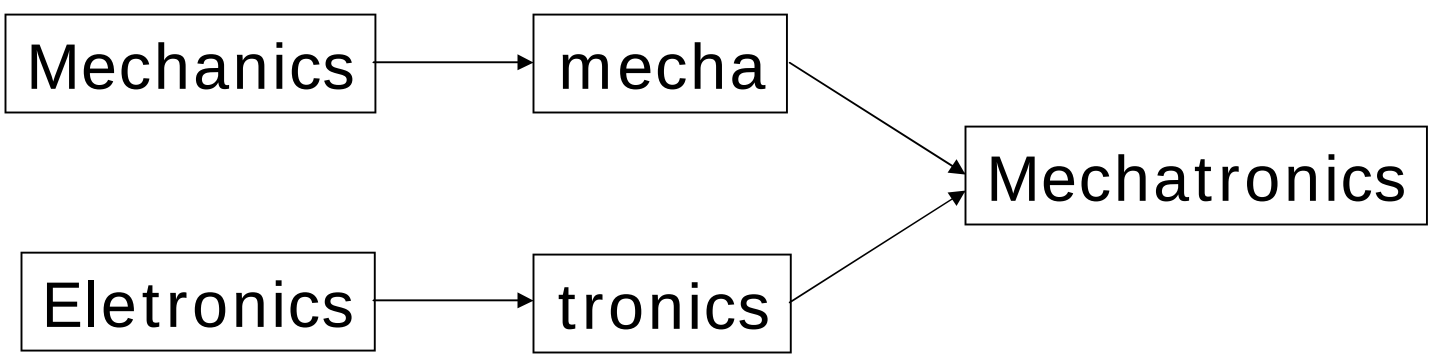
Intro to Mechatronics

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.



Mechatronics Defined — II

- "Integration of electronics, control engineering, and mechanical engineering."
  - W. Bolton, *Mechatronics: Electronic Control Systems in Mechanical Engineering*, Longman, 1995.
- "Application of complex decision making to the operation of physical systems."
  - D. M. Auslander and C. J. Kempf, *Mechatronics: Mechanical System Interfacing*, Prentice-Hall, 1996.
- "Synergistic integration 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.

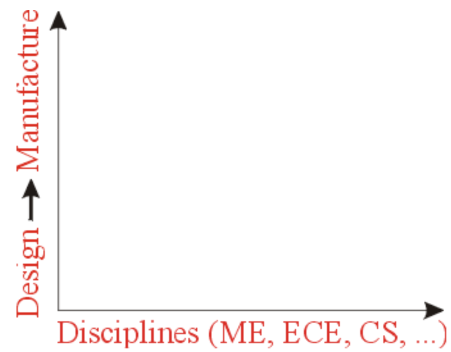
Mechatronics Defined — III

- "Synergistic use of precision engineering, control theory, computer science, and sensor and actuator technology to design improved products and processes."
  - S. Ashley, "Getting a hold on mechatronics," *Mechanical Engineering*, 119(5), 1997.
- "Methodology used for the optimal design 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.

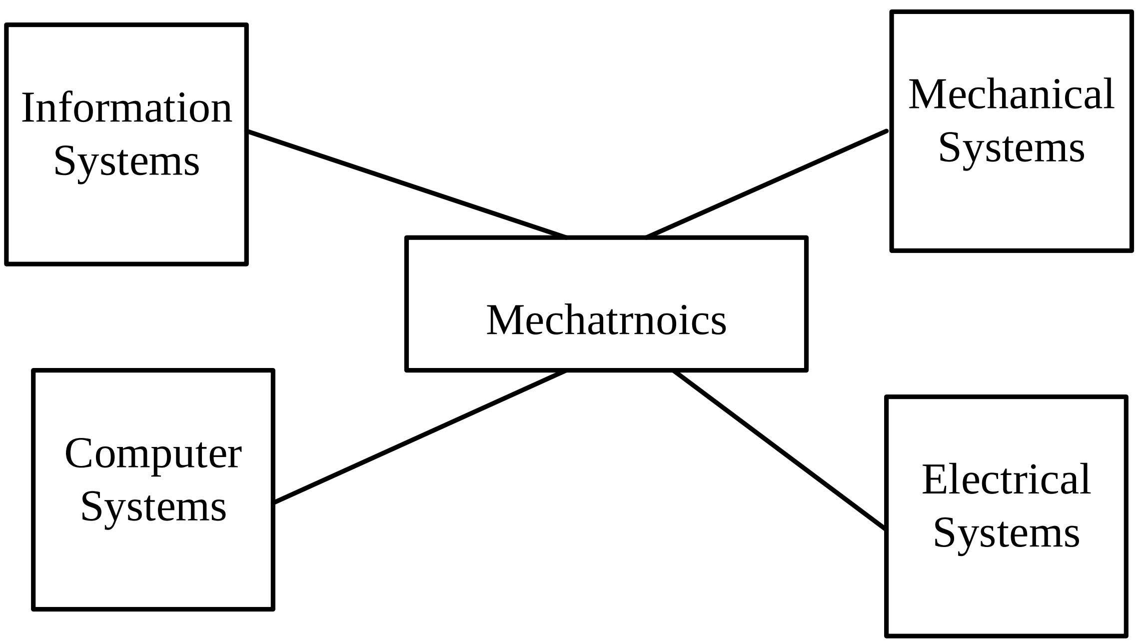
Product Realization Paradigm



- 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.

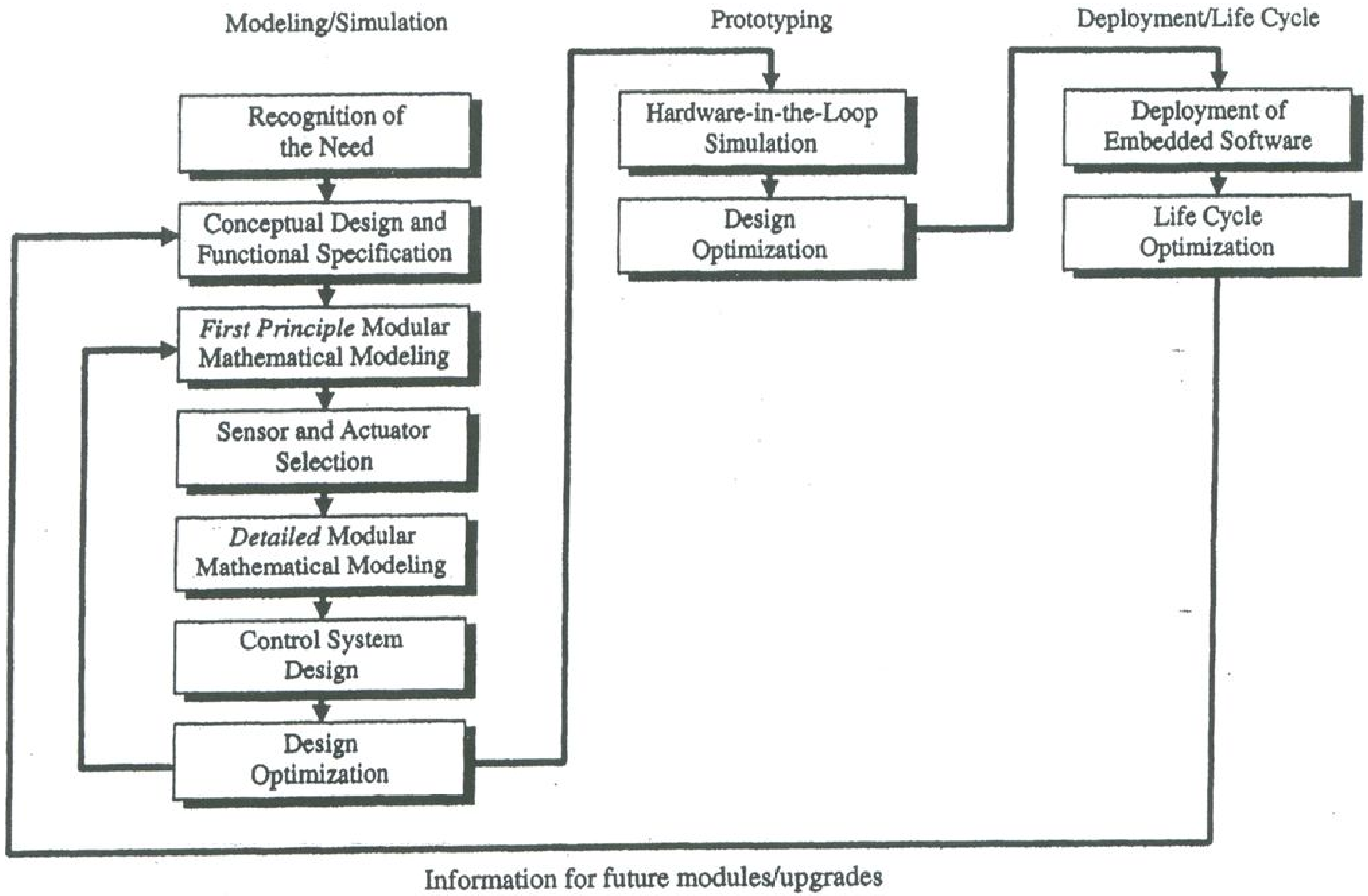
Sequential/Concurrent Product Realization

- 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



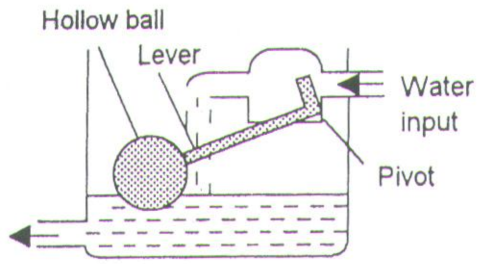
Evolution of Mechatronics as a Contemporary Design Paradigm

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

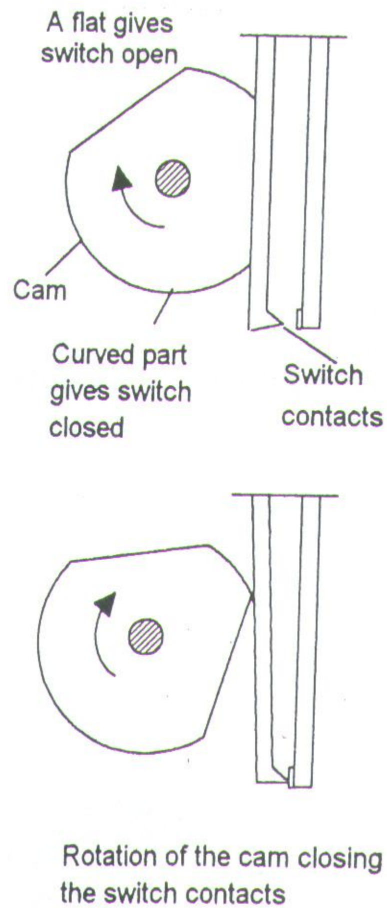
Industrial Revolution

- 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.

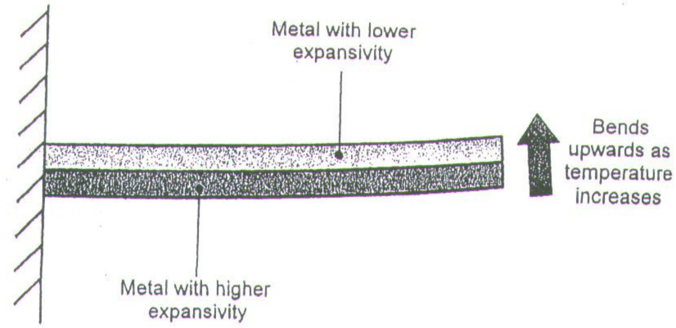
Examples of Predominantly Mechanical Designs



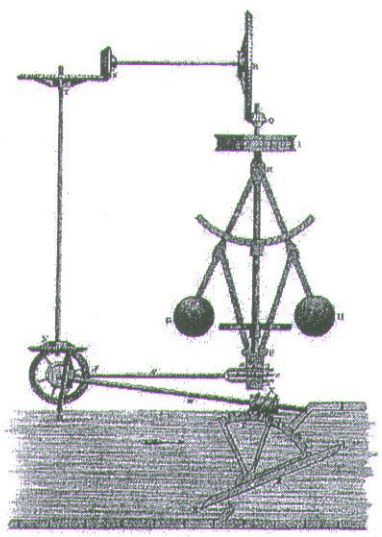
Float Valve



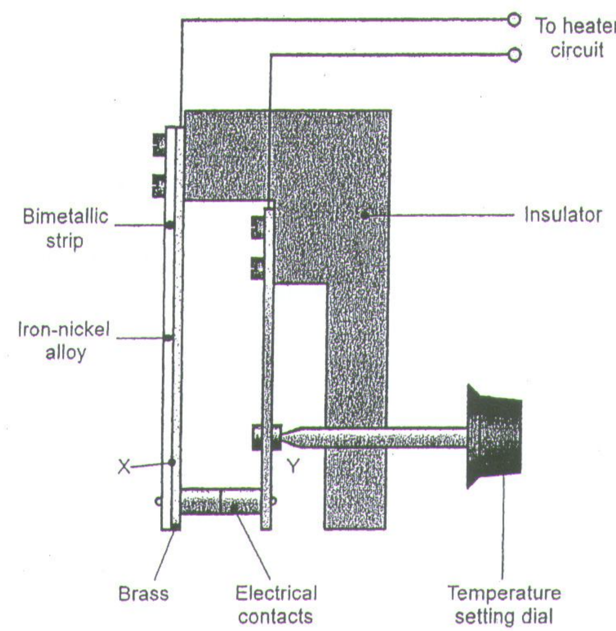
Cam Operated Switch



Bi-metallic Strip



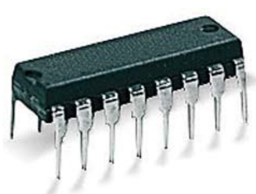
Watt's Governor



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

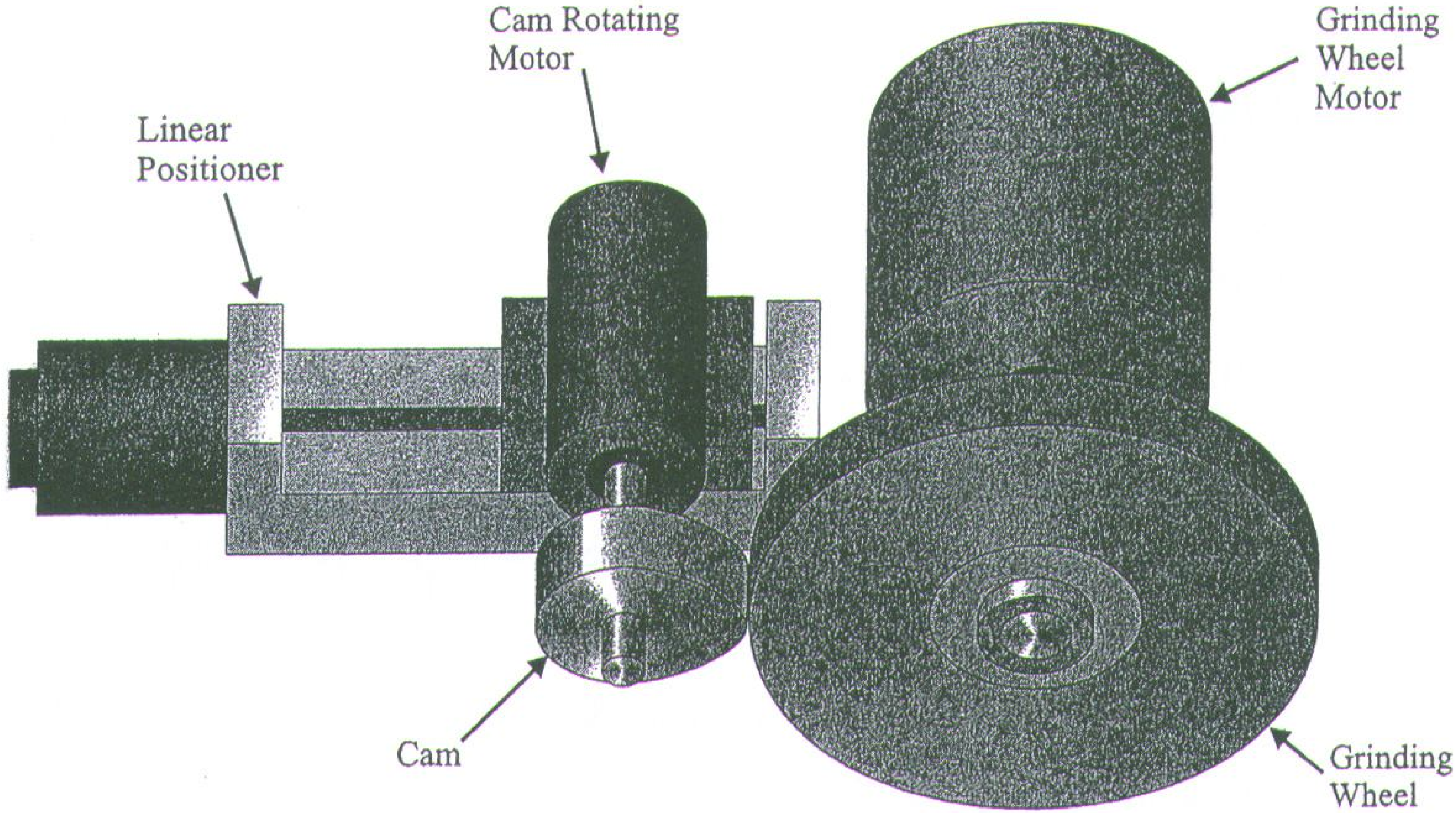
An A2D Converter

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

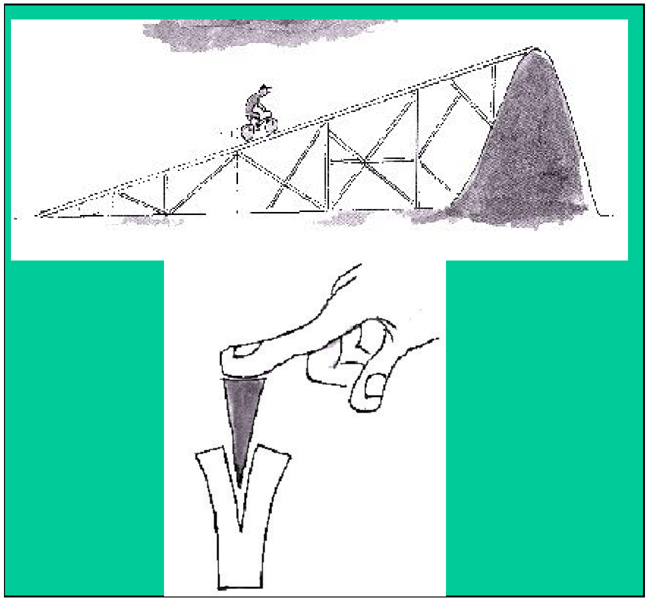


Masterless Cam Grinder

Elements of Mechatronics—Mechanical

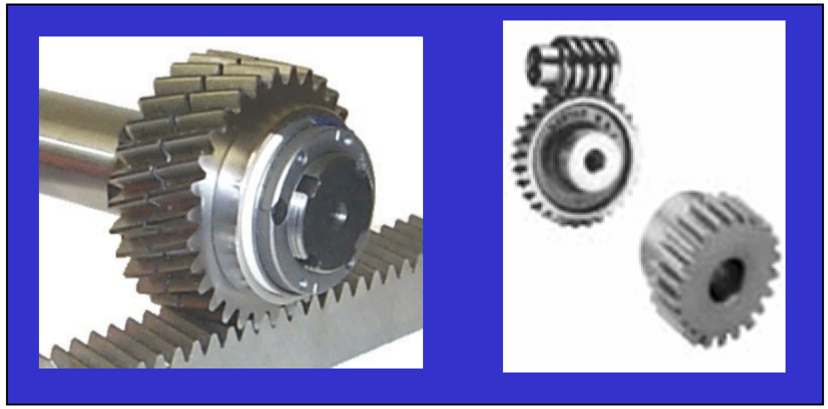
- Mechanical elements refer to
  - mechanical structure, mechanism, thermo-fluid, and hydraulic aspects of a mechatronics system.
- Mechanical elements may include static/dynamic characteristics.
- A mechanical element interacts with its environment purposefully.
- Mechanical elements require physical power to produce motion, force, heat, etc.

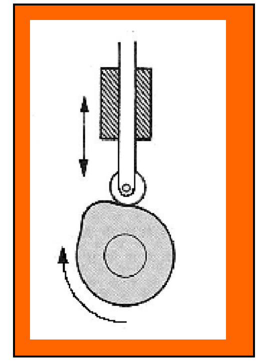
Machine Components: Basic Elements



Inclined plane wedge

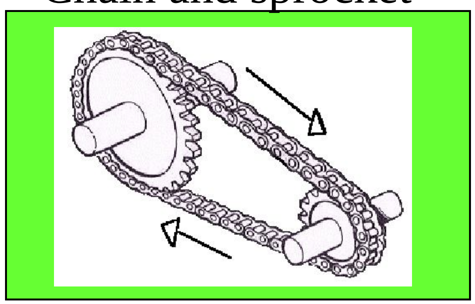
Gear, rack, pinion, etc.

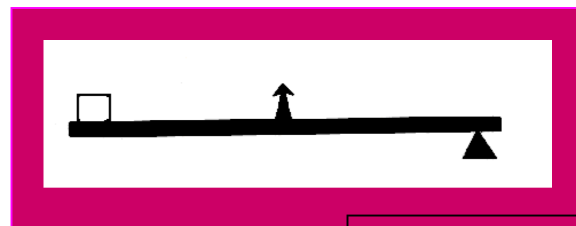




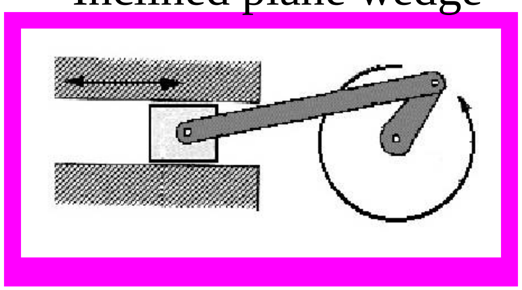
Cam and Follower

Chain and sprocket

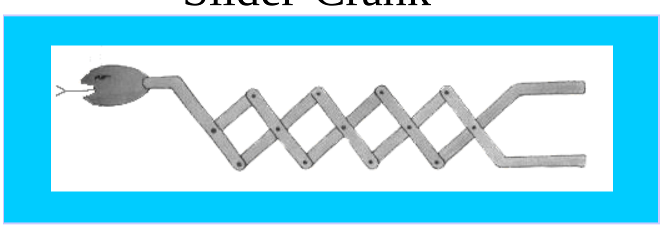




Lever



Slider-Crank



Linkage

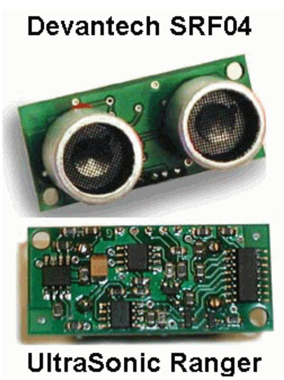
Wheel/Axle

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

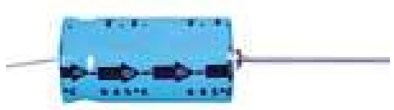


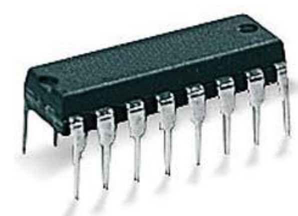
DC Motor

Pneumatic Cylinder

Elements of Mechatronics—Electrical/Electronic

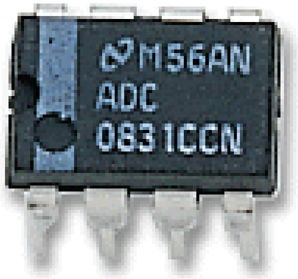
- Electrical elements refer to:
  - Electrical components (e.g., resistor (R), capacitor (C), inductor (L), transformer, etc.), circuits, and analog signals
- Electronic elements refer to:
  - analog/digital electronics, transistors, thyristors, opto-isolators, operational amplifiers, power electronics, and signal conditioning
- The electrical/electronic elements are used to interface electro-mechanical sensors and actuators to the control interface/computing hardware elements

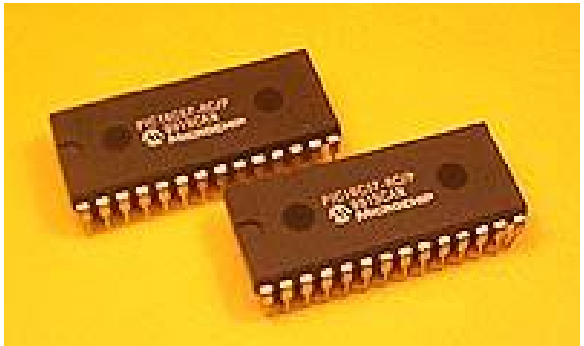
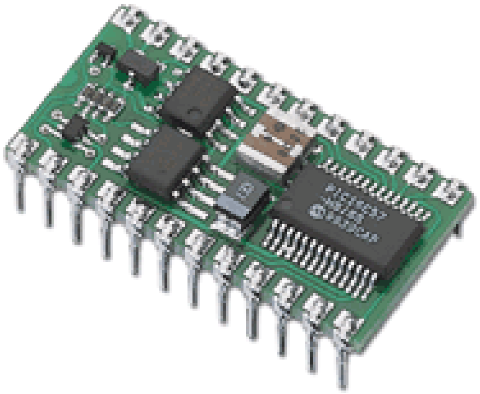




Elements of Mechatronics—Control Interface/Computing Hardware

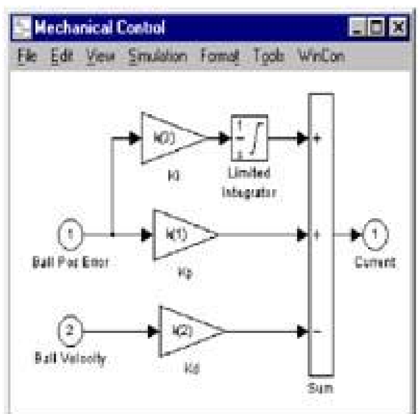
- Control interface/computing hardware elements refer to:
  - Analog-to-digital (A2D) converter, digital-to-analog (D2A) converter, digital input/output (I/O), counters, timers, microprocessor, microcontroller, data acquisition and control (DAC) board, and digital signal processing (DSP) board
- Control 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.

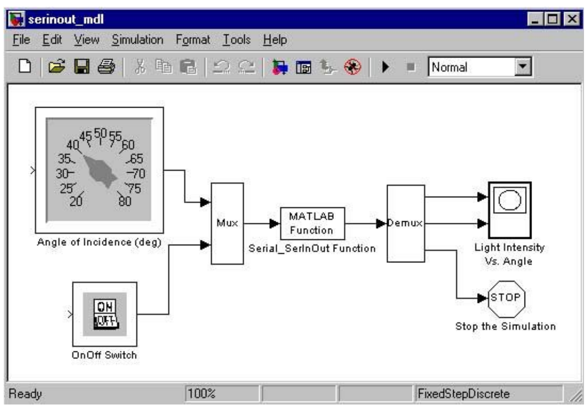


Elements of Mechatronics—Computer/Information System

- 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



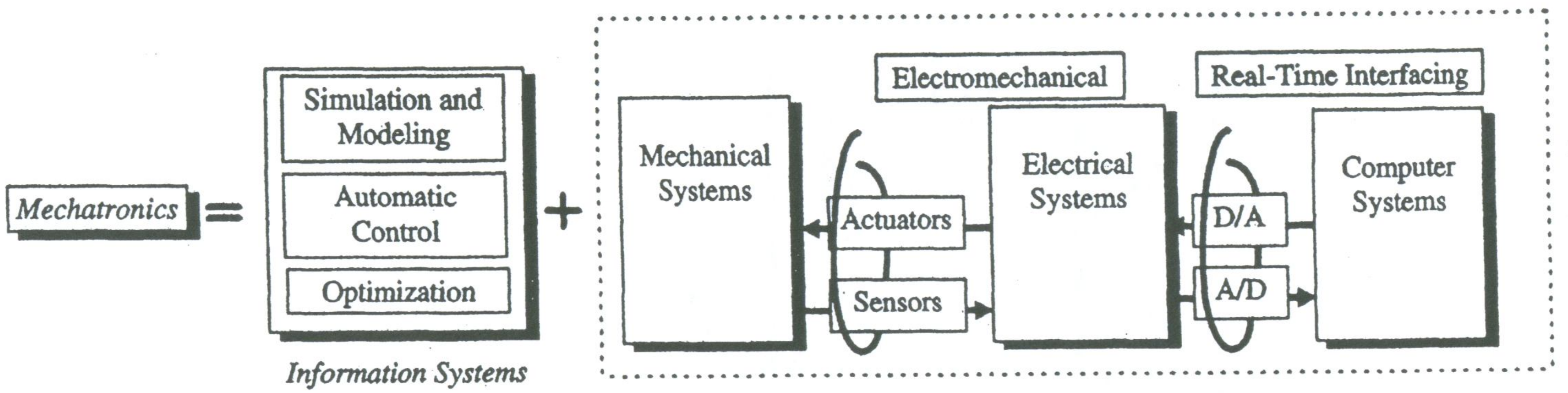


Elements of Mechatronics

- 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

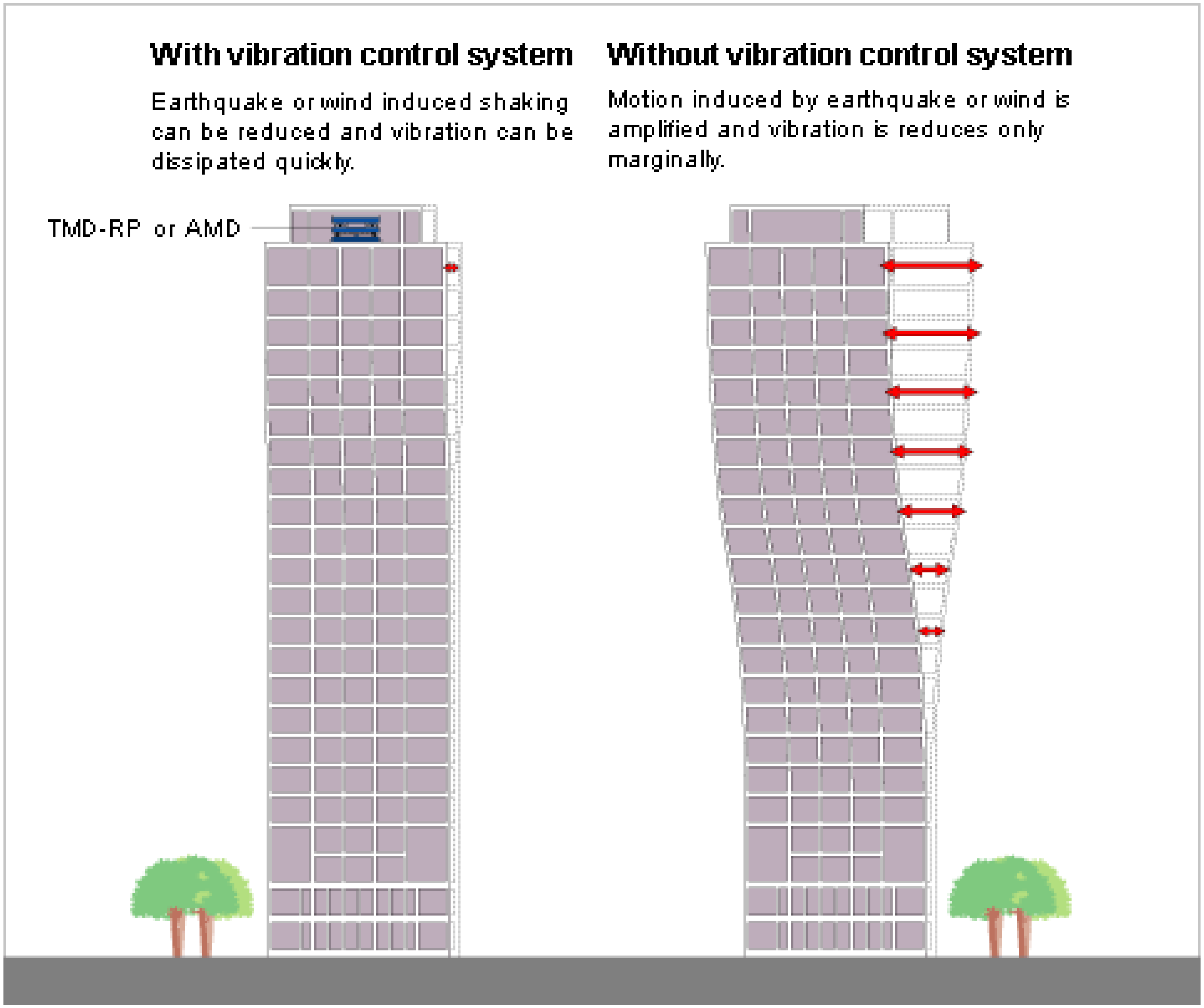
Key Elements of Mechatronics



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.

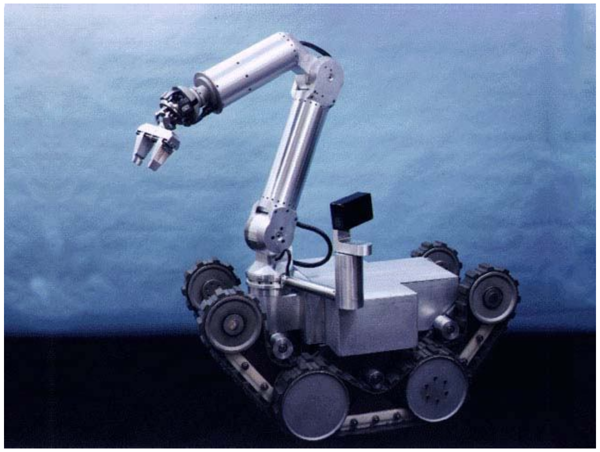
Structural Control

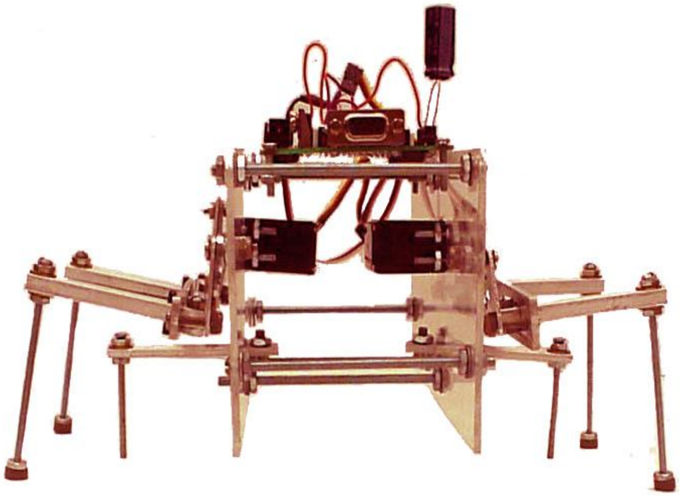


Home Automation

- 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 systen

Robotics





Mechatronics @ Poly

http://mechatronics.poly.edu/

Mechatronics @ Polytechnic University — Celebrating 150 Years in Brooklyn

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.

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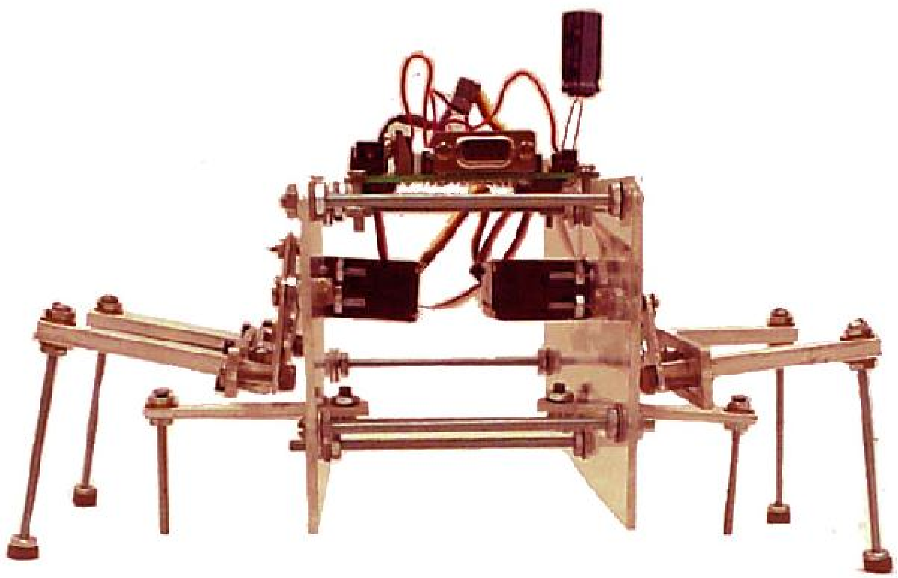


Six-legged Robot

Mechatronics @ Poly

CSS: Service

Outreach

FEATURE

Science and Mechatronics-Aided Research for Teachers

The “SMART” program provides teachers with training and workshops

“Smart” Teachers

Mr. Richard Balsamel of Science High School, Newark, NJ, raised over US$4,000 from his school district for mechatronics kits and supplies and began a mechatronics research club. In addition, he is introducing mechatronics in his physics classes by integrating four sample activities for students. Mr. David Deutsch of Manhattan Center for Science and Math High School, New York, NY, has raised over US$3,000 from his school and the Children’s Aid Society for mechatronics and robotics kits. He is training students in an after-school mechatronics club. Mr. Paul Friedman of Seward Park High School, New York, NY, has raised over US$1,500 from his school’s alumni association for robotics kits. He has partnered with a colleague to train students in an after-school program. Mr. Robert Gandolfo of Plainedge High School, North Massapequa, NY, reported on his SMART experience in his school district newspaper [12]. Mr. William Leacock of W. C. Mepham High School, Bellmore, NY, received a US$1,500 minigrant from his school district for mechatronics kits. Every other day, during a single class period of AP physics, he teaches a short lesson introducing his students to a hands-on activity planned for a double class period the following day. Mr. Leacock wrote the following to us: “The students are enjoying it so much that, even though I allow them a break in between the double periods, almost all of them stay and work right through the break. It is wonderful to see them learn and enjoy themselves so much.” Mr. Michael McDonnell of Midwood High School, Brooklyn, NY, used over US$5,000 funding from his school to obtain robotics kits and taught robotics to over 200 students in the Fall of 2003 and Spring of 2004 through robotics and advanced robotics courses. Furthermore, with colleagues, he applied for and received a three-year US$300,000 grant from his school district under the Vocational and Technical Education Act (VATEA). The VATEA grant will enable him to develop and implement a four-year robotics curriculum in his school. Finally, Ms. Marlene McGarrity of the Christa McAuliffe School, Brooklyn, NY, raised over US$1,500 for a project titled “Young Engineers are Made in Brooklyn Through Robotics and Mechatronics,” through an online grant agency. From this grant, she obtained wheeled robots and Mars rover kits, and is using these in her seventh-grade classroom. She also wrote an article [13] on her SMART experience.

This month’s book reviews include a critique of Isermann’s *Mechatronic System Fundamentals*. This review begins with a brief overview of the history of mechatronics from the industrial revolution through the present day. We also bring you reviews of books on important topics in control, namely, *Fundamentals of Adaptive Filtering* by Sayed and *Constrained Estimation and Control* by Goodwin, Seron, and Dona. Finally, the feature article by Åström, Klein, and Lennartsson on bicycle dynamics and control is complemented by a review of *Bicycling Science* by Wilson and Papadopoulos.

As usual, I welcome your comments and suggestions for future books that we might consider for review. I can be reached at:

Kirsten Morris
Department of Applied Mathematics
University of Waterloo
Waterloo, Ontario N2L 3G1 Canada
E-mail: kmorris@uwaterloo.ca

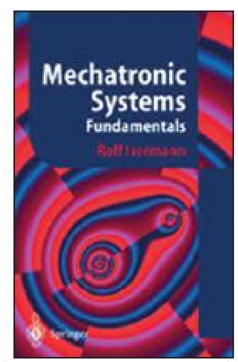
Mechatronic Systems Fundamentals by Rolf Isermann, Springer, 2003, 624 pp., ISBN 1-85233-693-5, US$124. *Reviewed by Vikram Kapila.*

Mechatronics as a Design Paradigm

Mechatronics is the synergistic integration of mechanical engineering, control theory, computer science, and electronics to manage complexity, uncertainty, and communication in engineered systems. Mechatronics is increasingly being recognized as a contemporary, integrative design methodology. The typical knowledge base for the optimal design and operation of mechatronic systems includes 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 technological application areas of mechatronics include medical, defense, manufacturing, robotics, automotive, and smart consumer products. Recently, *Technology Review: MIT’s Magazine of Innovation* identified mechatronics as one of the ten emerging technologies that will change the world [1].

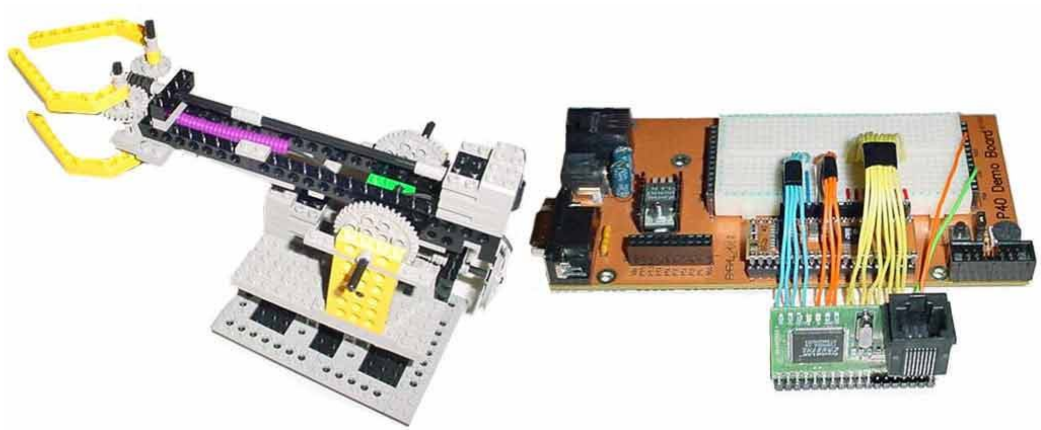
The evolution of mechatronics as a contemporary design paradigm can be viewed as a culmination of the industrial, semiconductor, and information revolutions that have led to major technological advancements in the design and operation of engineering products. Specifically, the industrial revolution enabled the design of products and processes that convert and transmit energy for industrial activities. Engineering designs of that era performed operations of motion transmission, sensing, actuation, and computation using mechanical components like cams, gears, levers, and linkages. Watt’s flywheel governor typifies the engineering designs of this era. Unfortunately, purely mechanical systems suffer from limited power amplification and energy losses due to tolerances, inertia, and friction [2].

Semiconductors led to the development of integrated circuit technology and constituted the next large impact on the design of engineering products. The development of cost-effective, miniaturized power electronics for efficient power amplification then followed. Semiconductor technology thus provided a practical means, through electrical supply, for delivering required levels of power to actuate mechanical devices. Similarly, on the sensing side, semiconductor technology afforded the ability to condition and encode physical measurements as analog/digital signals. Furthermore, hardwired, onboard, analog/digital electronics provided rudimentary computation. Rapid developments in electromechanical sensing and actuation hardware, which began in an earlier era, further fueled the adoption of semiconductor technology in the design and operation of mechanical devices. Now, the design of engineering products and processes had reached a phase where the mechanical device was energetically isolated [3] from the sensing, actuation, and computation operations.



Semiconductor and information technology industries experienced explosive growth in the closing decades of the 20th century. Computing hardware became ubiquitous and cheap, thus setting the stage for a momentous transformation in the design and operation of mechanical devices and systems. Information technology emerged as a technology enabler imparting intelligence to numerous consumer products, industrial processes, and machines. Microprocessors began replacing precision mechanical components. For example, precision-machined camshafts, which in many applications function as timing devices, were replaced by digital timers. In addition, the programmability of microprocessors provided a versatile and flexible alternative to hardwired analog/digital computation. With computation now being implemented as software, the mechanical device, sensors,

Mechatronics @ Poly



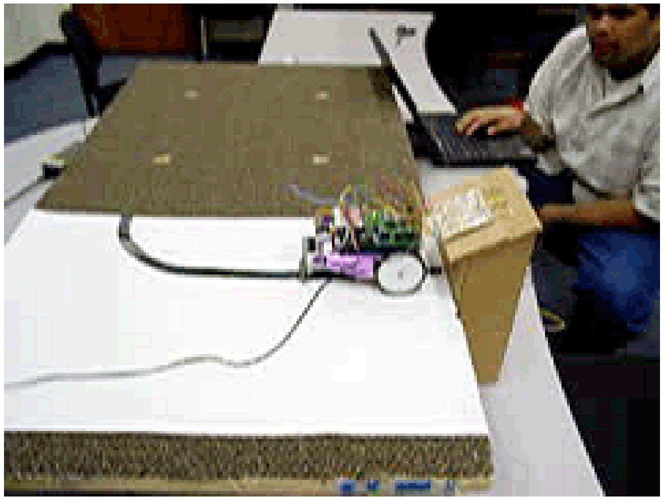
Remote Robot Arm Manipulation

Remote Emergency Notification System

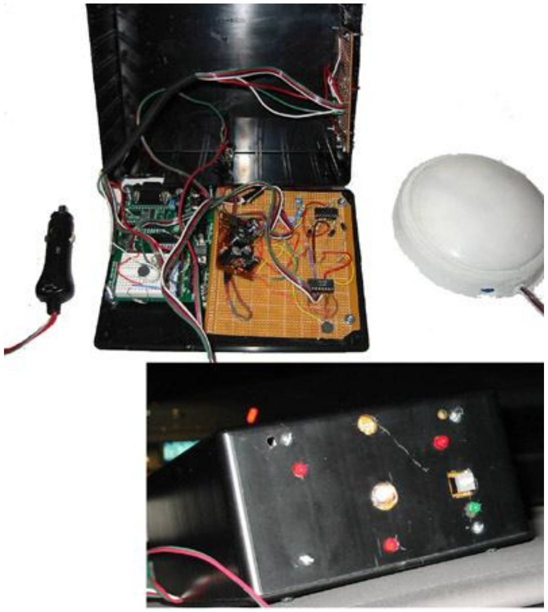
Type X

The Smart Walker

Mechatronics @ Poly



Smart Irrigation System



Safe N Sound Driver

Remote Emergency
Notification System

Smart Cane