Control Engineering the Hidden Technology

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The Hidden Technology

- Widely used
- Very successful
- Seldom talked about
- Except when disaster strikes
- Why?

Easier to talk about devices than ideas
Not enough attention to popularization
Engineering Education

Followed the pattern of emerging industries in the 19\textsuperscript{th} and 20\textsuperscript{th} century: Civil Engineering, Mining, Mechanical, Chemical, Electrical.

New fields such as **Control and Systems** which are not tied to particular industries appeared in the middle of the 20\textsuperscript{th} century.
1. Introduction
2. A Brief History
3. State of the Art
4. The Future
5. Conclusions
A Brief History

- Early use in many fields
  - Process control
  - Vehicle control
  - Communication
- Servomechanism Theory
- Consequences
- The Second Wave
Industrial Process Control

- Windmills Mead 1787
- Steam Engines 1788
- Governors 1890
- Water Turbines 1893
- Tolle’s Book 1905
- The PID Controller 1930
We know how to construct airplanes. Men also know how to build engines. Inability to balance and steer still confronts students of the flying problem. When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance.
Sperry’s Autopilot 1912
A Quiz!

Robot Piloted Plane makes Safe Crossing of the Atlantic
No hands on controls from Newfoundland to Oxfordshire
Take-Off, Flight and Landing are fully Automatic.

New York Times 19XX
Flight Control

The Wright Brothers 1903
Sperry’s Autopilot 1912
Robert E. Lee 1947
V1 and V2 (A4) 1942
Sputnik 1957
Apollo 1969
Mars Pathfinder 1997
The Feedback Amplifier

Telephone Calls Over Long Distances

The Problem: How to Increase Signal Strength?

The Solution: The Feedback Amplifier

Patented by Black 1928

Patent Granted 1937

Strong Development of Theory and Design Methods
Telecommunications
The Repeater Problem

Black’s Invention 1928
“Singing” = Instability
Nyquist’s Theorem 1932
Bode’s Paper 1940
Bode:
Network Analysis
and
Feedback Amplifier Design

\[
\frac{V_2}{V_1} = -\frac{R_2}{R_1} \cdot \frac{1}{1 + \frac{1}{A} \left(1 + \frac{R_2}{R_1}\right)}
\]
Mervin Kelley on Black 1957

It is no exaggeration to say that without Black’s invention of the feedback amplifier, the present long-distance telephone and television networks, which covers our entire country and the transoceanic telephone cables would not exist.
The Magic of Feedback

- Make precise systems from imprecise components
- Keep variables constant
- Stabilize unstable system
- Reduce effects of disturbances and component variations
- New degrees of freedom for designers
- Main drawback - danger of instability
The Scene of 1940

Widespread use of control in many fields

- Power generation and distribution
- Process control
- Autopilots for ships and aircrafts
- Telecommunications

The similarities were not recognized
A Discipline Emerges

Industrial Process Control
Telecommunications
Flight Control
Mathematics

Principles
Theory
Design
Methodology
Applications
The Black Box Concept

Abstraction
Information hiding
Transfer functions
Servomechanism Theory

- Foundations
  - Complex variables
  - Laplace Transforms

- System Concepts
  - Feedback
  - Feedforward

- Methodology Design
  - Frequency Response
  - Graphical Methods

- Analog Simulation
- Implementation
Cybernetics

Norbert Wiener 1948
Cybernetics - Control and Communication in Human and Machine
Interaction with neurophysiology
McCulloch and Pitts 1943
Consequences

Education
Application
Industrialization

Organisation
Journals
Conferences
The Second Wave

Driving Forces
- Space race
- Mathematics
- Computers
- A New Paradigm
- State Space
- Rapid Expansion
- Subspecialities

Optimal Control
- Nonlinear Control
- Computer Control
- Stochastic Control
- Robust Control
- System Identification
- Adaptive Control
- CACE
Optimal Control

Euler 1707–1783
Lagrange 1736–1813
Pontryagin 1908–1988
Hamilton 1805–1865
Jacobi 1804–1851
Bellman 1925–1984
Kalman Filtering

Gauss  1810 least squares
Wold  1935 innovations
Kolmogorov  1941 discrete time
Wiener  1941 spectral factorization
Kalman  1961 recursive equations
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Current Status

A well established body of ideas, concepts, theory and design methods.

Wide and growing application areas

Still developing rapidly
Perhaps Most Important

A good group of very talented and creative young researchers.
Applications

Energy generation
Energy transmission
Process control
Discrete manufacturing
Communication
Transportation
Buildings

Entertainment
Instrumentation
Mechatronics
Materials
Physics
Biology
Economics
CD Player

Tracking
Searching
Focusing
A Dilemma

Automatic control is a collection of ideas, concepts and theories with very wide applications areas. How to cope with:

- Coupling to hardware
- Coupling to industries
- Specific domain knowledge
- Academic positioning
A Soul but No Body

- Technology transfer
- Student attraction
- Searching for a home court
- Many base industries
- Generality
- Academic positioning
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Natural and Engineering Sciences

Understand Nature vs Man-made Systems
Equally Challenging
Extensive use of Mathematics
Design and Operation of Systems
Physical Laws vs System Principles
Isolation vs Interaction
Reductionism vs Systems
Theoretical Physics vs System Theory
The Future of Control

- Increased use in engineering
  - Control over/of communication networks
  - Autonomous systems

- Biology and Medicine
  - Many previous attempts, Will it work this time?

- Physics
  - Devices and Ideas, Quantum systems
Process and Control Design

- Wright Brothers rejected the dogma that aircraft should be inherently stable
- Minorsky 1922: It is an old adage that a stable ship is difficult to steer
- Integrated process and control design
- Control gives designers extra freedom
- The cardinal sin of control
Co-Design of Process and Control
The Mercedes A-class

Control comes to the rescue!

Unstable behavior improved by
Electronic Stabilization Program (ESP)
Computing and Control

- Software issues increasingly important
- Object oriented modeling
- Feedback scheduling
- Control of servers and nets
- Vision Feedback and haptics
- High level control principles
- Learning systems
Computers and Control

- Process control
- Regular
- Embedded

Step Length Control in ODE Solvers

- Dead-beat control was standard
- PI control gives much better behavior
- Control view gives better code
Physics

- Devices and ideas
- Particle Accelerators
  - The 1984 Nobel Prize Van Der Meer
- Adaptive Optics
- Atomic Force Microscope
- Quantum and Molecular Systems
- Turbulence
Adaptive Optics
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.

Mahlon B Hoagland and B Dodson The Way Life Works Times Books 1995
It is not the strongest of the species that survive, nor the most intelligent, it is the one that is most adaptable to change.
Educational Challenges

- Theory and applications expanding
- How to compactify the knowledge?
- The engineering aspect
- The field had changed a lot, the courses have not
- Relations to computing
Interesting Areas

- **C^3** - Control Computing Communication
  - Control over/of communication networks
- Biology and Medicine
  - Many previous attempts, Will it work this time?
- Complex systems
  - Autonomous and learning systems
  - Supply chains, quantum systems
Examples of New Problems

- Sensor-rich control
- Actuation-rich control
- High level control principles
Recipe for Success

- Good ideas and demanding problems
- Solid theory
- Good engineering
- Examples
  - Servomechanisms, Optimal control
  - Robust control, Nonlinear control
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Conclusions

- An exciting field
- Use of feedback often revolutionary
- Rapid growth of applications
- Streamline available knowledge
- Education is a key issue
- Many new challenging problems
Take Care of Both Body and Soul

- Intellectual challenges (the soul)
  Basics that generalizes easily
  Give the general picture
  Particular attention to introductory courses
- The engineering aspect (the body)
  Educate students broadly so that they can take full systems responsibility
- Learn theory and a particular domain
The End