Mechatronic Design

TOPIC:

Mechatronic Design Methodologies

Fernando Martell Chávez, Ph.D

Outline

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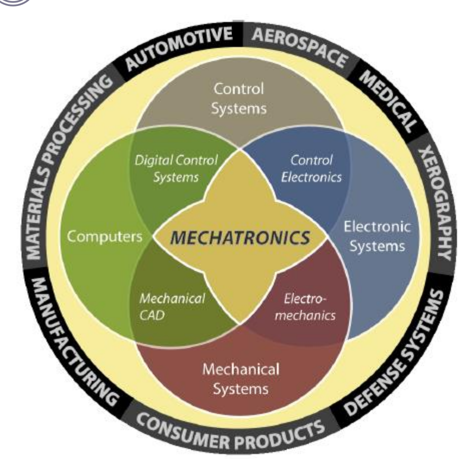
  - V-Model
- Modeling & Simulation
  - Definitions
  - Control Prototyping
  - Hardware in the loop
  - Computer Aided Systems



Multidisciplinary Systems

- Multidisciplinary systems are not new, they have been successfully designed and used for many years
- One of the most common is the electromechanical system, which often uses a computer algorithm to modify the behavior of a mechanical system
- Electronics are used to transduce information between the computer science and mechanical devices

Classical Electromechanical Design

- Traditionally an electromechanical system employed a sequential design-by-discipline approach.
  - The design is often accomplished in three steps:
    1. Mechanical design
    2. Power and microelectronics design
    3. The control algorithm design and implementation.
- Disadvantage:
  - By fixing the design at various points in the sequence, new constraints are created and passed on to the next discipline

Mechatronics: A Design Methodology

- The mechatronic system is multidisciplinary, embodying four fundamental disciplines: electrical, mechanical, computer science, and information technology
  - The difference between a mechatronic system and a traditional multidisciplinary system is not the constituents, but rather the philosophy in which they are designed
    - ***Interdisciplinary approach instead of multidisciplinary***
- *"Mechatronics is really nothing but good design practice"*
  - The basic idea is to apply new controls to extract new levels of performance from a mechanical device

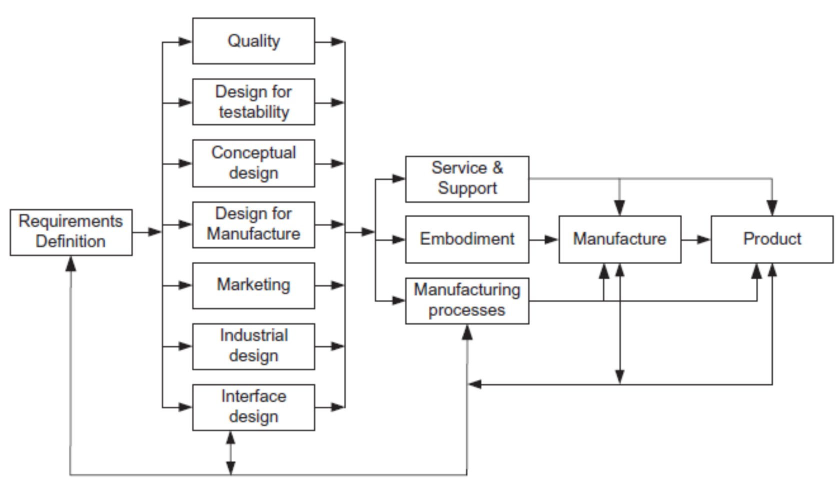
Mechatronics: A Design Methodology

- Mechatronics is a methodology used for the optimal design of electromechanical products
  - A ***methodology*** is a collection of practices, procedures, and rules used by those who work in a particular branch of knowledge
- The mechatronic design methodology is based on a ***concurrent*** (instead of sequential) approach to discipline design, resulting in products with more synergy

Concurrent Engineering

- Concurrent engineering is a design approach in which the design and manufacture of a product are merged in a special way
- It is necessary that the knowledge and necessary information be coordinated amongst different expert groups
- The characteristics of concurrent engineering are:
  - Better definition of the product without late changes
  - Design for manufacturing and assembly undertaken in the early design stage
  - Process on how the product development is well defined
  - Better cost estimates
  - Decrease in the barriers between design and manufacturing

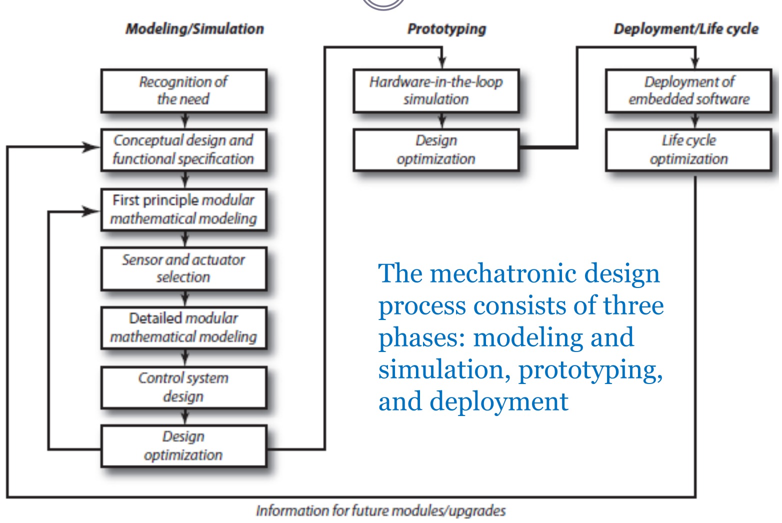
Concurrent Engineering



Mechatronic Design

- Mechatronics is a design philosophy: an integrating approach to engineering design
- Mechatronics makes the combination of actuators, sensors, control systems, and computers in the design process possible
- Starting with basic design and progressing through the manufacturing phase, mechatronic design optimizes the parameters at each phase to produce a quality product in a short-cycle time

Mechatronics Design Process



The mechatronic design process consists of three phases: modeling and simulation, prototyping, and deployment

Conventional versus Mechatronic Design

- *Comparison of design approaches*

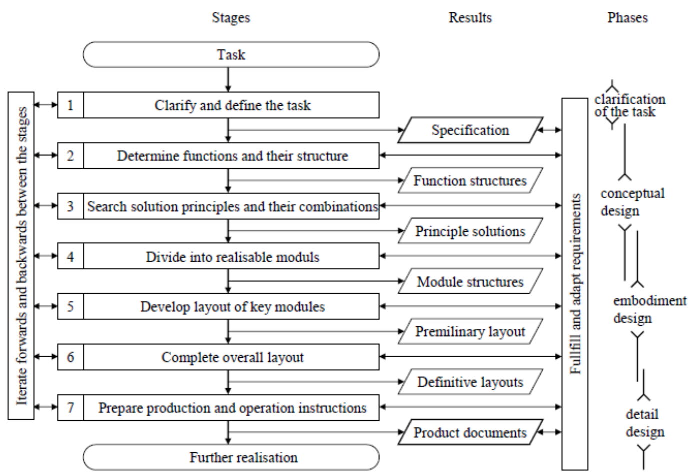
	Conventional Design	Mechatronic Design
	Added components	**Integration of components (hardware)**
1	Bulky	Compact
2	Complex mechanisms	Simple mechanisms
3	Cable problems	Bus or wireless communication
4	Connected components	Autonomous units
	Simple control	**Integration by information processing (software)**
5	Stiff construction	Elastic construction with damping by electronic feedback
6	Feedforward control, linear (analog) control	Programmable feedback (nonlinear) digital control
7	Precision through narrow tolerances	Precision through measurement and feedback control
8	Nonmeasurable quantities change arbitrarily	Control of nonmeasurable estimated quantities
9	Simple monitoring	Supervision with fault diagnosis
10	Fixed abilities	Learning abilities

Advantages of the Mechatronics Design

- The solution of tasks for designing mechatronic systems is performed as well on the mechanical as on the digital electronic side
- Thus, interrelations during the design play an important role; because the mechanical system influences the electronic system and vice versa, the electronic system has influence on the design of the mechanical system
- This means that simultaneous engineering has to take place, with the goal of designing an overall integrated system and also creating synergetic effects

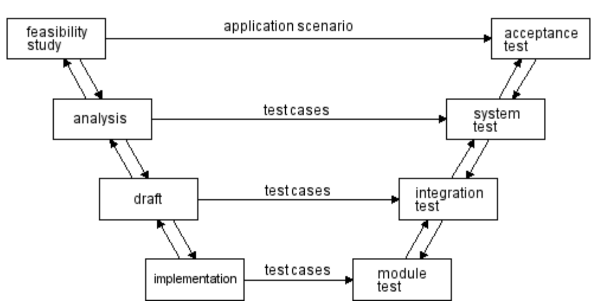
Guideline for development of Mechanical Systems

- VDI-2221

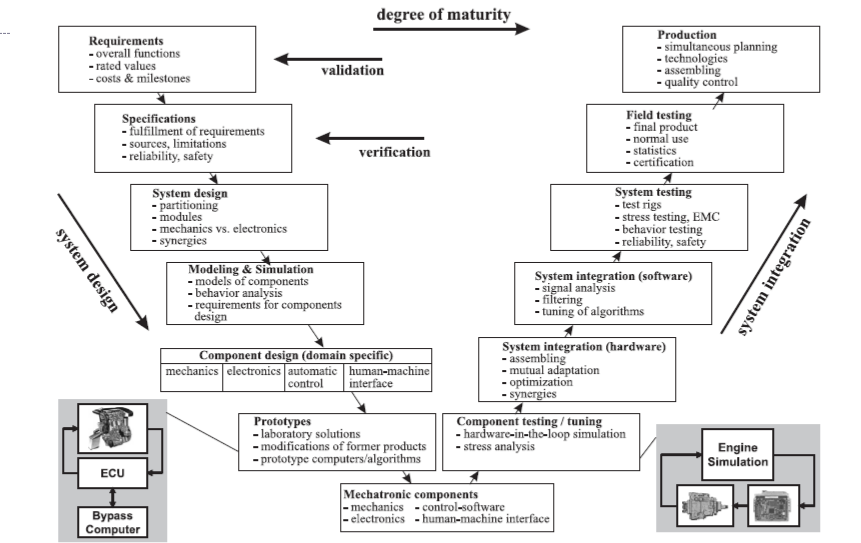


V-Model for development of IT Systems

- The V-model represents a software and hardware development process
- It demonstrates the relationships between each phase of the development life cycle and its associated phase of testing
- The horizontal and vertical axes represents time or project completeness (left-to-right) and level of abstraction



V–Model for Mechatronic Design (VDI-2206)



VDI stand for Verein Deutsche Ingenieure (Society of German Engineers)

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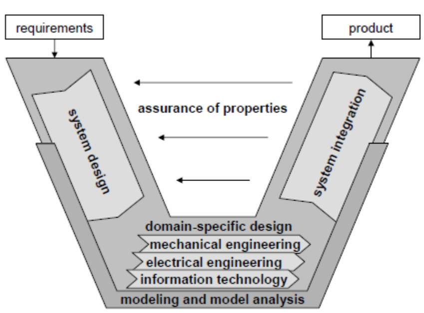

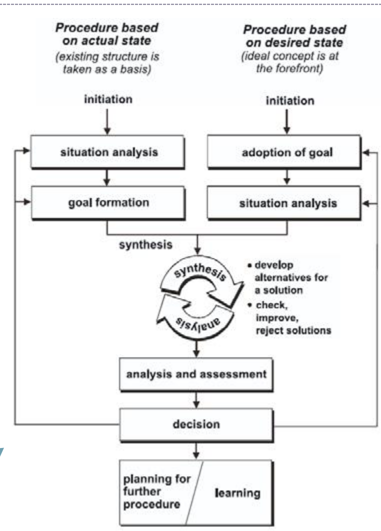

- V-Model is for the Macro-Level
- Problem Solving for Micro-Level

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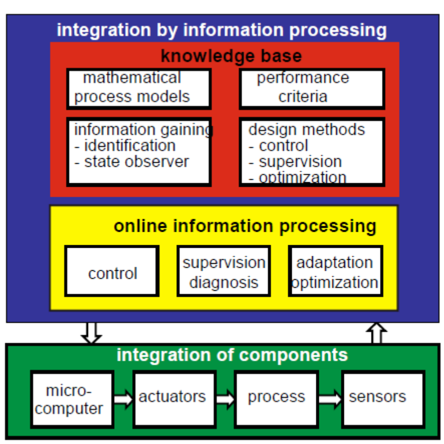
Advantages of the Mechatronics Design

- 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 the mechanical, electrical, 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
  - ***The integration and interface among those subsystems is essential***
  - *An integrated process founded upon interdisciplinary synergy*

Mechatronics: Better System Integration



Software Integration

Hardware Integration

Mechatronic overall integration

Mechatronic System Design

- Concurrent engineering of the mechatronics design approach relies heavily on the use of ***system modeling and simulation*** throughout the design and prototyping stages
  - Modeling is the process of representing the behavior of a real system by a collection of mathematical equations and logic
  - Simulation is the process of solving the model and is performed on a computer

System Modeling

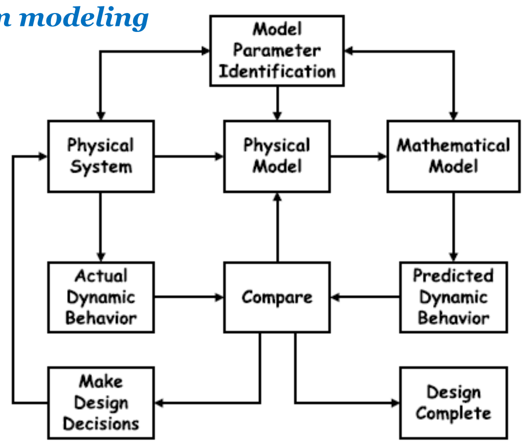
- Models are cause-and-effect structures—they accept external information and process it with their logic and equations to produce one or more outputs
- Models can be text-based programming or block diagrams. It is especially important that it be programmed in a visually intuitive environment
  - Block diagrams
  - Flow charts
  - State transition diagrams
  - Bond graphs

System Modeling

- Mathematical process models for static and dynamic behavior are required for various steps in the design of mechatronic systems, such as simulation, control design, and reconstruction of variables
- There are two ways to obtain these models:
  - *Theoretical modeling based on first (physical) principles*
  - *Experimental modeling (identification) with measured input and output variables*

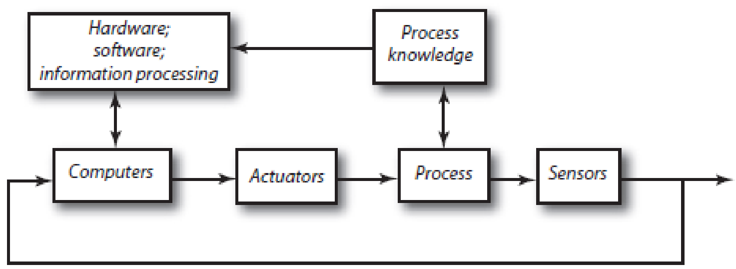
Modeling and Experimental Validation

- ***The mathematical modeling represents the behavior of the physical system but the design of the physical systems may be improved by the system modeling***



Mechatronic System Integration

- The integration within a mechatronic system is performed through the combination of hardware (components) and software (information processing)
    - Hardware integration results from designing the mechatronic system as an overall system and bringing together the sensors, actuators, and microcomputers into the mechanical system
    - Software integration is primarily based on advanced control functions

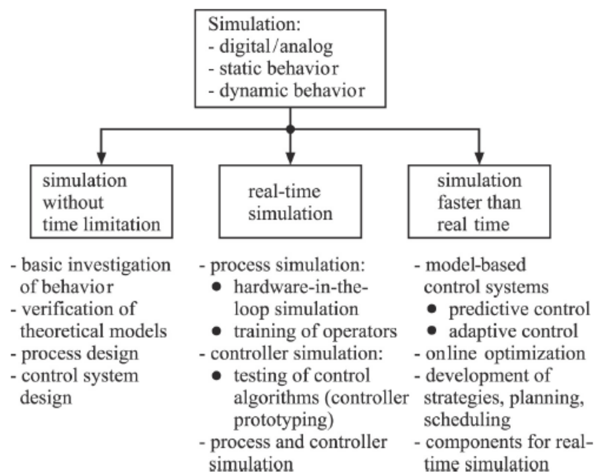


System Simulation

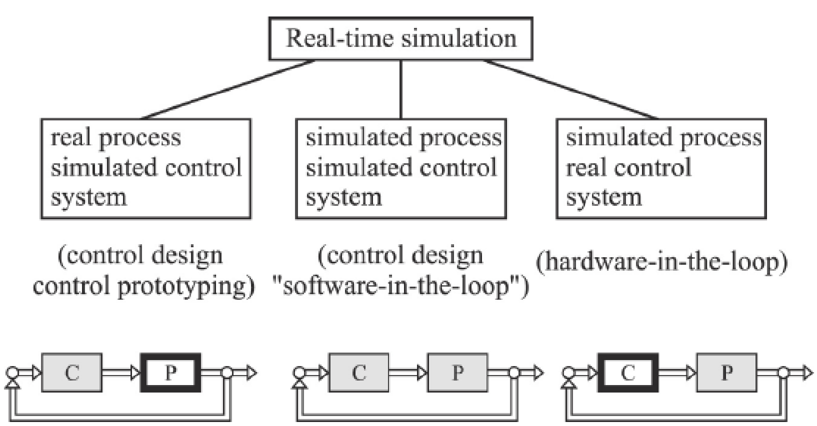
- Through system simulation interdisciplinary techniques provides ideal conditions to raise the synergy, thereby providing a catalytic effect for the new solutions to technically complex situations

- Mechatronics uses the control systems to provide a coherent framework of component interactions for system analysis
    - ***The overall system design (hardware and software components) is benefited from early control system design***

Simulation Alternatives



Real Time Simulation



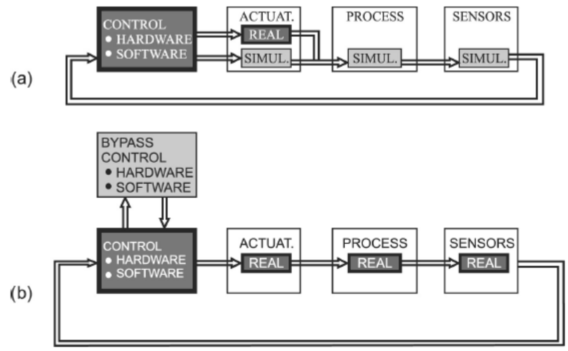
Hardware in the Loop Simulation

- The ***hardware-in-the-loop simulation*** (HIL)is characterized by operating real components in connection with real-time simulated components
  - Usually, the control system hardware and software is the real system, as used for series production
  - The controlled process (consisting of actuators, physical processes, and sensors) can either comprise simulated components or real components

Control Prototyping

- ***Control prototyping*** is a simulation scheme when the process, the actuators, and sensors may be real components
- It is useful for the design and testing of complex control systems and their algorithms under real-time constraints
  - Example: A real-time controller simulation (emulation) with hardware (a development board) other than the final series production hardware (special ASICS)

Simulation: Hybrid Structures



Real-time simulation: hybrid structures. (a) Hardware-in-the-loop simulation. (b) Control prototyping.

Computer-Aided Systems

- The comprehensive development of mechatronic systems starts with modeling and simulation, model building for static and dynamic models, transformation into simulation models, programming and computer-based control, and final implementation
- Since many of the steps in the mechatronic design process rely on computer-based tasks (such as information fusion, management, and design testing), an efficient ***computer-aided prototyping environment*** is essential

Relevance of Computer-Aided Systems

- **Modeling:**
  - Block diagrams for working with understandable multi-disciplinary models that represent a physical phenomenon.
- **Simulation:**
  - Numerical methods for solving models containing differential, discrete, linear, and nonlinear equations.
- **Project Management:**
  - Database for maintaining project information and subsystem models for eventual reuse
- **Design:**
  - Numerical methods for constrained optimization of performance functions based on model parameters and signals

Relevance of Computer-Aided Systems

- **Analysis:**
  - Frequency-domain and time-domain tools
- **Real-Time Interface:**
  - A plug-in card is used to replace part of the model with actual hardware by interfacing to it with actuators and sensors.
- **Code Generator:**
  - Produces efficient high-level source code (such as C/C++) from the block diagram. The control code will be compiled and used on the embedded processor
- **Embedded Processor Interface:**
  - Communication between the process and the computer-aided prototyping environment.

Summary

- Mechatronics is the application of complex decision making (***computational intelligence***) to the operation of physical systems
- A mechatronic system is not just a marriage of electrical and mechanical systems and is more than just a control system; it is a ***complete integration*** of all of them
- Mechatronics is a ***methodology*** used for the optimal design of electromechanical products

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