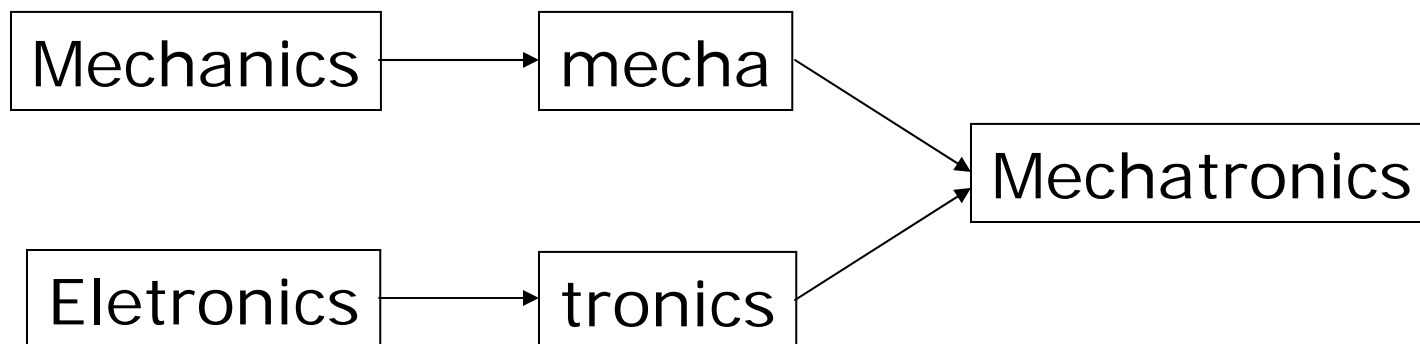# Intro to Mechatronics

Mechatronics Defined — I

- "The name [mechatronics] was coined by Ko Kikuchi, now president of Yasakawa Electric Co., Chiyoda-Ku, Tokyo."

  – R. Comerford, "Mecha … what?" *IEEE Spectrum*, 31(8), 46-49, 1994.

- "The word, mechatronics is composed of *mecha* from mechanics and *tronics* from electronics. In other words, technologies and developed products will be incorporating electronics more and more into mechanisms, intimately and organically, and making it impossible to tell where one ends and the other begins."

  – T. Mori, "Mechatronics," *Yasakawa Internal Trademark Application Memo*, 21.131.01, July 12, 1969.

Mechanics → mecha ↘

Eletronics → tronics → Mechatronics

Mechatronics Defined — II

- "Integration of electronics, control engineering, and mechanical engineering."

    – W. Bolton, *Mechatronics: Electronic Control Systems in Mechanical Engineering*, Longman, 1995.

- "Application of <u>complex decision making</u> to the operation of physical systems."

    – D. M. Auslander and C. J. Kempf, *Mechatronics: Mechanical System Interfacing*, Prentice-Hall, 1996.

- "<u>Synergistic integration</u> of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes."

    – F. Harshama, M. Tomizuka, and T. Fukuda, "Mechatronics-what is it, why, and how?-and editorial," *IEEE/ASME Trans. on Mechatronics*, 1(1), 1-4, 1996.

Mechatronics Defined — III

- "Synergistic use of precision engineering, control theory, computer science, and sensor and actuator technology to design <u>improved</u> products and processes."

    – S. Ashley, "Getting a hold on mechatronics," *Mechanical Engineering,* 119(5), 1997.

- "Methodology used for the <u>optimal design</u> of electromechanical products."

    – D. Shetty and R. A Kolk, *Mechatronics System Design*, PWS Pub. Co., 1997.

- "Field of study involving the analysis, design, synthesis, and selection of systems that combine electronics and mechanical components with modern controls and microprocessors."

    – D. G. Alciatore and M. B. Histand, *Introduction to Mechatronics and Measurement Systems*, McGraw Hill, 1998.

- Aside: Web site devoted to definitions of mechatronics:

    – http://www.engr.colostate.edu/~dga/mechatronics/definitions.html

Mechatronics: Working Definition for us

Mechatronics is the synergistic integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software to manage complexity, uncertainty, and communication in engineered systems.

Product Realization Paradigm
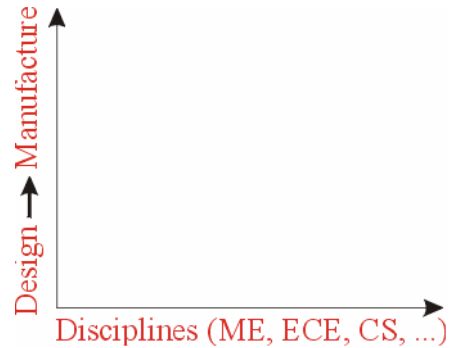
- Engineered products frequently involve components from more than one discipline

- Traditional product realization

  – Discipline specific sequential process (design then manufacture)

  – Drawback: cost overruns due to redesign/re-tooling

- A better but still deficient approach

  – Discipline specific concurrent process (design for manufacturing)

  – Bottleneck: sub-optimal integration

- Mechatronics based product realization exploits

  – Integrated process founded upon interdisciplinary synergy

Disciplinary Foundations of Mechatronics

- Mechanical Engineering

- Electrical Engineering

- Computer Engineering

- Computer/Information Systems
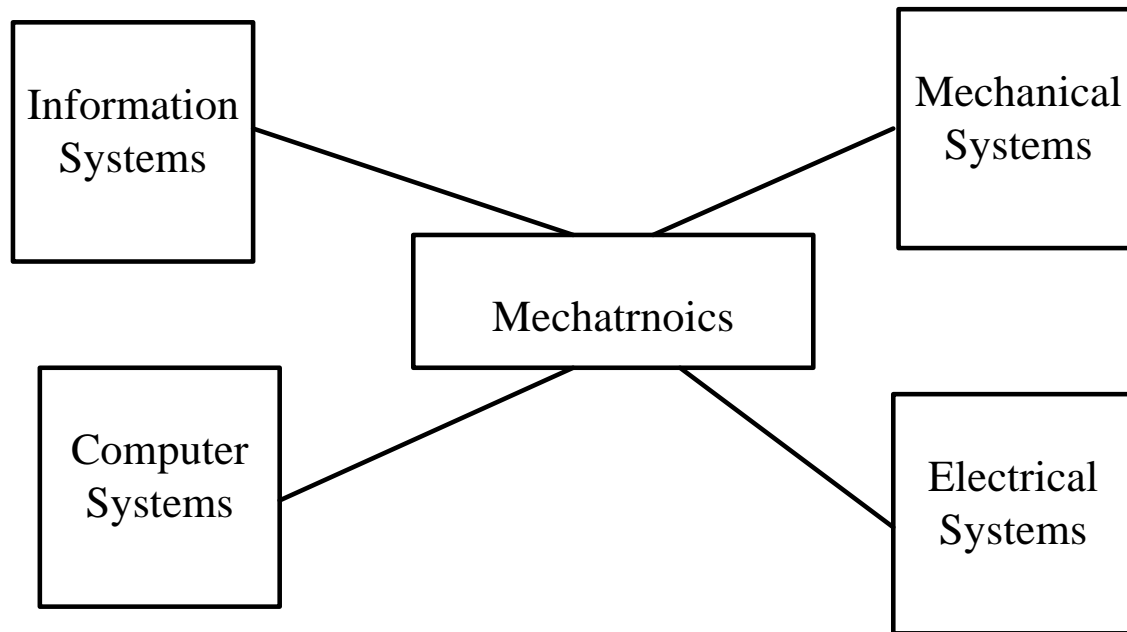
Multi-/Cross-/Inter-Disciplinary

- Products and processes requiring inputs from more than one discipline can be realized through following types of interactions.

  - Multi-disciplinary: This is an additive process of brining multiple disciplines together to bear on a problem.

  - Cross-disciplinary: In this process, one discipline is examined from the perspective of another discipline.

  - Inter-disciplinary: This is an integrative process involving two or more disciplines simultaneously to bear on a problem.

Sequential/Concurrent Product Realization

- Sequential and discipline specific concurrent design processes for product realization are at best multi-disciplinary calling upon discipline specialists to "design by discipline."

  – Design mechanical system "plant."

  – Select sensors and actuators and mount on plant.

  – Design signal conditioning and power electronics.

  – Design and implement control algorithm using electrical, electronics, microprocessor, microcontroller, or microcomputer based hardware.

Mechatronics-based Product Realization

- Systems engineering allows design, analysis, and synthesis of products and processes involving components from multiple disciplines.

- Mechatronics exploits systems engineering to guide the product realization process from design, model, simulate, analyze, refine, prototype, validate, and deployment cycle.

- In mechatronics-based product realization: mechanical, electrical, and computer engineering and information systems are integrated throughout the design process so that the final products can be better than the sum of its parts.

- Mechatronics system is not

  - simply a multi-disciplinary system

  - simply an electromechanical system

  - just a control system

Mechatronic Design Process

Modeling/Simulation   Prototyping   Deployment/Life Cycle

Recognition of the Need

Conceptual Design and Functional Specification

First Principle Modular Mathematical Modeling

Sensor and Actuator Selection

Detailed Modular Mathematical Modeling

Control System Design

Design Optimization

Hardware-in-the-Loop Simulation

Design Optimization

Deployment of Embedded Software

Life Cycle Optimization

Information for future modules/upgrades

Evolution of Mechatronics as a Contemporary Design Paradigm

- Technological advances in design, manufacturing, and operation of engineered products/devices/processes can be traced through:

  - Industrial revolution

  - Semiconductor revolution

  - Information revolution

Industrial Revolution

- Allowed design of products and processes for energy conversion and transmission thus allowing the use of energy to do useful work.

- Engineering designs of this era were largely mechanical

  - e.g., operations of motion transmission, sensing, actuation, and computation were performed using mechanical components such as cams, gears, levers, and linkages).

- Purely mechanical systems suffer from

  - Power amplification inability.

  - Energy losses due to tolerances, inertia, and friction.

Examples of Predominantly Mechanical Designs

Hollow ball
Lever
Water input
Pivot

Float Valve

A flat gives switch open
Cam
Curved part gives switch closed
Switch contacts

Rotation of the cam closing the switch contacts

Cam Operated Switch

Metal with lower expansivity
Bends upwards as temperature increases
Metal with higher expansivity

Bi-metallic Strip

Watt's Governor

To heater circuit
Bimetallic strip
Iron-nickel alloy
Insulator
X
Y
Brass
Electrical contacts
Temperature setting dial
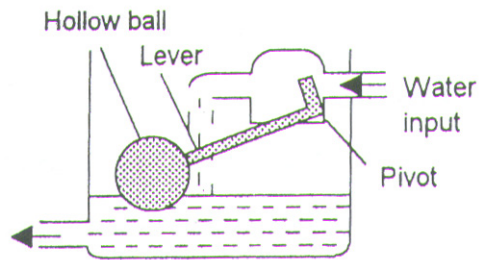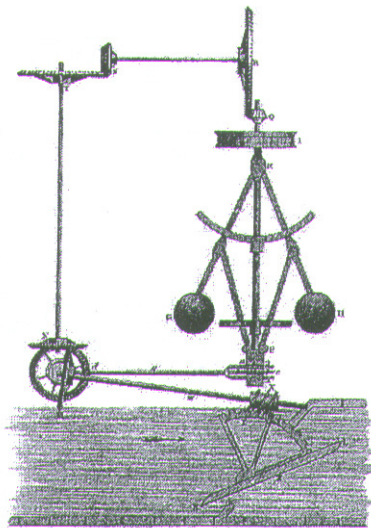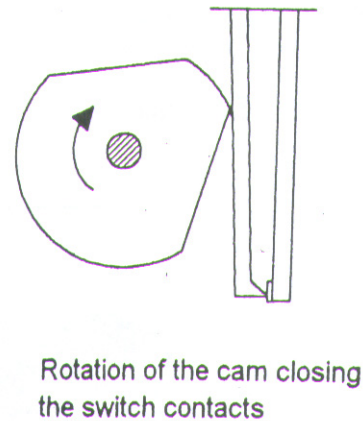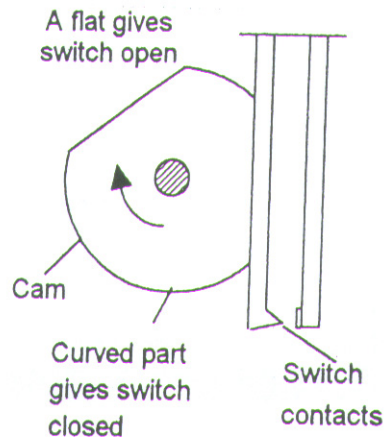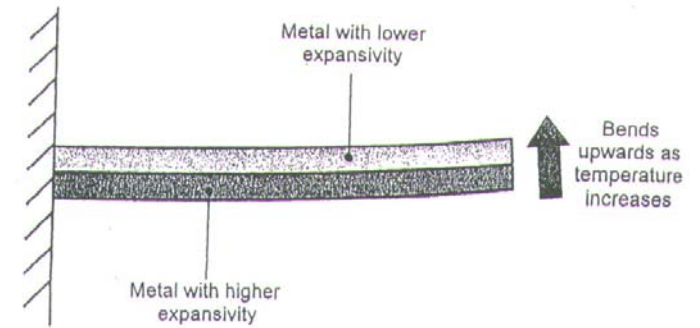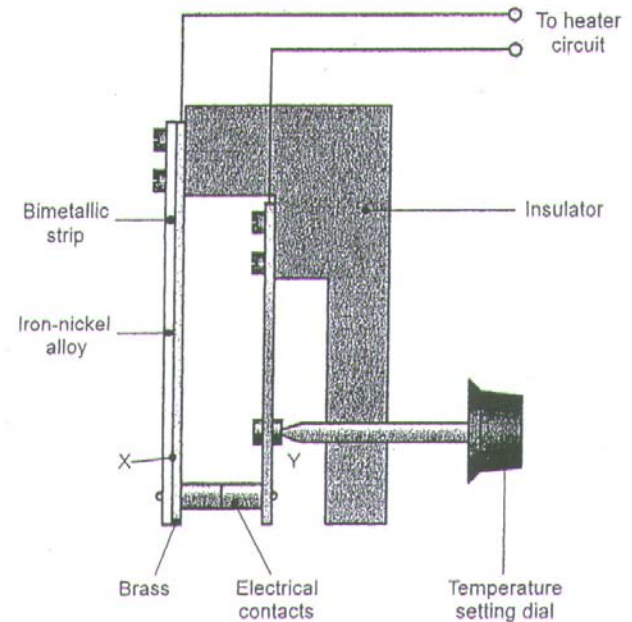
Thermostat

Semiconductor Revolution

- Led to the creation of integrated circuit (IC) technology.

- Effective, miniaturized, power electronics could amplify and deliver needed amount of power to actuators.

- Signal conditioning electronics could filter and encode sensory data in analog/digital format.

- Hard-wired, on-board, discrete analog/digital ICs provided rudimentary computational and decision-making circuits for control of mechanical devices.
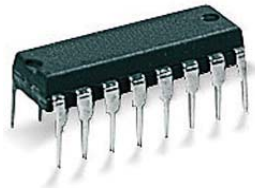
An Integrated Circuit   An A2D Converter   An Operational Amplifier
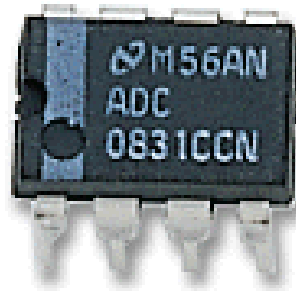
Information Revolution

- Development of VLSI technology led to the introduction of microprocessor, microcomputer, and microcontroller.

- Now computing hardware is ubiquitous, cheap, and small.

- As computing hardware can be effortlessly interfaced with real world electromechanical systems, it is now routinely embedded in engineered products/processes for decision-making.

  - Microcontrollers are replacing precision mechanical components, e.g., precision-machined camshaft that in many applications functions as a timing device.

  - Programmability of microcontrollers is providing a versatile and flexible alternative to the hard-wired analog/digital computational hardware.

  - Integrated computer-electrical-mechanical devices are now capable of converting, transmitting, and processing both the *physical energy* and the *virtual energy* (information).

- Result: Highly efficient products and processes are now being developed by judicious selection and integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software.

Mechatronics Revolution: Example

Linear Positioner

Cam Rotating Motor

Grinding Wheel Motor

Cam

Grinding Wheel
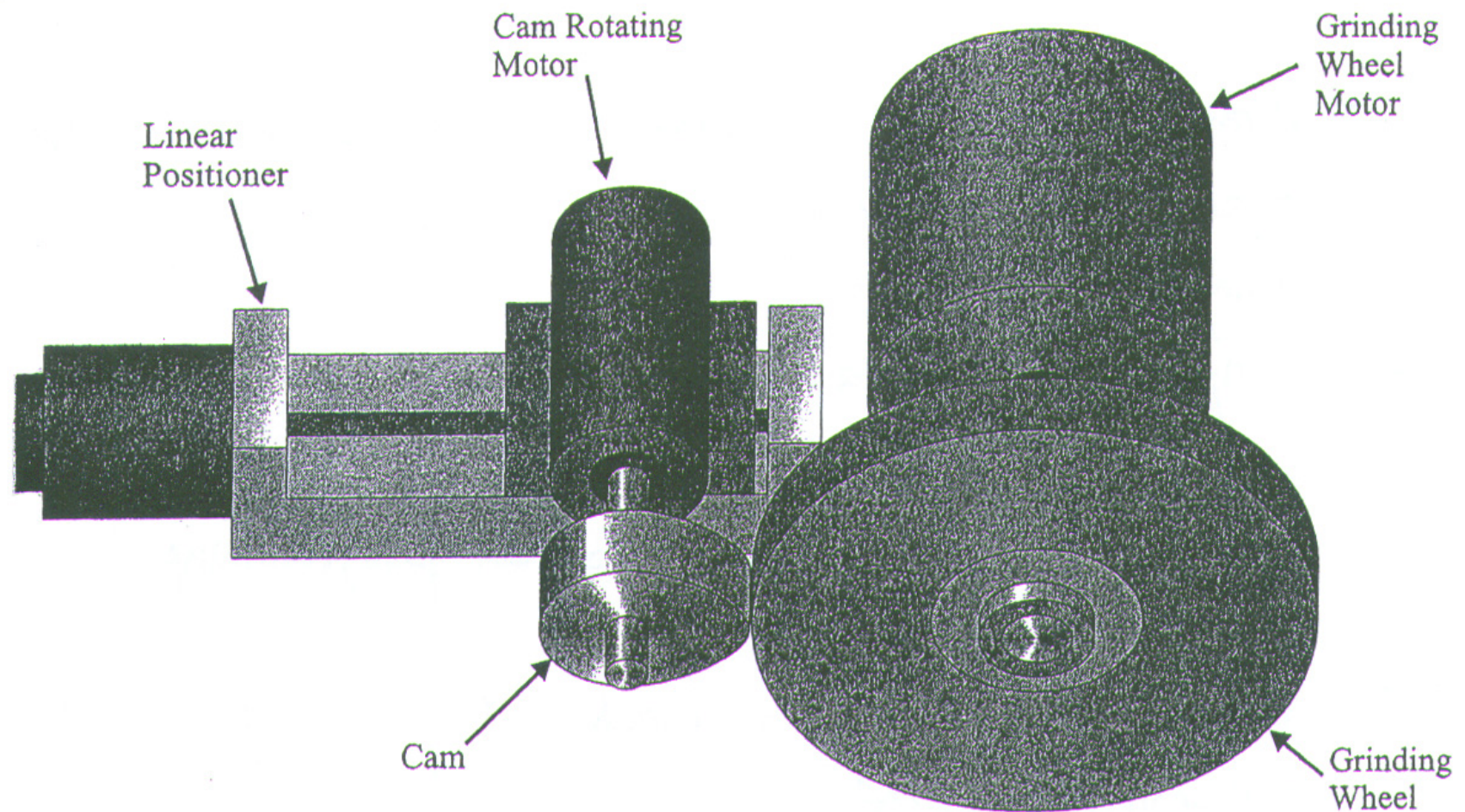
Masterless Cam Grinder

Elements of Mechatronics—Mechanical

- Mechanical elements refer to

  - mechanical structure, mechanism, thermo-fluid, and hydraulic aspects of a mechatronics system.

- Mechanical elements may include static/dynamic characteristics.

- A mechanical element interacts with its environment purposefully.

- Mechanical elements require physical power to produce motion, force, heat, etc.

Machine Components: Basic Elements
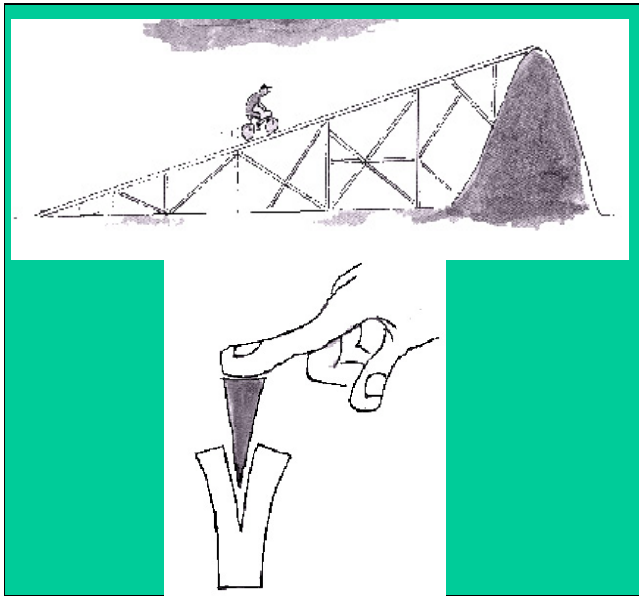
Gear, rack, pinion, etc.

Cam and Follower

Inclined plane wedge
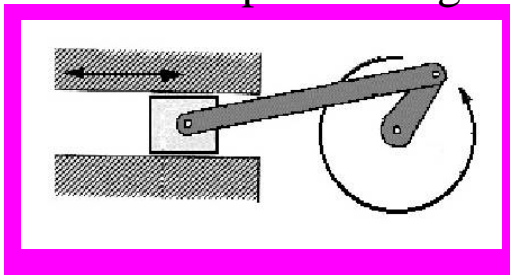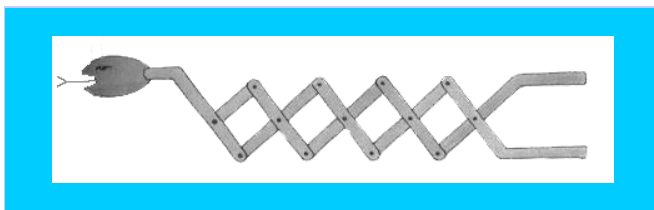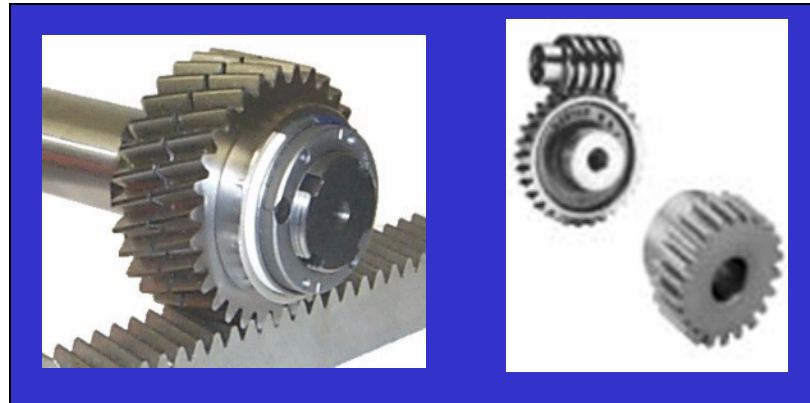
Chain and sprocket

Lever

Slider-Crank

Linkage
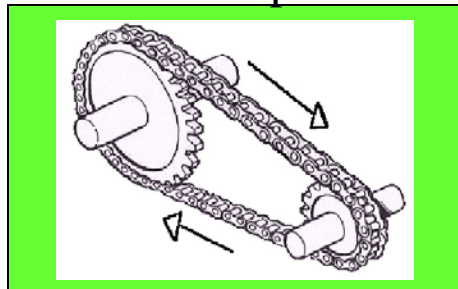
Wheel/Axle

Springs

Elements of Mechatronics—Electromechanical

- Electromechanical elements refer to:

  – Sensors

    - A variety of physical variables can be measured using sensors, e.g., light using photo-resistor, level and displacement using potentiometer, direction/tilt using magnetic sensor, sound using microphone, stress and pressure using strain gauge, touch using micro-switch, temperature using thermistor, and humidity using conductivity sensor

  – Actuators

    - DC servomotor, stepper motor, relay, solenoid, speaker, light emitting diode (LED), shape memory alloy, electromagnet, and pump apply commanded action on the physical process

- IC-based sensors and actuators (digital-compass, -potentiometer, etc.).

Flexiforce Sensor
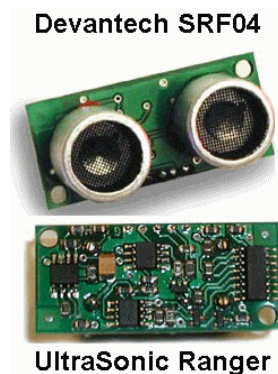
UltraSonic Ranger

DC Motor

Pneumatic Cylinder

Elements of Mechatronics—Electrical/Electronic

- Electrical elements refer to:

  – Electrical components (e.g., resistor (R), capacitor (C), inductor (L), transformer, etc.), circuits, and analog signals

- Electronic elements refer to:

  – analog/digital electronics, transistors, thyristors, opto-isolators, operational amplifiers, power electronics, and signal conditioning

- The electrical/electronic elements are used to interface electro-mechanical sensors and actuators to the control interface/computing hardware elements

Elements of Mechatronics—Control Interface/Computing Hardware

- Control interface/computing hardware elements refer to:

  - Analog-to-digital (A2D) converter, digital-to-analog (D2A) converter, digital input/output (I/O), counters, timers, microprocessor, microcontroller, data acquisition and control (DAC) board, and digital signal processing (DSP) board

- Control interface hardware allows analog/digital interfacing

  - communication of sensor signal to the control computer and communication of control signal from the control computer to the actuator

- Control computing hardware implements a control algorithm, which uses sensor measurements, to compute control actions to be applied by the actuator.
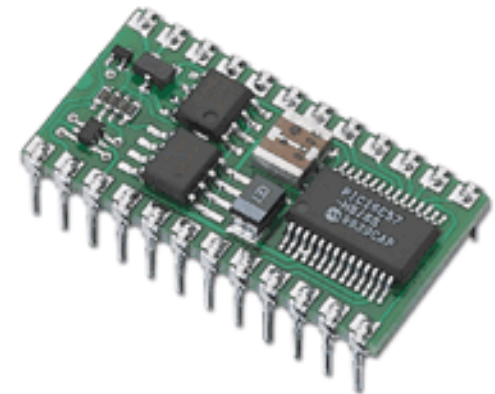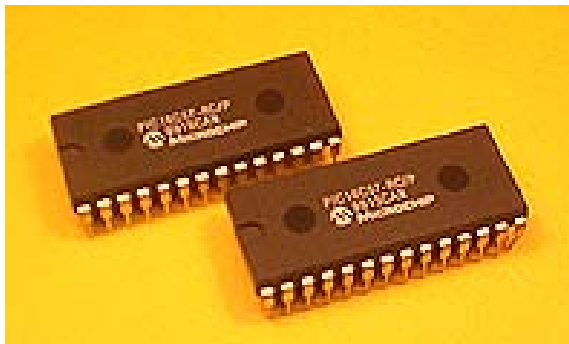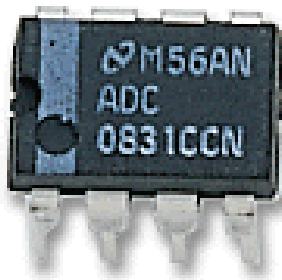
Elements of Mechatronics— Computer/Information System

- Computer elements refer to hardware/software utilized to perform:

  - computer-aided dynamic system analysis, optimization, design, and simulation

  - virtual instrumentation

  - rapid control prototyping

  - hardware-in-the-loop simulation

  - PC-based data acquisition and control
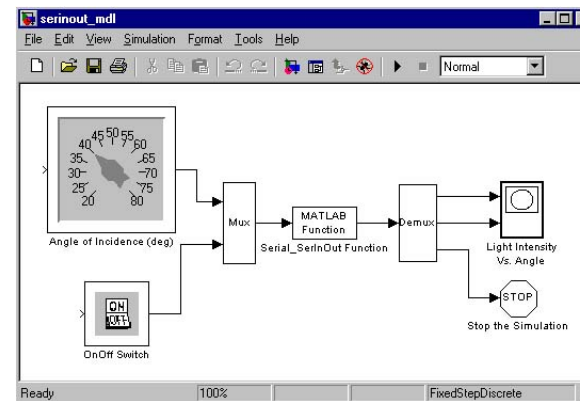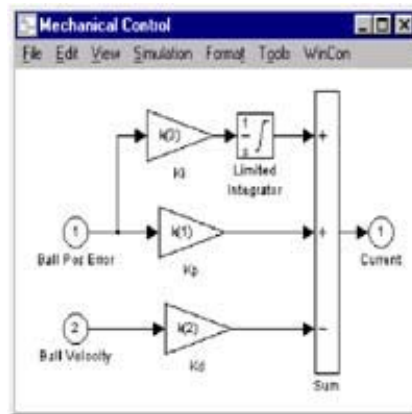
Elements of Mechatronics

- Typical knowledgebase for optimal design and operation of mechatronic systems comprises of:
  - Dynamic system modeling and analysis
    - Thermo-fluid, structural, hydraulic, electrical, chemical, biological, etc.
  - Decision and control theory
  - Sensors and signal conditioning
  - Actuators and power electronics
  - Data acquisition
    - A2D, D2A, digital I/O, counters, timers, etc.
  - Hardware interfacing
  - Rapid control prototyping
  - Embedded computing

Balance theory, simulation, hardware, and software

Key Elements of Mechatronics
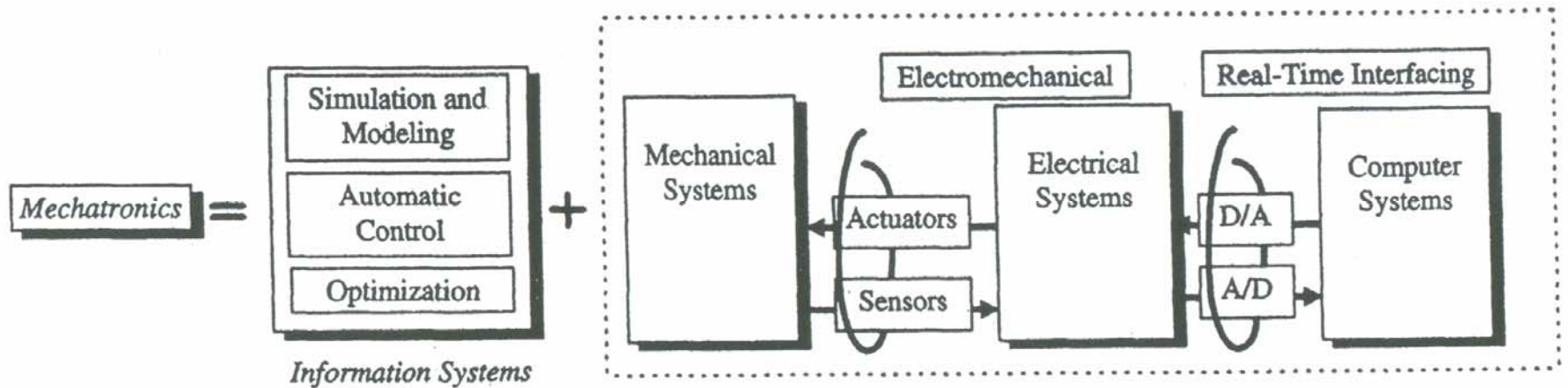
Mechatronics Applications

- Smart consumer products: home security, camera, microwave oven, toaster, dish washer, laundry washer-dryer, climate control units, etc.

- Medical: implant-devices, assisted surgery, haptic, etc.

- Defense: unmanned air, ground, and underwater vehicles, smart munitions, jet engines, etc.

- Manufacturing: robotics, machines, processes, etc.

- Automotive: climate control, antilock brake, active suspension, cruise control, air bags, engine management, safety, etc.

- Network-centric, distributed systems: distributed robotics, tele-robotics, intelligent highways, etc.

Structural Control

With vibration control system

Earthquake or wind induced shaking can be reduced and vibration can be dissipated quickly.

TMD-RP or AMD
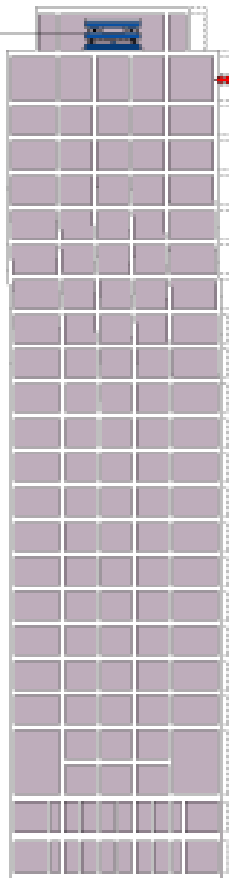
Without vibration control system

Motion induced by earthquake or wind is amplified and vibration is reduces only marginally.
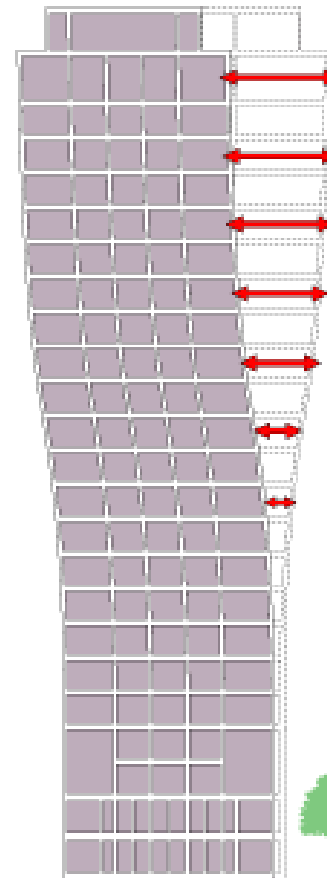
Home Automation

- Using a computer:
  - Turn on the lights at preset times
  - Adjust brightness
  - Turn on the heat at preset times or temperatures
  - Serve as a security system

Robotics

Mechatronics @ Poly

http://mechatronics.poly.edu/

Mechatronics @ Polytechnic UNIVERSITY
CELEBRATING 150 YEARS IN BROOKLYN
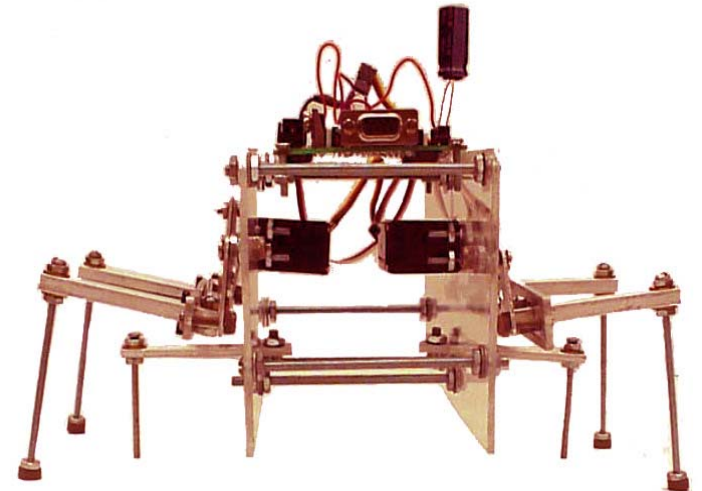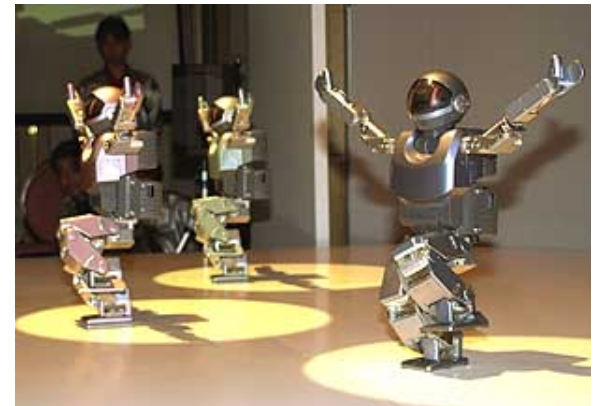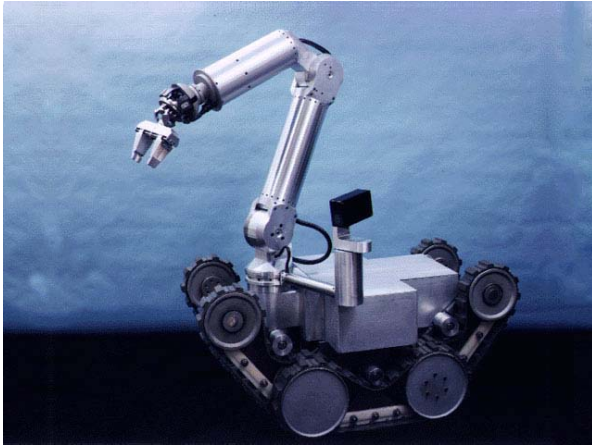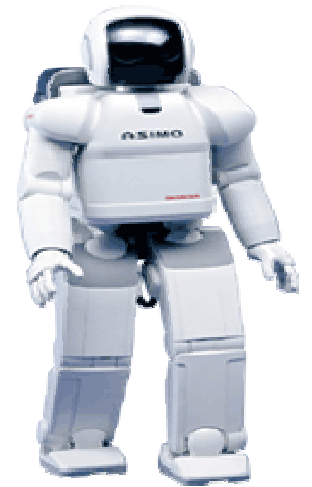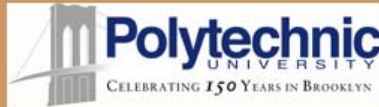
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The exciting field of mechatronics-increasingly recognized as a contemporary, integrative design methodology-is serving as a vehicle to engage and stimulate the interest of Polytechnic students in hands-on, interdisciplinary, collaborative learning. Mechatronics is a synergistic integration of mechanical engineering, control theory, computer science, and electronics to manage complexity, uncertainty, and communication in engineered systems. The typical knowledgebase for the optimal design and operation of mechatronics and smart systems comprises of system modeling and analysis, decision and control theory, sensors and signal conditioning, actuators and power electronics, hardware interfacing, rapid control prototyping, and embedded computing. The relevant technology applications of mechatronics include medical, defense, manufacturing, robotics, automotive, and distributed systems and smart consumer products. This web site is aimed at students, educators, and engineers interested in learning, practicing, and promoting the fascinating discipline of mechatronics. Here you will find ongoing mechatronics related educational, research, and outreach activities being undertaken by Polytechnic faculty and students.
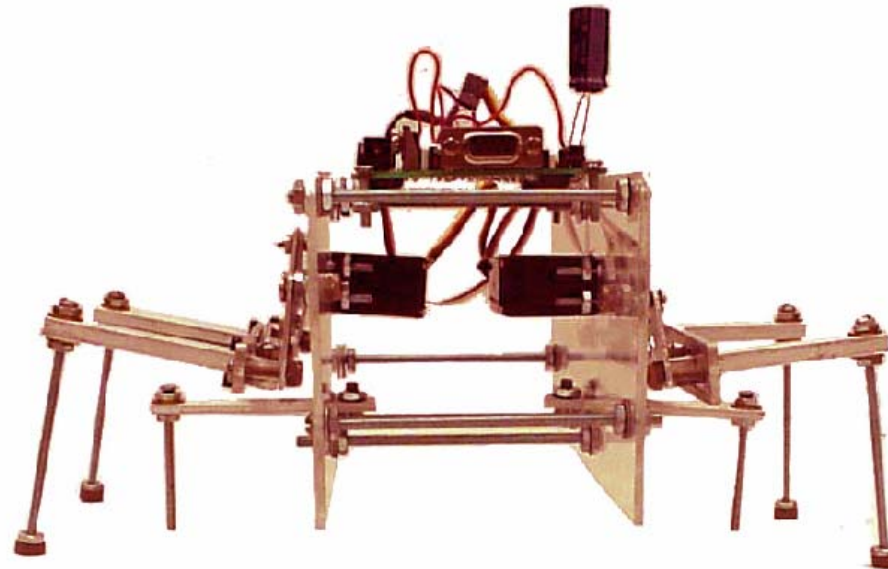
Six-legged Robot

Mechatronics @ Poly

CSS: Service

Outreach