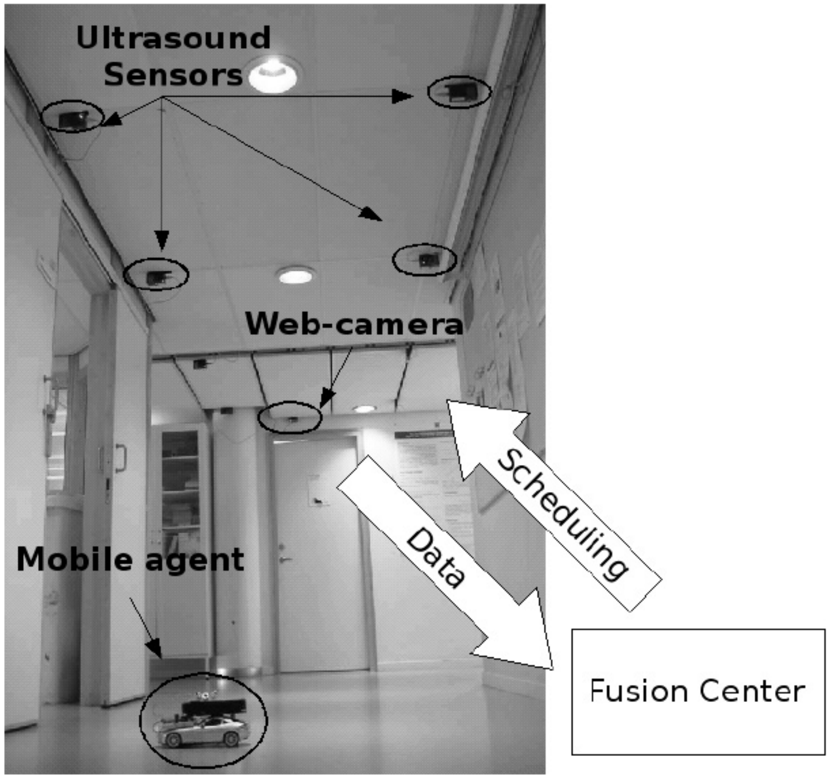
Link scheduling and routing for wireless HART

Energy efficient networking

Control algorithms adapted to WSNs

Test bed and test cases

Internal test bed at KTH, industrial test case at Boliden (with ABB)



Sample problems

Scheduling for wireless HART networks

- Scheduling of deadline-constrained traffic
- Data evacuation on trees and graphs
- Graph (routing) for increased resiliency
- Control algorithms for wHART networks

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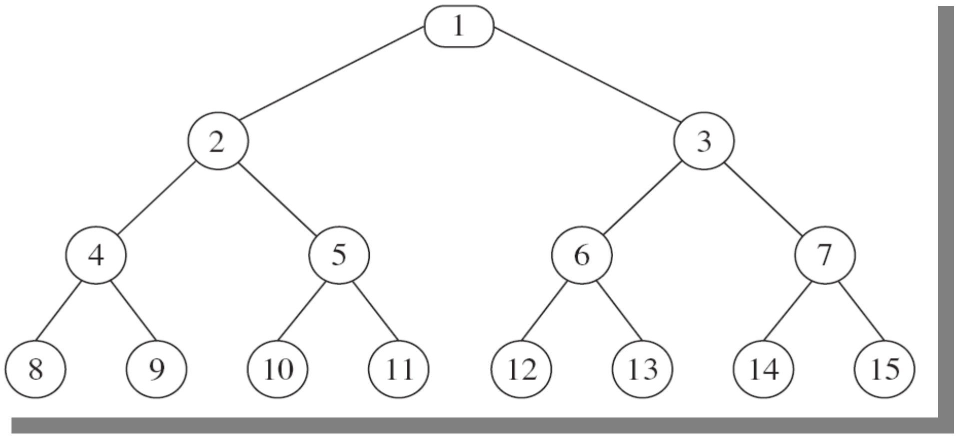

Link scheduling to evacuate dat

- in minimal time,
- using minimum no. channels

System identification

Researchers: Märta Barenthin, Mathias Barkhagen, Cristian Rojas, Bo Wahlberg, Håkan Hjalmarsson

Visitors 2008-2009:

Roland Hildebrand (Université Joseph Fourier, Grenoble)
Alireza Karimi (EPFL)
Xavier Bombois (TU Delft)

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Research focus:

Orthonormal basis functions (Laguerre, Kautz)
Subspace identification
Nonlinear systems
Identification for control
Experiment design
Model accuracy

Results and research

What do we bring to WIDE?

1) Analysis tools for model accuracy and experiment design

Geometric view

Brings the subspace spanned by the predictor gradient into focus

Can be used to analyze structural properties, e.g. what happens when a new input or new output is added to the system?

Potential for WIDE: Analysis of identification in decentralized systems. Which network structures are good and which are bad, from an identification point of view?

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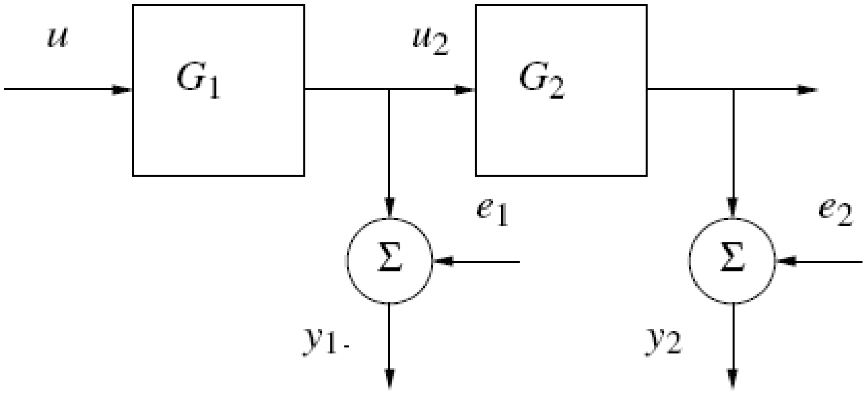
Sample problem: Cascade (serial) system



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Very common structure!

Sensor y_1 often worse than y_2. Typically, speed and position or flow and level.

Result: Sensor y_2 useless for estimating G_1 when $G_1 = G_2$.

Results and research

2) How to cope with the ”curse of dimensionality”

Common belief: Complex systems = Difficult system id. problems

Key insight: ”Clever” excitation can

- make important properties visible in data and easy to estimate, but also
- hide irrelevant properties so that these do not have to be identified.

Embodied in optimal experiment design

Example: Use a constant input to estimate the static gain. Works for any LTI system!

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Results and research

3) Experience from identification for control

The application governs the properties of interest

Optimal experiment design [c.f. 1)+2) above]

Challenge: Do the modeling requirements for MPC differ from ”traditional” control?

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Earlier study with ABB

Subspace system identification

Merging of submodels using structure

Model reduction to simplify the resulting model to be used for optimization

Model reduction

Researchers: 1 Ph.D. student (to be recruited),
Bo Wahlberg, Henrik Sandberg

Visitors during 2008-2009:

Michael Cantoni (Univ. of Melbourne)
Alexander Lanzon (Univ. of Manchester)

Research focus:

Structure constraints, networked models, LMIs

Model reduction for system identification

Time-varying and stochastic systems

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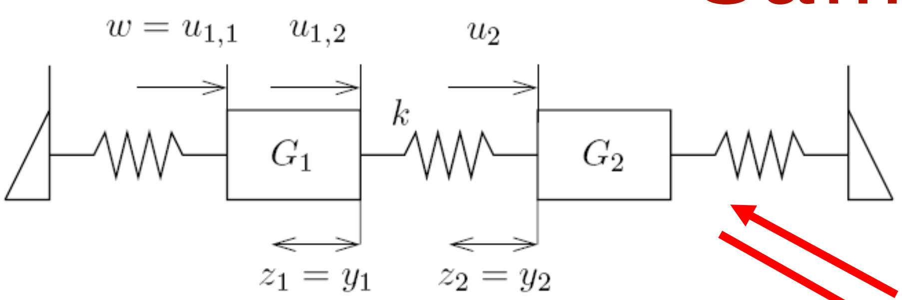
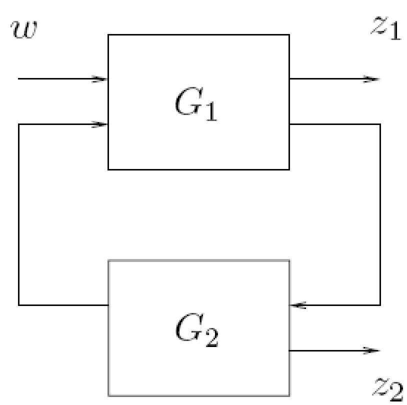
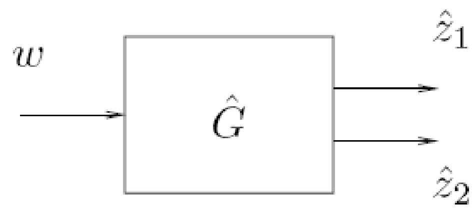
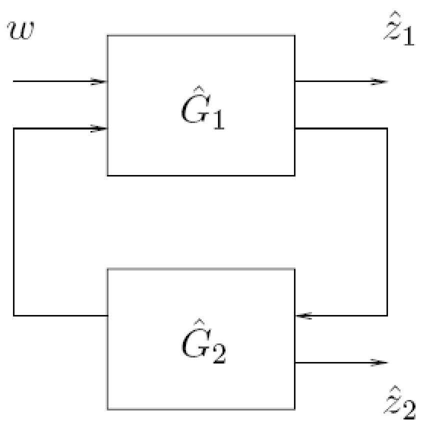
Sample problem



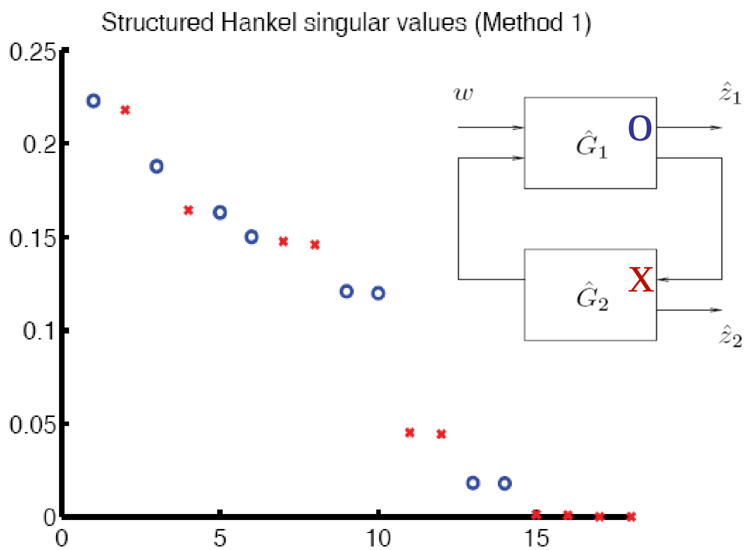


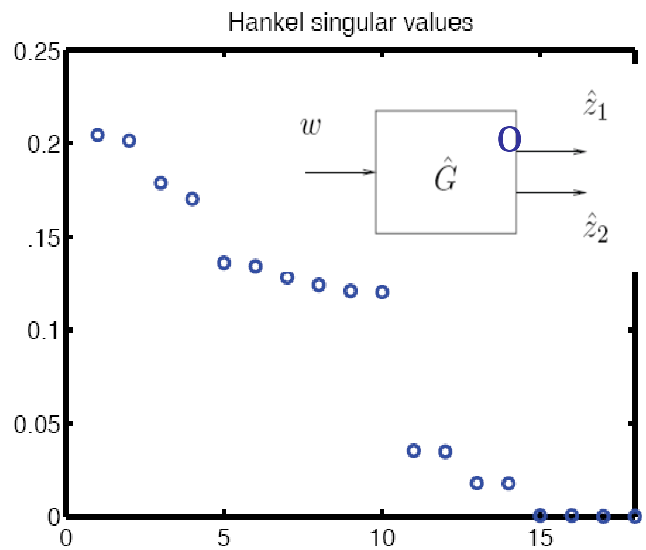
“Normal” model reduction





Structured model reduction





Results and research

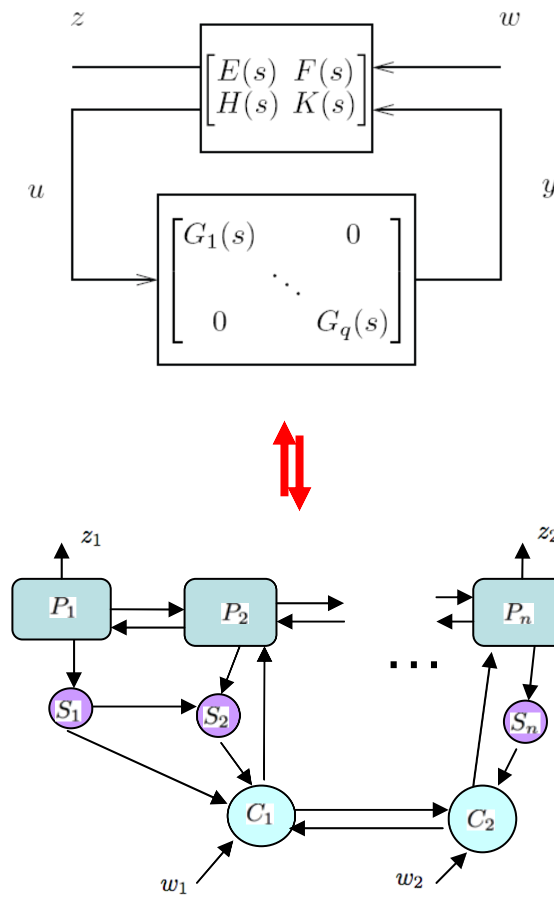
Theory

Linear Fractional Transforms (LFTs) for modeling of networked systems

Structured Hankel singular values $\sigma_{k,i}$

Global error bounds to determine sufficient submodel complexity

$$\|\mathcal{F}_l(N,G) - \mathcal{F}_l(N,\hat{G})\|_\infty \leq 2\sum_{k=1}^{q}\sum_{i=r_k+1}^{n_k}\sigma_{k,i}$$



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Evaluation

Reduce order of distributed controllers and plants (ongoing)

Quantify importance of links in models (ongoing)

Large-scale models needed!