A Brief History of Control Engineering

Water Clock

A Water Clock, or clepsydra, (a Greek word meaning water thief) is a device that uses the flow of water under gravity to measure time.

Ktesibios (300-230 B.C.) used a float in the overflow tank to regulate the level, and therefore, the flow.

Ktesibios is considered the first builder of a system with feedback control.

Windmills

1787

Steam Engines

1788

Thomas Savery was an English military engineer and inventor who in 1698, patented the first crude steam engine, based on Denis Papin's Digester or pressure cooker of 1679.

Thomas Newcomen was an English blacksmith, who invented the atmospheric steam engine, an improvement over Thomas Savery's previous design.

The Newcomen engine was the predecessor to the Watt engine and it was one of the most interesting pieces of technology developed during the 1700's.

James Watt (1736-1819) was a Scottish inventor and mechanical engineer, born in Greenock, who was renowned for his improvements of the steam engine.

Watt's engine soon became the dominant design for all modern steam engines and helped bring about the Industrial Revolution.

James Watt designed his first governor in 1788 following a suggestion from his business partner Matthew Boulton. It was a conical pendulum governor (flyball governor) and one of the final series of innovations Watt had employed for steam engines.

James Clerk Maxwell: Governors 1868

James Clerk Maxwell wrote a famous paper "On governors", which is quite frequently considered a classical paper in feedback control theory, in 1868.

Routh and Hurwitz 1877, 1895

Edward Routh: Stability of motion,
Adolf Hurwitz: Routh-Hurwitz Criterion

Wright brothers: Airplane 1901

Wilber Wright in 1901, "We know how to construct airplanes. Men also know how to build engines. The 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.”

**Elmer Sperry:** 1914
Automatic ship steering mechanism, PID control and
automatic gain adjustment to compensate for the
disturbances

**Nicholas Minorsky:** 1922
Steering control of ship,
Position control system analysis, PID controller

**Harold Hazen:** 1934
Servomechanism theory

**Harry Nyquist:** 1932
Nyquist Analysis

**Harold Black:** 1934
Negative feedback amplifier
Negative feedback on systems

**A. Ivanoff:** 1933
Temperature regulation

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### What is Control?
- **Manipulation of the inputs to a physical system in order to cause desirable behavior.**
  - Cause output variables to track desired values
  - Impose desirable dynamical behavior, e.g., stabilize an unstable system

- **Open loop (feedforward) control**
  - Exploit knowledge of system behavior to compute necessary inputs
  - Requires accurate model of system

- **Closed loop (feedback, active) control**
  - Process information from sensors to derive appropriate inputs
  - Allows compensation for model uncertainty, disturbances, noise
  - Alters system dynamics

\[ R(s) \xrightarrow{K(s)} U(s) \xrightarrow{G(s)} Y(s) \]

\[ R(s) \xrightarrow{E(s)} K(s) \xrightarrow{U(s)} G(s) \xrightarrow{H(s)} Y(s) \]
The Magic of Feedback

- The adjustment of system inputs based on the observation of its outputs
- Feedback is a universal strategy to cope with uncertainty

In engineering we use feedback:

- Cause a system to behave as desired
- Keep variables constant
- Stabilize unstable system
- Reduce effects of disturbances
- Minimize the effect of component variations

Contemporary Applications

Widespread use of automatic control in many fields

- Power generation
- Power transmission
- Process control
- Discrete manufacturing
- Robotics
- Communications
- Automotive
- Buildings
- Aerospace
- Medicine
- Marine Engineering
- Computers
- Instrumentation
- Mechatronics
- Materials
- Physics
- Biology
- Economics

There is a unified framework of theory, design methods and computer tools that cut across fields of application.
Examples

- **Flight control systems**
  Commercial & military “fly-by-wire”
  Autopilot, auto-landing
  UAV

- **Robotics**
  Precision positioning in manufacturing
  Remote space/sea environments
  Minimally-invasive surgery
  RPV’s for surveillance, search and rescue

- **Automotive**
  Engine
  Transmission
  Cruise, climate control
  ABS, Traction control, ESP
  Active suspension

- **Power plants**
  Various temps/pressures
  Power output
  Emissions control

- **Heating, ventilation, air conditioning (HVAC)**

- **Materials processing**
  Rapid thermal processing

- **Noise and vibration control**
  Active mounts
  Speaker systems

- **Intelligent vehicle highway systems**
  ‘platooning’ for high speed, high density travel
  Automatic merge
  Obstacle avoidance

- **Smart engines**
  Compression systems stall, surge, flutter control
  Combustion systems lean air/fuel ratio for low emissions, improved efficiency

- **Vapor deposition**
Aerospace Control

- The Wright Brothers 1903
- Sperry’s Autopilot 1912
- V1 & V2 Rockets 1942
- Sputnik 1957
- Apollo 1969
- Mars Pathfinder 1997
- V-22 Osprey 2000
- International Space Station

Telecommunications: The Feedback Amplifier

The Goal: Telephone Calls Over Long Distances
The Problem: How to Increase Signal Strength?
The Solution: The Feedback Amplifier
Patent application by Black 1928
Patent Granted 1937
Development of the feedback amplifier led to new approaches to stability analysis and new methods of feedback system design.
**Automotive Control Systems**

- Cruise Control
- ABC-active body control
- ABS-anti-lock braking system
- ASR acceleration skid control
- ESP electronic stabilization program
- SBC sensotronic brake control
- BAS brake assist system
- Proximity controlled cruising

A typical automobile has 200-300 feedback controllers. Here are a few examples in a contemporary Mercedes.

**Biology/Biomechanics**

- Feedback governs how we grow, respond to stress and challenge.
- Feedback regulates factors such as body temperature, blood pressure, and cholesterol level.
- Feedback makes it possible for us to stand upright.
- Feedback enables locomotion.
- Feedback operates at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies. Feedback control is used to design drug treatment strategies for diseases like HIV/AIDS, Cancer

- Biologically inspired control
**Evolution of the Control Discipline**

- **Classical control**  **1940**
  Frequency-domain based tools for linear systems
  Mainly useful for single-input single-output (SISO) systems
  WWII years saw 1st application of ‘optimal’ control
  Still the main tools used in practice

- **Modern control**  **1960**
  ‘State space’ approach for linear systems
  Useful for SISO and multi-input multi-output (MIMO) systems
  Relies on linear algebra computations rather than Laplace transform
  Performance and robustness measures not always explicit
  Just in time for space exploration

- **Optimal control**  **1970**
  Find the input that optimizes some objective function (e.g., minfuel, min time)
  Used for both open loop and closed loop design

- **Robust control**  **1980**
  Generalizes classical control to MIMO case
  Enabled by modern control development

- **Nonlinear, adaptive, hybrid ...**  **2000**

**Key Technology Trends**

- **Computation/microprocessors**
  Cheap and powerful microprocessors opened the door to widespread control applications from 1970’s onward

- **Sensors and actuators**
  Sensors continue to get smaller, cheaper, faster
  Macro/micro-scale actuation evolving (power electronics, piezo-electric, EM-rheological fluids)

- **Communications and networking**
  Networks replacing point-to-point communication in large systems (e.g., electric power systems) and small (e.g. automotive)
Research Applications in ME

• Automotive
• Aircraft/Flight Safety
• Power Plants
• Robotics
• Autonomous Vehicles
• Mechatronics
• Biology/Biomechanics
• Electric Power Systems

Summary

• Course content.
• What is a control system?
  Open loop/closed loop (feedforward/feedback)
• Why is control relevant to ME?
  Applications! Applications! Applications!
• Why so much math?
  Abstraction to accommodate many applications in a common framework
  Explicit design approaches to meet (optimize) specific performance goals.