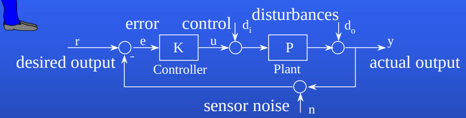
Topic 2

Artificial intelligence in control and manufacturing

- **Introduction, or what is modern control?**
- **Limitations of conventional controllers**
- **Intelligent control: definition**
- **Intelligent control structures**
- **Intelligent control applications**

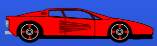
What Is Control?



- Design K s.t. closed loop system exhibits high performance.

  - P : Physical System to be Controlled
  - K : System to be Designed

Example: Vehicle Cruise Control

- P - Vehicle 
- r - Speed reference command (desired speed)
- y - Actual speed
- u - Fuel flow to engine
- K - Controller

What Needs To Be Controlled?

•*Acoustic* - acoustic cancellation for a concert hall; intelligent hearing devices

•*Aerospace* - altitude hold system for aircraft; all-weather landing system; control of remotely piloted vehicles; launch vehicles

•*Automation and Manufacturing* - navigation system for an autonomous robot (e.g. pathfinder)

•*Biological* - neuromuscoloskeletal control systems; cardiovascular control systems

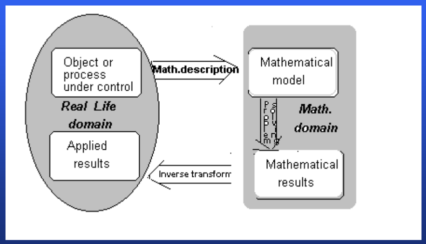
What Needs To Be Controlled?

- *Capital Investment* - variable risk securities portfolio risk/return; asset management
- *Defense* - high performance fighters; tactical missiles; ballistic missile theatre defense; guidance and navigation; attack helicopters
- *Electrical* - diffusion furnaces; semiconductor processes; read/write head control for optical storage
- *Mechanical* - active suspension for mobile laboratory
- *Materials* - control of smart composite (deformable) materials

What Needs To Be Controlled?

- *Medicine* - control of telemedical robotic systems for precision surgery
- *Nuclear* - temperature control for nuclear reactor
- *Ocean* - depth control for underwater exploration vehicle; submarine
- *Space Based Surveillance* - pointing control system for telescopic imaging, weather, surveillance, monitoring system; satellites
- *Structural* - active earthquake control for skyscrapers

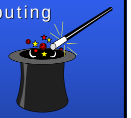
Modern control theory and practice: relationship



Limitations of conventional controllers

* Plant nonlinearity - The efficient linear models of the process or the object under control are too restrictive, nonlinear models are computationally intensive and have complex stability problems.
* Plant uncertainty - A plant does not have accurate models due to uncertainty and lack of perfect knowledge.
* Multivariables, multiloops, and environment constraints - Multivariate and multiloop systems have complex constraints and dependencies.
* Uncertainty in measurements - Uncertain measurements do not necessarily have stochastic noise models.
* Temporal behaviour - Plants, controllers, environment, and their constraints vary with time. Moreover, time delays are difficult to model.

New Technologies



- Affordable High Performance Computing
- Hi-fidelity Simulation Capability
- Hi-fidelity Animation Capability
- Object Oriented Programming (OOP) Framework

- *Intelligent Systems Are Coming*….

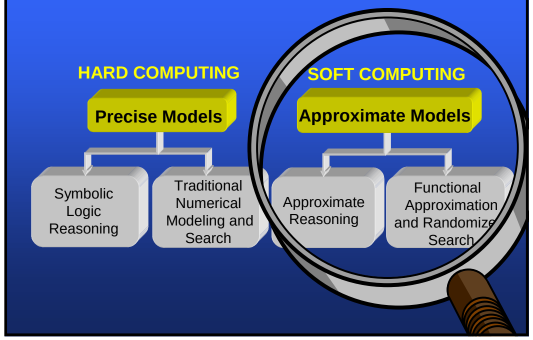
Revolutionary Times

For the first time in history, amazing new computing technologies are becoming accessible to the masses!

- *Intelligent Systems Are Coming*….
- *Intelligent Systems Require Feedback*...

Soft Computing

- Soft Computing (SC): the symbiotic use of many emerging problem-solving disciplines.
  - According to Prof. Zadeh:
    "...in contrast to traditional hard computing, soft computing exploits the tolerance for imprecision, uncertainty, and partial truth to achieve tractability, robustness, low solution-cost, and better rapport with reality"
  - Soft Computing Main Components:
    -Approximate Reasoning:
      » Probabilistic Reasoning, Fuzzy Logic
    -Search & Optimization:
      » Neural Networks, Evolutionary Algorithms



Trends in the industry

- Increases in "intelligence" in manufacturing in the past 20 years have been in design and in planning
- In the next 20 years we predict a substantial change in
- intelligence at the unit process (individual machine) level, with great resulting increases in productivity
- Example: factor of ten increase in machine tool productivity
- Example: moving toward the "12 month" car
- This trend is a result of enabling technology plus user
- value plus open architectures
- *
- Underlying driver is Moore's Law

What is Intelligence in Intelligent Control?

Systems which are:

- Non-linear
- Adaptive
- Goal-Oriented
- Knowledge Based
- Autonomous
- Capable of Learning
- Able to deal with uncertainty
- Able to deal with symbolic reasoning...

All involve model based sensing and model based **control**

Intelligent control system: definition

An intelligent system has the ability to act appropriately in an uncertain environment, where an appropriate action is that which increases the probability of success, and success is the achievement of behavioral subgoals that support the system's ultimate goal. In order for a man-made intelligent system to act appropriately, it may emulate functions of living creatures and ultimately human mental faculties.

Levels of Intelligence

- At a minimum, intelligence requires the ability to sense the environment, to make decisions and to control action.
- Higher levels of intelligence may include the ability to recognize objects and events, to represent knowledge in a world model, and to reason about and plan for the future.
- In advanced forms, intelligence provides the capacity to perceive and understand, to choose wisely, and to act successfully under a large variety of circumstances so as to survive and prosper in a complex and often hostile environment.
- Intelligence can be observed to grow and evolve, both through growth in computational power and through accumulation of knowledge of how to sense, decide and act in a complex and changing world.

Control and Intelligent Systems

- The concepts of intelligence and control are closely related and the term "Intelligent control" has a unique and distinguishable meaning.
- An intelligent system must define and use goals. Control is then required to move the system to these goals and to define such goals. Consequently, any intelligent system will be a control system. Conversely, intelligence is necessary to provide desirable functioning of systems under changing conditions, and it is necessary to achieve a high degree of autonomous behavior in a control system. Since control is an essential part of any intelligent system, the term "intelligent control systems" is sometimes used in engineering literature instead of "intelligent systems" or "intelligent machines".

Learning in Control

- 1. Learning about the plant; that is learning how to incorporate changes and then how to derive new plant models.
- 2. Learning about the environment ; this can be done using methods ranging from passive observation to active experimentation.
- 3. Learning about the controller; for example, learning how to adjust certain controller parameter to enhance performance.
- 4. Learning new design goals and constraints.

Evolution of control systems: a bit of history

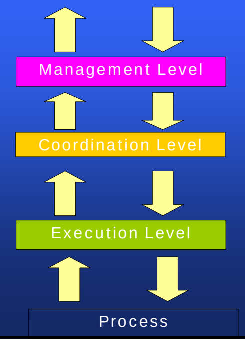
- The first feedback device on record was the water clock invented by the Greek Ktesibios in Alexandria Egypt around the 3rd century B.C..
- The first mathematical model to describe plant behavior for control purposes is attributed to J.C. Maxwell, who in 1868 used differential equations to explain instability problems encountered with James Watt's flyball governor;
- the governor was introduced in 1769 to regulate the speed of steam engine vehicles. It signaled the end of the era of intuitive invention.
- Control theory made significant strides in the past 120 years, with the use of frequency domain methods and Laplace transforms in the 1930s and 1940s and the development of optimal control methods and state space analysis in the 1950s and 1960s. Optimal control in the 1950s and 1960s, followed by progress in stochastic, robust, adaptive and nonlinear control methods in the 1960s to today, have made it possible to control more accurately significantly more complex dynamical systems than the original flyball governor.

Conventional control models and design

- Conventional control systems are designed today using mathematical models of physical systems.
- A mathematical model, which captures the dynamical behavior of interest, is chosen and then control design techniques are applied, aided by CAD packages, to design the mathematical model of an appropriate controller.
- The controller is then realized via hardware or software and it is used to control the physical system.
- The procedure may take several iterations.
- The mathematical model of the system must be "simple enough" so that it can be analyzed with available mathematical techniques, and "accurate enough" to describe the important aspects of the relevant dynamical behavior.
- It approximates the behavior of a plant in the neighborhood of an operating point.

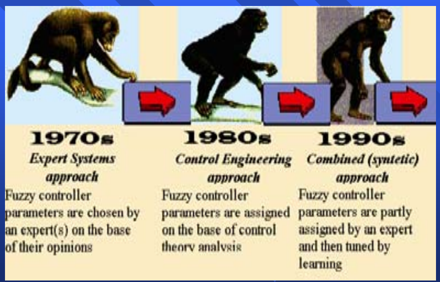
Intelligent Control Structure

- Hierarchical architecture
- Commands are issued by higher levels
- Response data flows upwards
- Delegation and distribution of tasks between levels
- All subsystems provide status and health info



L. Reznik

FUZZY CONTROLLER DESIGN METHODOLOGY EVOLUTION



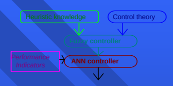
DESIGN APPROACHES CLASSIFICATION

- 1) expert systems approach
  - originates from the methodology of expert systems
  - justified by a consideration of a FC as an expert system applied to control problem solving.
  - fuzzy sets are applied to represent the knowledge or behaviour of a control practitioner (an application expert, an operator) who may be acting only on the subjective or intuitive knowledge.
  - too subjective and prone to errors
- 2) control engineering approach
  - to evaluate a quality of a FC the criteria commonly used in control engineering practice are applied
  - the feedback structure of the FC is commonly applied with the error signal chosen as one of the inputs
  - fuzzy PID-like (as well as PD-like, PI-like) controllers are extremely popular
  - the membership functions and scaling factors are selected on the base of their influence on the FC control surface, and rules are formulated considering the control trajectory
  - proposes to design a FC by investigating how the FC stability and performance indicators depend upon different FC parameters
- 3) intermediate approaches,
  - suppose setting some of the parameters (e.g. membership functions) by the experts and fixing the others (e.g. rules) with the methods inherited from the control system design.
- 4) combined approaches and synthetic approaches
  - include the initial choice of the FC structure and parameters made by the expert and further their adjustment performed with the control engineering methods

AI vs. CE approaches

- AI approach
  - allows to capture in a FC design the vagueness of a human knowledge and express the design framework with natural languages.
  - leads to that feature of FC which becomes more and more important, especially in design applications: the design process of a FC becomes more understandable, looks less sophisticated and superficial to a human designer and becomes more attractive and threfore cheaper than a conventional one
- Control engineering
  - allows to apply in a FC design traditional criteria and develop design methodologies to satisfy conventional design specifications including such parameters as e.g. overshoot, integral and/or steady-state eerror.
  - enhancing FC engineering methods with an ability to learn and a development of an adaptive FC design would significantly improve the quality of a FC, making it much more robust and expanding an area of possible apllications

Tuning (adjustment) of fuzzy controller parameters

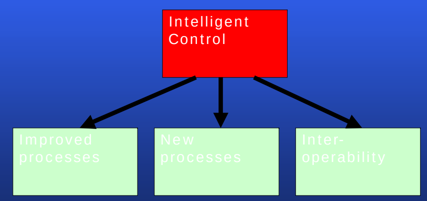


1. Conventional methods:
   1.1. least-square method variations,
   1.2. gradient descent method variations
2. Intelligent methods with applications of fuzzy logic, neural networks, and genetic algorithms
   2.1. tuning with fuzzy meta-rules,
   2.2 adjustment with neural networks,
   2.3 optimisation with genetic/evolutionary algorithms.

- In an intelligent design fuzzy logic is utilised to incorporate the available knowledge into the controller design, and ANN and/or GA technology are applied to adaptively develop an optimal control strategy. The control system structure in this case can be presented as in Fig. 8 [11]. One should note that there exist another trend in combining FL and ANN technologies and creating new synergisms such as adaptive network based fuzzy inference systems (ANFIS) [7]. In this approach the controller design originates from the ANN framework.

Combined structure for a FC

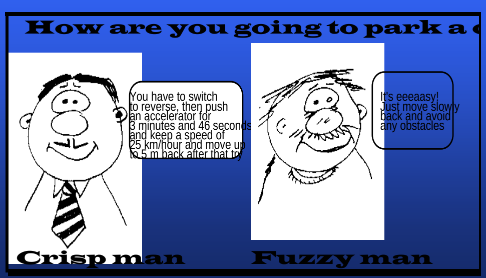
Intelligent Control: Applications



Intelligent Control: conditions to apply

- Appropriate controllers
- Appropriate sensors
- Model of the system under control to allow:
  – Model based perception
  – Model based control

Does intelligent control work? Your experience



Does intelligent control work? Consumer products

Panasonic®/National® Fuzzy Logic

Rice Cooker

* Fuzzy Logic controls the cooking process self adjusting for rice and water conditions

Does intelligent control work? Consumer products

National® Deluxe Electric Fuzzy Logic

Thermo Pot

This is a big deal unit representing the best technology available in producing clean boiled water on demand. for making tea.

Does intelligent control work?
An unmanned voice-controlled helicopter

The helicopter Yamaha R-50 is a scaled down (3.6 meters head to tail) real helicopter with all the machinery for flying, plus all the control gears but minus the human accommodation. The engine, with the exhaust pipe, looks like the one used in one of the Yamaha motorcycles.

Does intelligent control work?
An unmanned voice-controlled helicopter

The reasons to apply intelligent control:

Over 50 years since the helicopter and conventional control technique have been developed., however, has been limited to

(1) hovering control,

(2) maintaining the height after reaching a stable flight and

(3) change of route at intervals in accordance with the determined route.

Only partial automation has been accomplished. Most of control has been manually operated.

At present, although an unmanned helicopter has been developed in every large country of the world, its control technique has been confined to the remote control system using manual operation

Does intelligent control work?
An unmanned voice-controlled helicopter

Intelligent control in view of helicopter characteristics:

A. Nonlinear behaviour: a helicopter has the nonlinear characteristics. The conventional control methods use a linear theory suitable only for linear systems. Intelligent control is intrinsically nonlinear one and is thus suitable for the nonlinear system control.

B. Unstable system: the helicopter is intrinsically unstable, and there is a time delay between the input and output operations.

C. Effect of the environment: a helicopter is very sensitive to the wind. Exposing to the side wind leads to instability during the time of hovering. Now there are no techniques associated with the conventional control method to deal with the change of the environment.

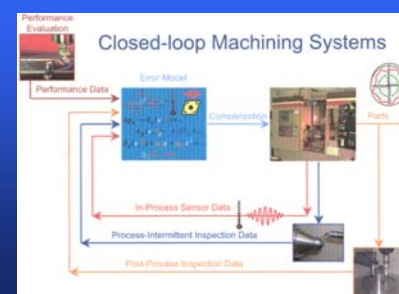
Does intelligent control work?

* Automatic control of dam gates for hydroelectric power plants (Tokio Electric Pow.)
* Simplified control of robots (Hirota, Fuji Electric, Toshiba, Omron)
* Camera aiming for the telecast of sporting events (Omron)
* Efficient and stable control of car engines (Nissan)
* Cruise-control for automobiles (Nissan, Subaru)
* Substitution of an expert for the assessment of stock exchange activities (Yamaichi, Hitachi)
* Optimised planning of bus time-tables (Toshiba, Nippon-System, Keihan-Express)
* Archiving system for documents (Mitsubishi Elec.)

Does intelligent control work?

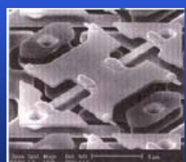
* Prediction system for early recognition of earthquakes (Seismology Bureau of Metrology, Japan)
* Medicine technology: cancer diagnosis (Kawasaki Medical School)
* Recognition of motives in pictures with video cameras (Canon, Minolta)
* Automatic motor-control for vacuum cleaners with a recognition of a surface condition and a degree of soiling (Matsushita)
* Back light control for camcorders (Sanyo)

Intelligent control:does it work?



Intelligent Control: does it work?
Micro-Electro-Mechanical Systems (MEMS) – mechanical sensors integrated with associated electronics

Acceleration and force sensors



Suspended membranes: temperature, pressure, humidity, flow rate