Mechatronic System Design: Modeling, Design, and Control Integration

An Introduction

MESB413-Mechanical Engineering Dept.

Current Situation

- Electronics, Microcontrollers, Precision Sensors & Actuators Are Everywhere!
- With the explosively increasing cost/size-effectiveness of computers, mechatronic systems are becoming common in any engineering discipline dealing with the modulation of physical power.
- In mechatronic systems, computing is central.
- What are the aspects of mechatronics that set it apart from other engineering disciplines?

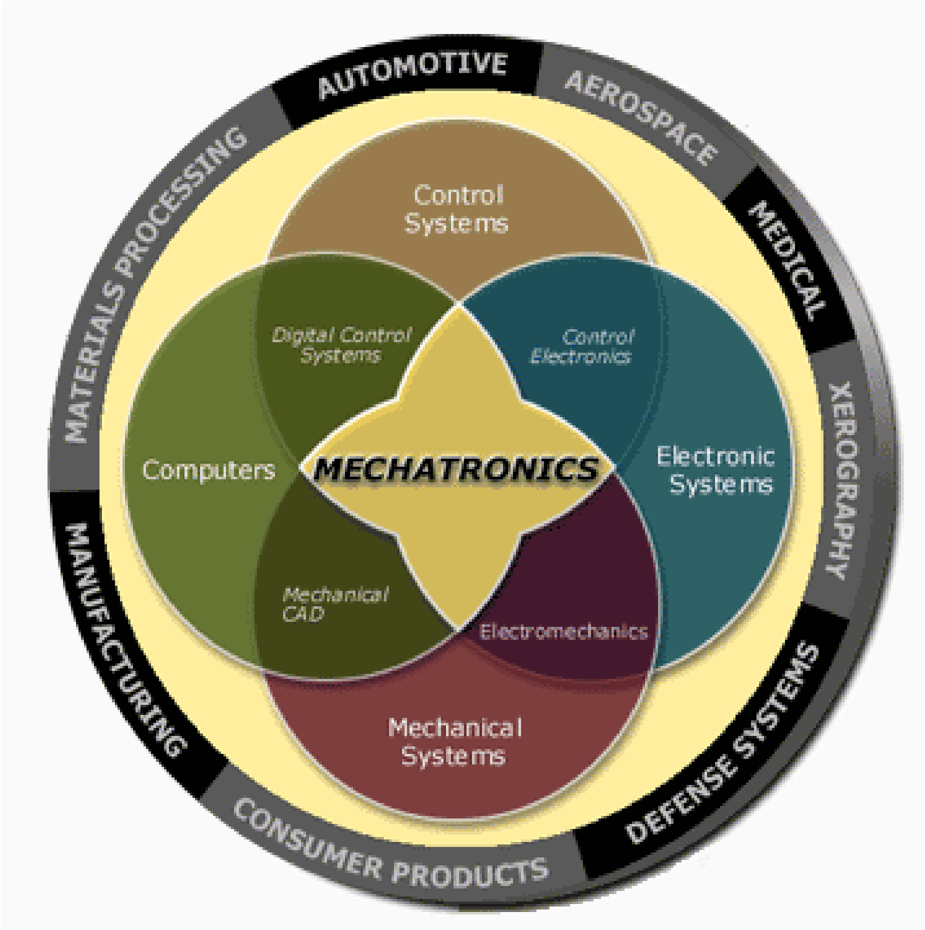
Relevant Questions

What are the Challenges presented to Engineering Educators by the Field of Mechatronics ?

How can a company stay successful in an industry where electronics, computers, and control systems are integral parts of an overall system and performance, reliability, low cost, and robustness are absolutely essential ?

What is Mechatronics?

Mechatronics is the *synergistic* combination of mechanical engineering, electronics, controls engineering, and computers, all *integrated* through the design process. It involves the application of *complex decision making* to the operation of physical systems. Mechatronic systems depend for their unique functionality on computer software.



- The uniqueness associated with mechatronics comes from its exploitation of computation to create systems that are qualitatively unlike any that came before.
- Mechatronics includes many physical systems, not just traditional mechanical systems.
- What is software and how does it fit in? Until very recently, it was not a significant factor.
  - Software is really a medium in itself, independent of implementation.
  - It is the source of unparalleled complexity – for better or worse!
  - Engineering systems with software-based control can work miracles, but the technology also brings risks.

- So Mechatronics includes:
  - *The application of complex decision making to the operation of physical systems. Mechatronic systems depend for their unique functionality on software.*
  - This distinguishes modern mechatronics from earlier attempts at complexity.
  - Practitioners of mechatronics must have the skills and understanding to create and manage the complexity.
- In earlier definitions of mechatronics, decision making was electronically-based (digital and analog), e.g., brushless dc motor with electronic commutation.

- Now computing is the preferred decision-making medium and mechatronics involves a wide variety of physical systems, e.g., manufacturing automation, automotive and aerospace control, process systems, thermal and environmental control, building vibration control, etc.
- The key point is the centrality of decision making and not the means of realizing it, since other technologies could supplement or supplant software algorithmic languages.
- Mechatronics can be applied to existing technologies or can make new technologies possible.

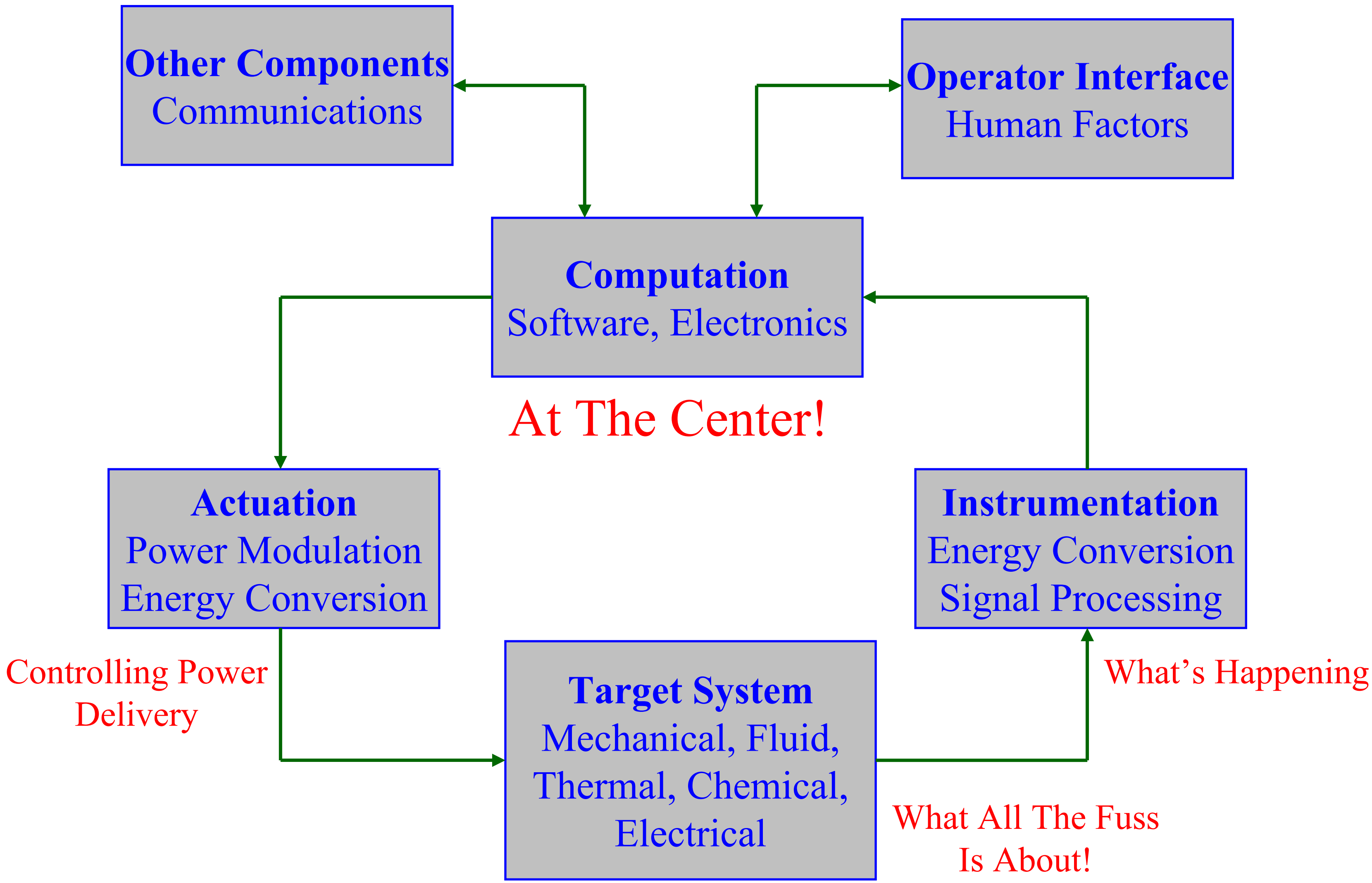
– Examples:
  - Mechatronic automobile engine controls have produced performance improvements.
  - In machine tools with the CNC controller, the entire manufacturing process has been affected and the introduction of mechatronics has resulted in a qualitative improvement.
  - The automated teller machine (ATM) is a technology that is not even conceivable without mechatronics.

- New technologies carry new risks with them!

- The unique factor in mechatronics is its dependence on sophisticated real-time computation to define the nature of the engineering system in which the computation is embedded.
- Successful mechatronic system designs require an organized approach to the design of such software. A focused design methodology must be followed so that conceptualization and documentation of mechatronic software can be done independent of the medium used for its implementation.

Mechatronic System Elements

The 4 Central Components are energetically isolated



- Once isolated from the instruments on one side and the actuators on the other side, computation could be implemented using the most effective computing medium, independent of any needs to pass power through the computational element.
- The medium has been the digital computer and the medium of expression for digital computers is software.
- This ability to isolate is recent.
- In myriads of machines that use linkages, cams, gears, etc., to produce desired motions, computation is tied to measurement and/or actuation.

- Many such systems are being redesigned with software-based controllers with associated improvements in performance, productivity (due to much shorter times needed to change products), and reliability.
- The development of electronic amplification techniques opened the door to mechatronics.
  - Op-Amp based circuits could provide both isolation and generation of a wide variety of linear and nonlinear, static and dynamic computing functions.
  - Developments in power electronics provided the same kind of flexibility and isolation on the actuation side that op-amps provide on the signal side.

- Power electronics gave a means for translating commands computed in electronic form into action.
- Digital electronics added enormously to the range of computational functions that could be realized and also formed the basic technology for implementing computers.
- With the use of computers it is software rather than electronics that represents the medium of expression.
- Although mechatronics based on electronic computing elements opened a new world of mechanical system control, software has extended that world in unimaginable ways.
- Real-Time Software is at the heart of mechatronic systems.

- Real-Time Software
  - Real-time software differs from conventional software in that its results must not only be numerically and logically correct, they must also be delivered at the correct time.
  - Real-time software must embody the concept of duration, which is not part of conventional software.
  - Real-time software used in most mechanical system control is also safety-critical. Software malfunction can result in serious injury and/or significant property damage.
  - Asynchronous operations, which while uncommon in conventional software, are the heart and soul of real-time software.

The Design Challenge

The cost-effective incorporation of electronics, computers, and control elements in mechanical systems requires a new approach to design.

The modern mechanical engineer must draw on the synergy of

Mechatronics.

The Realm of Mechatronics

- High Speed
- High Precision
- High Efficiency
- Highly Robust
- Micro-Miniature

Difficulties in Mechatronic Design

- Requires *System* Perspective
- *System* Interactions Are Important
- Requires *System* Modeling
- Control *Systems* Go Unstable

Mechatronic Design Concepts

- Direct Drive Mechanisms
- Simple Mechanics
- System Complexity
- Accuracy and Speed from Controls
- Efficiency and Reliability from Electronics
- Functionality from Microcomputers

Think System !

Benefits To Industry

Starting at design and continuing through manufacture, mechatronic designs optimize the available mix of technologies to produce quality precision products and systems in a timely manner with features the customer wants.

- Shorter Development Cycles
- Lower Costs
- Increased Quality
- Increased Reliability
- Increased Performance
- Increased Benefits To Customers

Is Mechatronics New?

Mechatronics is simply the application of the latest, cost-effective technology in the areas of computers, electronics, controls, and mechanical systems to the design process to create more functional and adaptable products.

Just Good Design Practice!

Many Forward-Thinking Designers and Engineers have been doing this for years!

There Is Something New Here!

Mechatronics encompasses the knowledge base and the technologies required for the flexible generation of controlled motion.

Mechatronics demands horizontal integration among the various disciplines as well as vertical integration between design and manufacturing.

Mechatronics is a significant design trend – an evolutionary development – a mixture of technologies and techniques that together help in designing better products.

Mechatronics is having a profound influence on the way all mechanical engineers are now expected to design

and

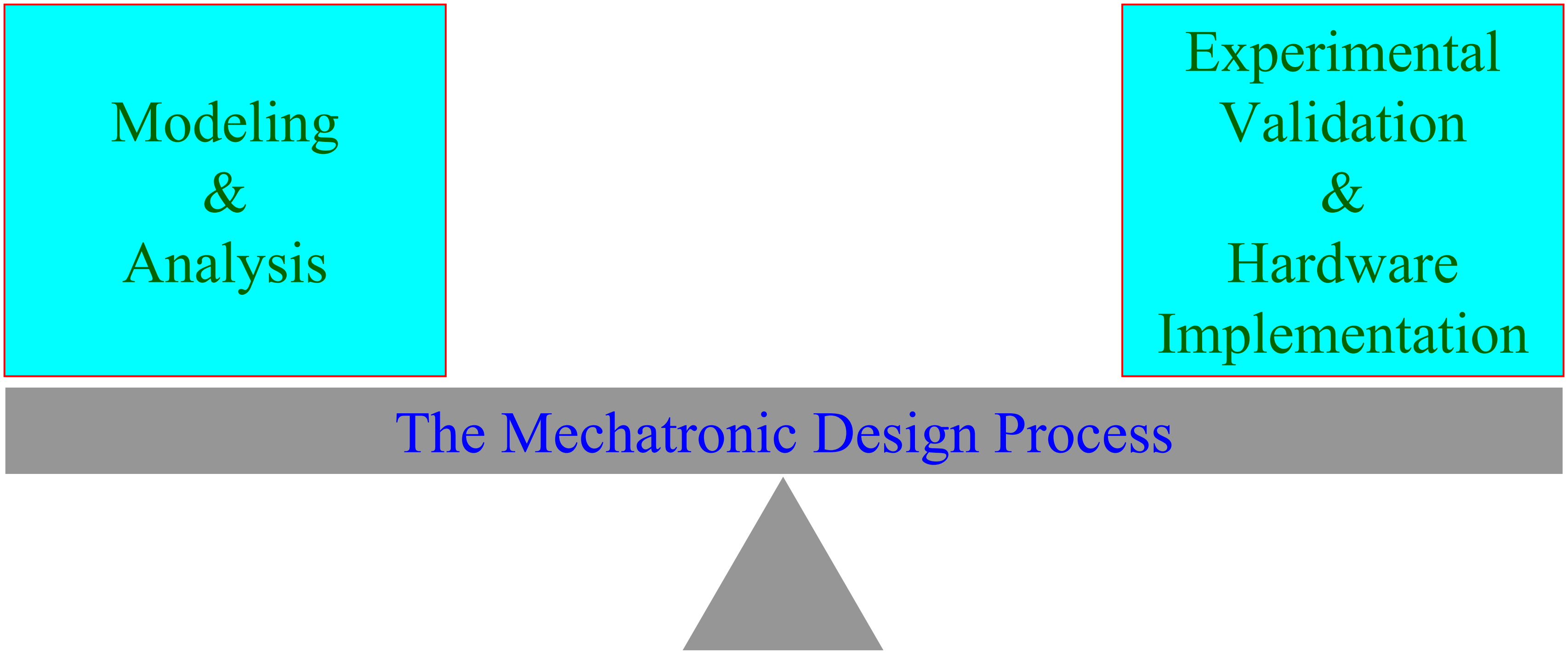
On the way professors must now teach design!

Mechatronics has gained industrial and academic acceptance worldwide as a field of study and practice.

Who is the Mechatronics Engineer?

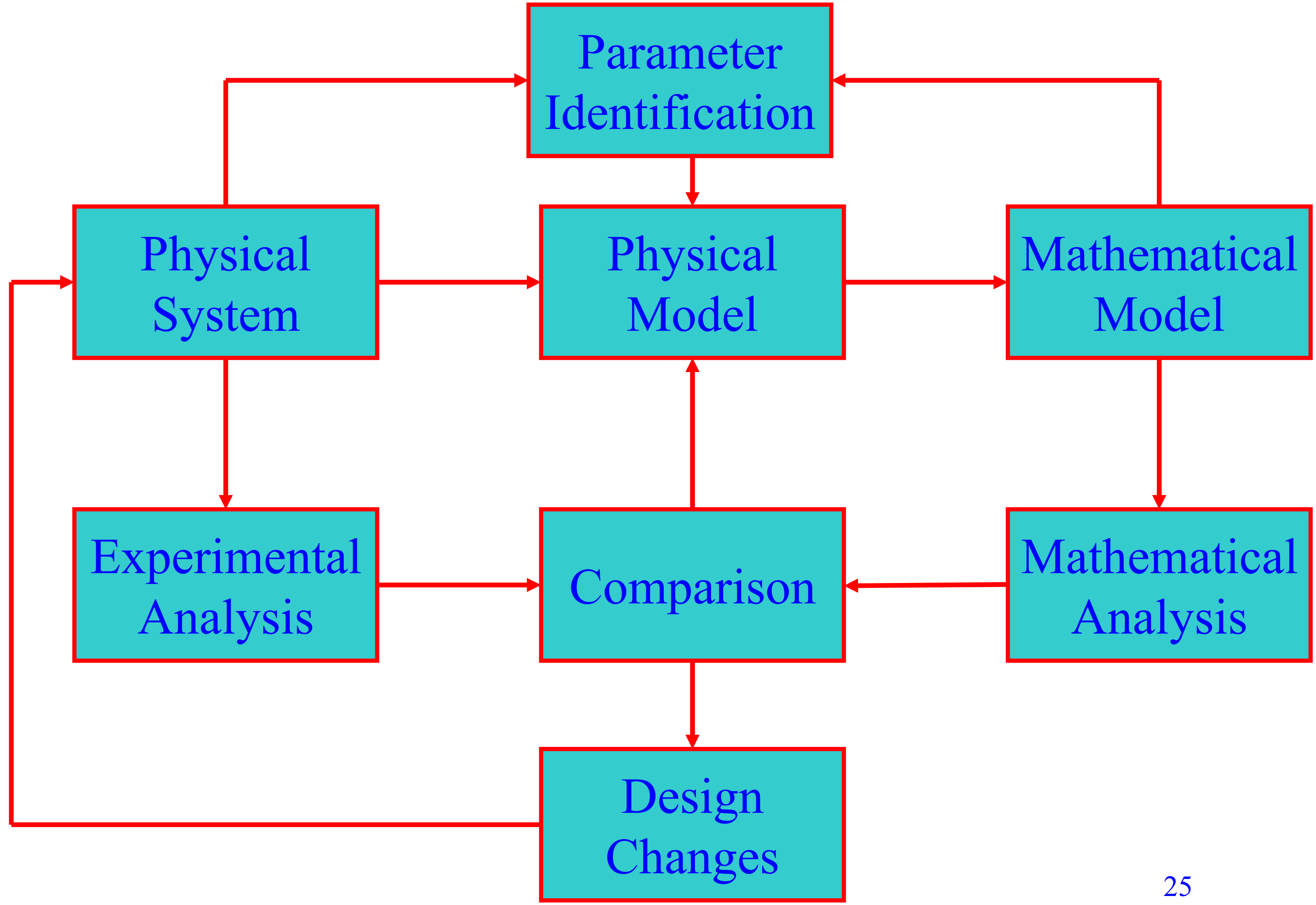
- Leader in the initiation and integration of design
- Interdisciplinary knowledge of various techniques
- Ability to master the entire design process from concept to manufacturing
- Ability to use the knowledge resources of other people and the particular blend of technologies which provide the most optimal design solution

Balance: The Key to Success



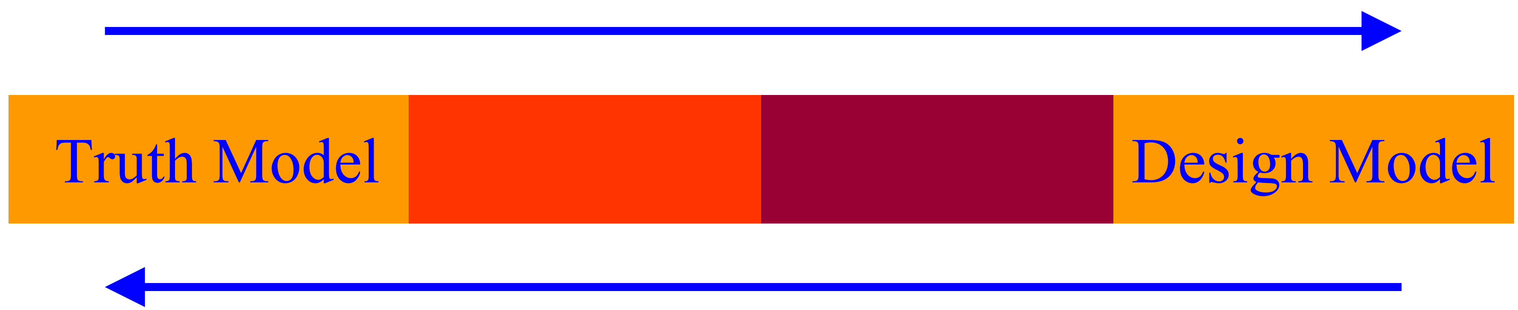
Computer Simulation Without Experimental Verification Is At Best Questionable, And At Worst Useless!

Dynamic System Investigation



Modeling:
Physical and Mathematical

Less Real, Less Complex, More Easily Solved



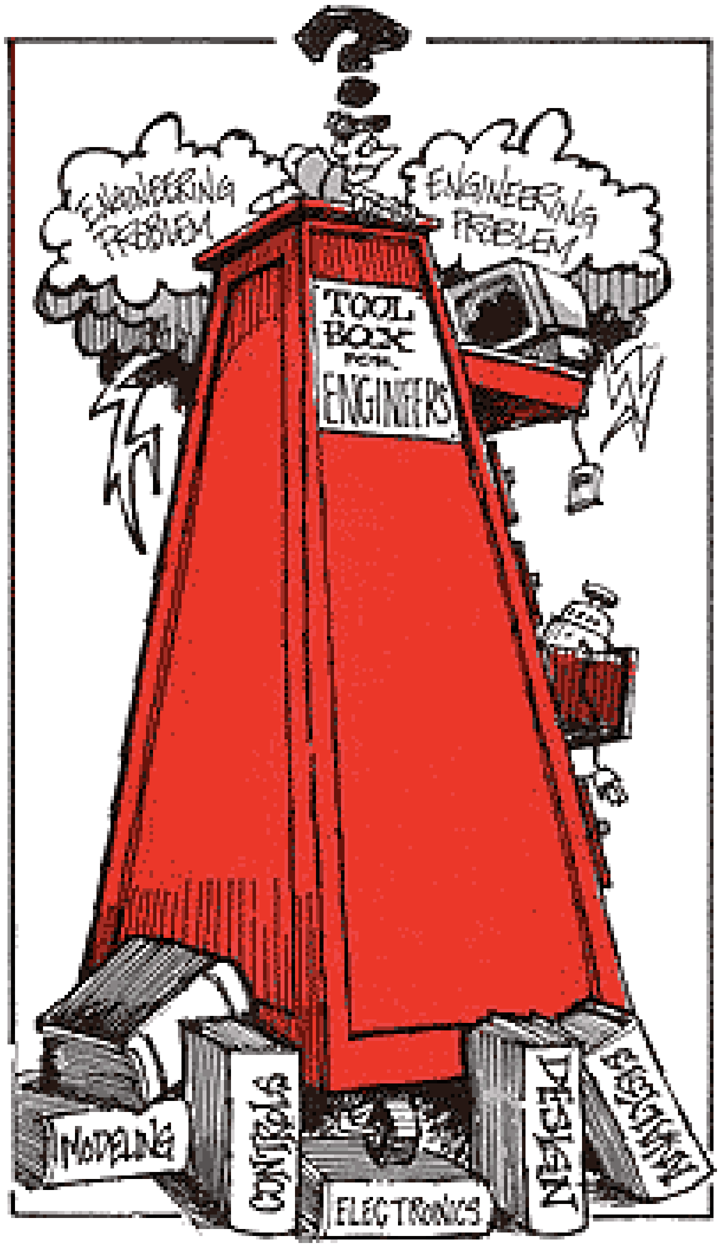
More Real, More Complex, Less Easily Solved

Hierarchy Of Models

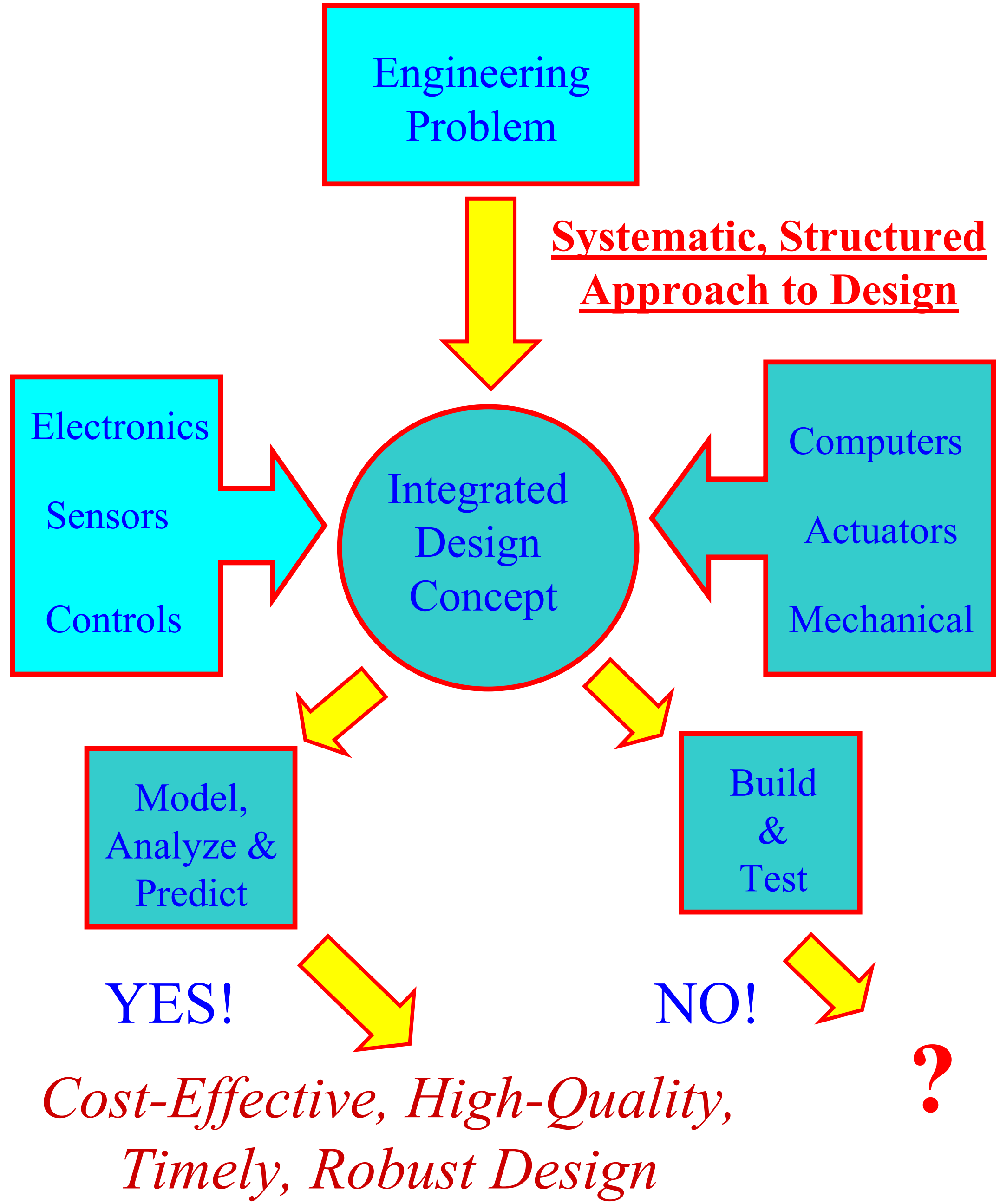
Always Ask: Why Am I Modeling?

What Skills Are Currently Lacking?

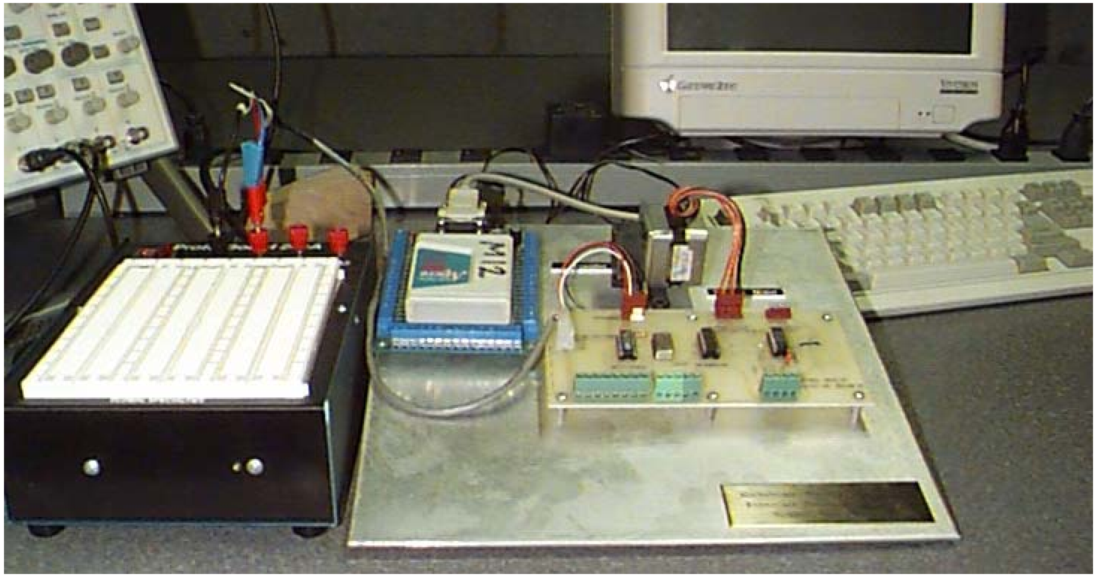
- Control Design and Implementation is still the domain of the specialist.
- Controls and Electronics are still viewed as afterthought add-ons.
- Very few practicing engineers perform any kind of physical and mathematical modeling.
- Mathematics is a subject that is not viewed as enhancing one’s engineering skills but as an obstacle to avoid.
- Very few engineers have the balance between analysis and hardware essential for success in Mechatronics.



ENGINEERING PROBLEM
ENGINEERING PROBLEM
TOOL BOX FOR ENGINEERS
MODELING
CONTROLS
ELECTRONICS



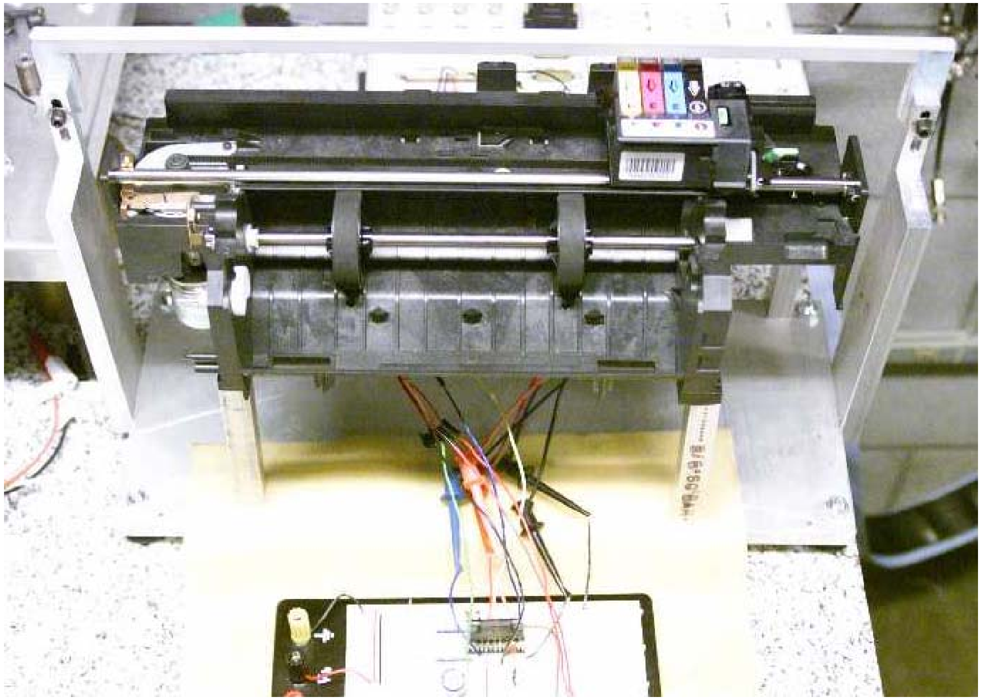
Engineering Problem
Systematic, Structured Approach to Design
Electronics
Sensors
Controls
Integrated Design Concept
Computers
Actuators
Mechanical
Model, Analyze & Predict
Build & Test
YES!
NO!
Cost-Effective, High-Quality, Timely, Robust Design
?

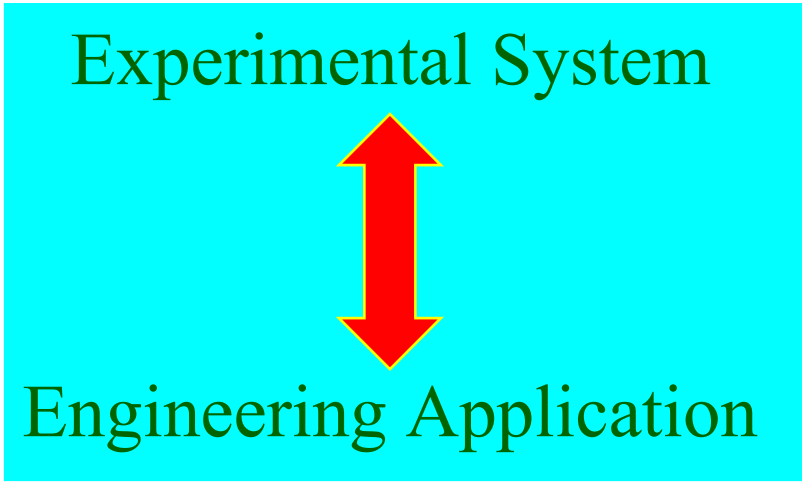


Mechatronics Training Hardware Systems

Stepper Motor System Design:
Ink-Jet Printer Application

Stepper Motor Open-Loop and Closed-Loop Control



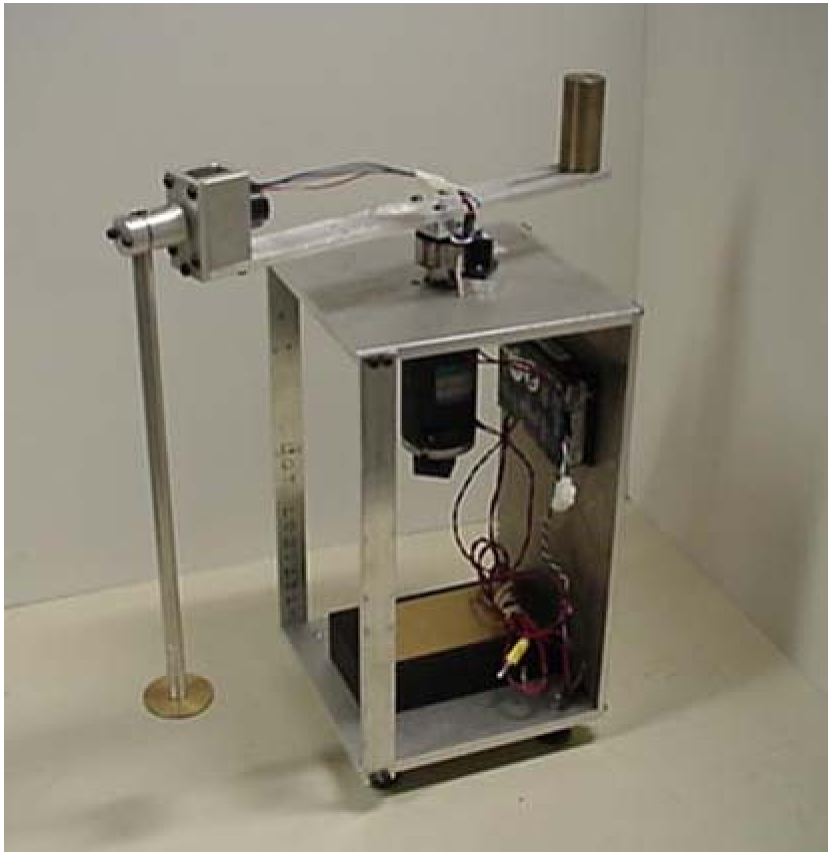


Industry's Challenge

- Train the engineers you have in the mechatronics approach to design.
- Give them the tools to be successful:
  - Knowledge: modeling, analysis, controls
  - Hardware: sensors, actuators, instrumentation, real-time control, microcontrollers
  - Software for Simulation and Control Design, e.g., Matlab / Simulink, Electronics Workbench
- Give them the time to use these tools!

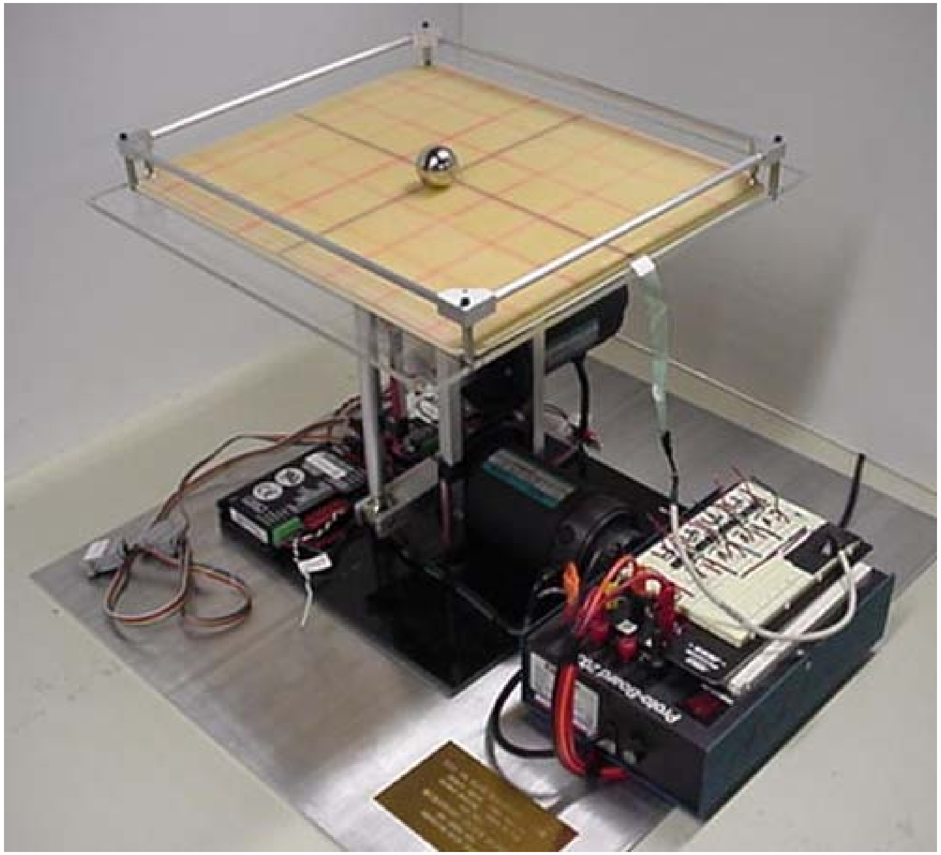
Mechatronics
is the
Career of the Future
for
Mechanical Engineers.

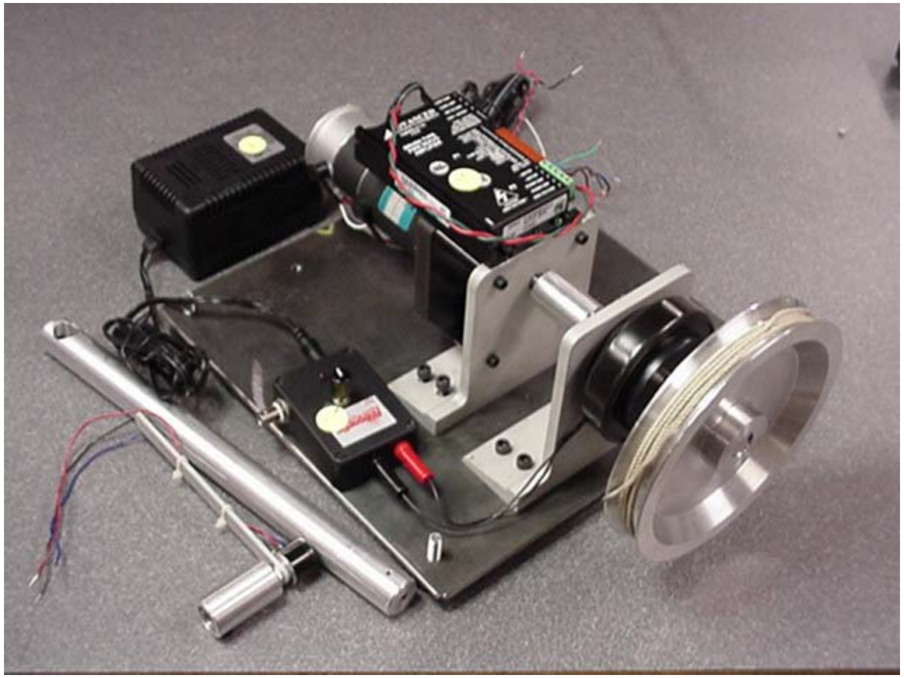
Mechatronic Teaching Systems



Rotary Inverted Pendulum System

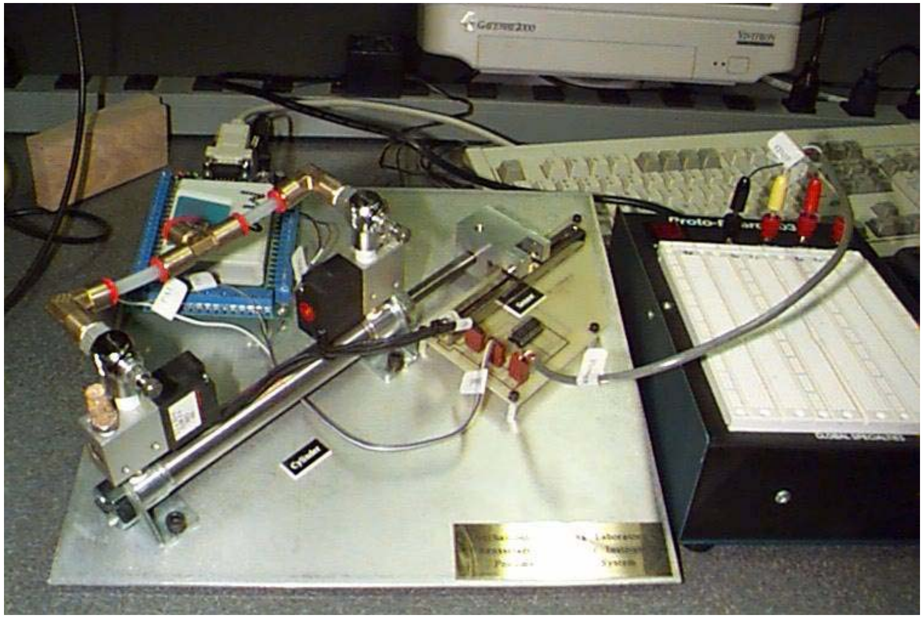
Ball-on-Plate Balancing System

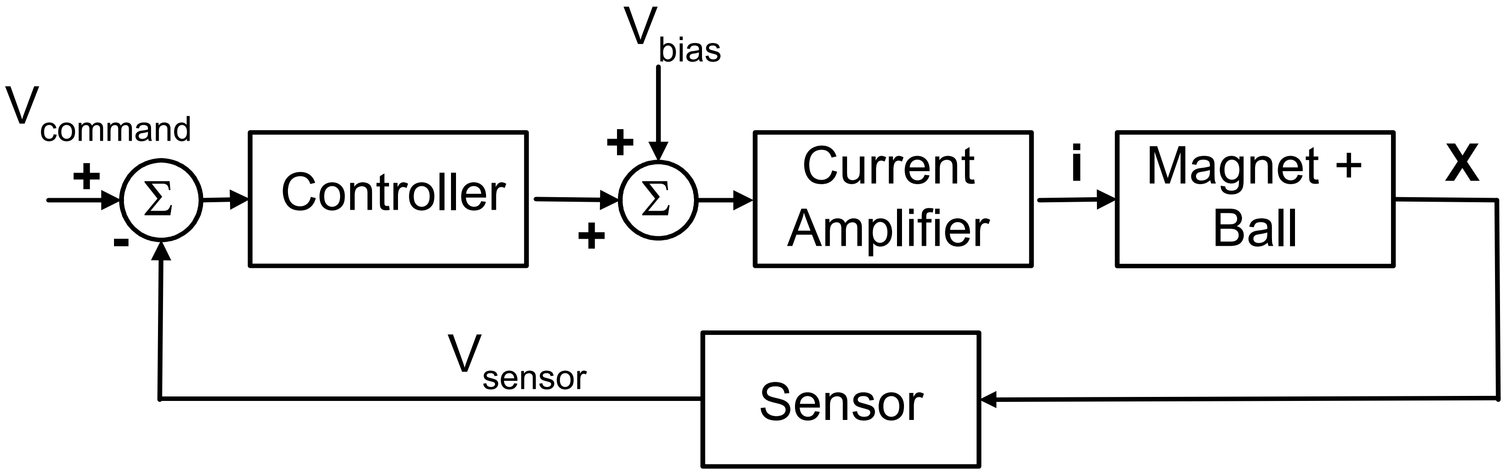




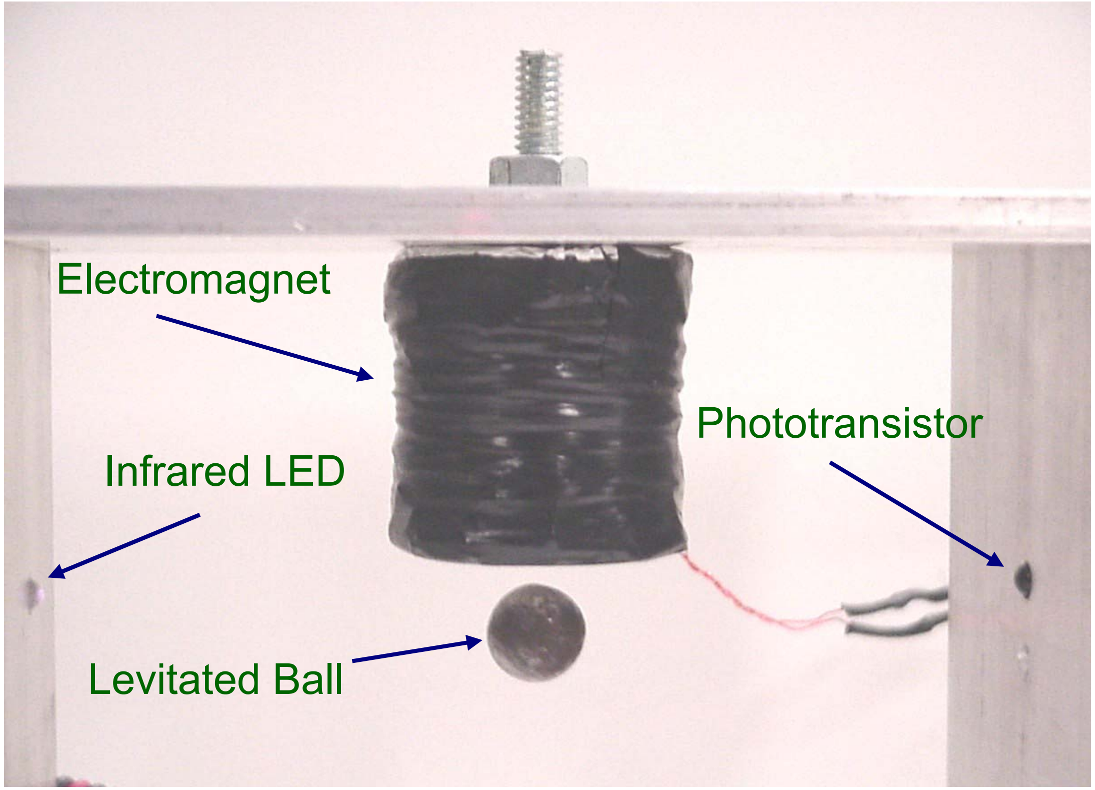
Magneto-Rheological Fluid Rotary Brake/Damper System

Pneumatic System Closed-Loop Position Control

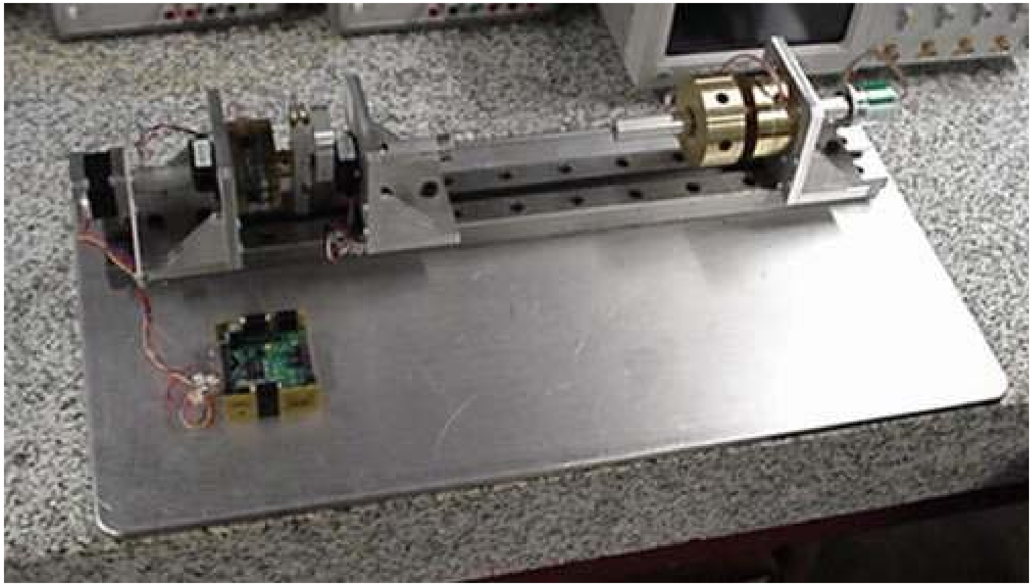




Magnetic Levitation System



Testbeds to Study the Effects of Variable Inertia, Gear Backlash, Drive-Shaft Compliance, and Coulomb Friction on Accurate Positioning



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All these systems are industrially relevant and require a complete dynamic system investigation with a balance between modeling / analysis and hardware implementation.

Only a Mechatronics engineer can accomplish this!