Present Developments in Control Applications

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Acknowledgements

Numerous friends and colleagues in industry and academia
Control Emerges

- Drivers: gun control, radar ...
- Block diagrams, transfer functions
- Design tools: graphical
- Analog computing
- Holistic view of theory & applications
The Second Phase

- Drivers: space, computer control, mathematics
- Rapid growth of subspecialties
- Optimal, stochastic, nonlinear, ...
- Computational tools
- Impressive development of theory
- Holistic view was lost
The Third Phase?

- Drivers: embedded systems, networks, biology, physics, ...
- Autonomy, distribution
- Exploding applications
- Hardware and software platforms
- Holistic view will be recovered?
1. Introduction
2. Control Everywhere
3. A Closer Look
4. The Systems View
5. Conclusions
Breakthrough Technologies

Everything will, in some sense, be smart; that is, every product, every service, and every bit of infrastructure will be attuned to the needs of the humans it serves and will adapt its behavior to those needs.

Sensing, actuation, and control

NAE The Engineer of 2020
Power Generation and Distribution
Process Control
Discrete Manufacturing
Vehicles
Consumer Electronics
Biomedical
DLR Robots and Hands

LWR III: 7 joints weight/load ~ 1
150 W, 3 cables

Hand II: 13 joints 3 kg finger force

Gerd Hirzinger DLR
Instruments Giga to Nano

Adaptive Optics

Atomic Force Microscope

CONTROL UNIT
REF. → PID → SWEEP-GENERATOR

PHOTO DIODE
CANTILEVER
SAMPLE

LASER
SCANNER

Secondary mirror
Tripod
50 m Primary mirror
Physics

- Devices and ideas (feedback in nature)
- Particle Accelerators
- Adaptive Optics
- Atomic Force Microscope
- Quantum and Molecular Systems
  - NMR, Quantum computing
- Turbulence
Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure, and cholesterol level. The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.

M. B Hoagland and B Dodson The Way Life Works Times Books 1995
Key Drivers

- Insight and understanding
- Knowledge and education
- Power of feedback and computing
- Tools
- Control a commodity?
The Power of Feedback

- Good systems from bad components
- Attenuate disturbances
- Stabilize unstable system
- Shape behavior
- Risk of instability
Tools

- Sensors, actuators, process interfaces
- Computers, signal processors, FPGA
- Tools for modeling, analysis, simulation and design
- Operating systems, automatic code generation

The MathWorks

NATIONAL INSTRUMENTS

dSPACE
NASA’s X43-A Scramjet Achieves Record-Breaking Mach 10 Speed Using MathWorks Tools for Model-Based Design

The Challenge
To design and automatically generate flight control software for a scramjet vehicle traveling at Mach 10 speed

The Solution
Use Simulink® to model and validate control systems, Real-Time Workshop® to automatically generate flight code, and MATLAB® to process and analyze post-flight data

The Results
Reduced development time by months
Accurately predicted separation clearance
Aided in achieving SEI CMM Level 5 process rating

Our autopilot worked on the first try, which is amazing given that a vehicle like this had never been flown before. MathWorks tools helped us design and implement control systems that kept the vehicle stable throughout the flight."

Dave Bose,
Analytical Mechanics Associates
Rapid Prototyping

Drivven: “We prototyped a full-authority engine control system ... in just 3 man-months. In past projects, it took us at least 2 man-years and over $500,000 to develop similar ECU systems.”
Cross Direction Control

Several hundred sensors and actuators, millisecond operation, controlling paper thickness to within microns!
Mill Wide Control

Billerud Gruvön plant

- 660,000 ADt/year Containerboard
- Three fiber lines Sack
- Six paper machines Kraft
- Market pulp

Dynamic mass balance

Diffusören är inbakad i kokaren Flash 1-spliten är en intern loop

Modelica modeling

25 Production units
38 Buffer tanks
250 Streams
250 Measurements
2500 Variables

Each cycle approx. 30 minutes
Optimization
State Estimation
Simulation

Slide from Alf Isaksson
Global Enterprise Control

- **Strategic, Enterprise system, global, 1-10 years**
- **Tactical, Manufacturing system, 10 km, year, shift, ms**
- **Operational, Process Control, 1 km, shift, ms**
Embedded APC Tools – What’s new?

- **NO** extra databases
- **NO** database synchronization issues
- **NO** watchdog timers
- **NO** fail/shed logic design
- **NO** custom DCS programming
- **NO** interface programming
- **NO** operator interface development

**Traditional Advanced Control**

**Embedded APC**:
- Can run in DCS controllers
- Redundant and fast (1/sec)
- Integrated operator user interface
- Configuration through standard Control Studio
- Automated step and Model ID
- Off-line simulation and training
Automotive

Engine control
Power trains
Cruise control
Adaptive cruise control
Traction control
Lane guidance assistance
Platooning
Automotive

- Strongly enhanced performance
- Strong technology driver
- Large numbers (microcontroller)
- Low cost
- Safe design and operation of networked embedded systems
Biology

- Schrödinger 1944
- Wiener 1948
- von Neumann 1958
- Bellman Mathematical Biosciences
- Understanding dynamics and control crucial
- Biomedical engineering
- Systems Biology
Leading biologists have recognized that new systems-level knowledge is urgently required in order to conceptualize and organize the revolutionary developments taking place in the biological sciences, and new academic departments and educational programs are being established at major universities, particularly in Europe and in the United States.

Eduardo Sontag 2006
Signaling Circuit in Mammalian Cell
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The Systems Perspective

In the past steady increases in knowledge has spawned new microdisciplines within engineering. However, contemporary challenges – from biomedical devices to complex manufacturing designs to large systems of networked devices – increasingly require a systems perspective.

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C³BMP

- Computing
- Mathematics
- Control
- Physics
- Biology
- Communication
Modeling and Simulation

There will be growth in areas of simulation and modeling around the creation of new engineering “structures”. Computer-based design-build engineering ... will become the norm for most product designs, accelerating the creation of complex structures for which multiple subsystems combine to form a final product.

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The Modeling Barrier

Control

Physics

Block diagrams ODEs

Mass, energy, momentum

Important to have multiple views

Block diagrams are not suitable for serious physical modeling
Modelica (www.modelica.org)

- Block diagrams and ODEs (imperative models) are not suited for physical modeling
- Behavior-based (declarative) modeling is a good alternative
- European activity based on industry/university collaboration
- Groups with broad competence and experience
Modelica (www.modelica.org)

- Mimics how an engineer builds a real system
- Object oriented, component-based, multi-domain
- Efficient engineering through reuse
- Model libraries (free and commercial)
- Simulator Dymola
- Extensive symbolic manipulation, automatic inversion, ...
- Efficient real-time code
- Syntax and semantics formally defined
Automotive Climate Control

- Audi, BMW, Daimler Chrysler, Volkswagen and their suppliers have standardized on Modelica
- Suppliers provide components and validated Modelica models based on the AirConditioning library from Modelon
- Car manufacturers evaluate complete system by simulation
- IP protected by extensive encryption

Picture courtesy of Behr GmbH & Co.
The Implementation Barrier

Control

Feedback, Stability,
Moderate complexity ODE, PDE
Robustness

Computing

Logic, languages, architecture
High complexity, DES, FSM
Abstractions

Networked embedded systems
Control and Computing

Vannevar Bush 1927: Engineering can progress no faster than the mathematical analysis on which it is based. Formal mathematics is frequently inadequate for numerous problems, a mechanical solution offers the most promise.

Herman Goldstine 1962: When things change by two orders of magnitude it is revolution not evolution.

Gordon Moore 1965: The number of transistors per square inch on integrated circuits has doubled in approximately 18 months.

Software has unfortunately not kept up
Networked Embedded Systems

- It has been predicted that by the year 2010 about 90% of all program code will be implemented for embedded systems.
- Dramatic growth of complexity. Ex. automotive system: Thousands of functions, 10M lines of code, 5 bus systems, 80 ECUs
- How to design, commission, operate, and upgrade with guaranteed performance
Systems Biology

Replace processors

Replace algorithm

Augment with Off-line optimization

Camera with higher resolution

Model changed will system still work?

Replace network

Warranty
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Conclusions

- Tremendous advances
- Control everywhere
- Massive computations
- The systems challenge
- Like 1956 but at a higher level
- A role for IFAC?