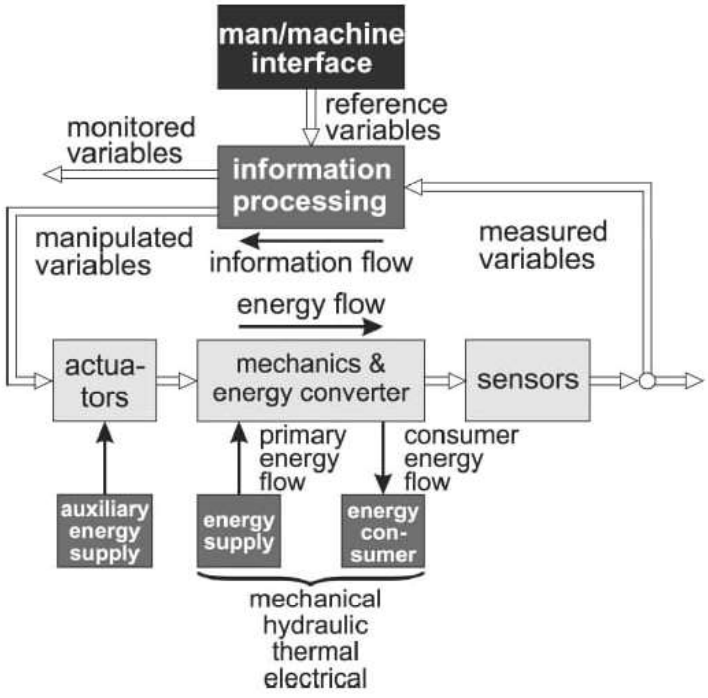
TABLE 2.2 Properties of Conventional and Mechatronic Design Systems

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

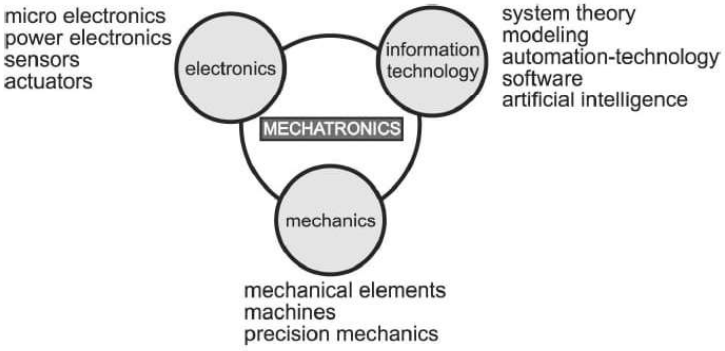


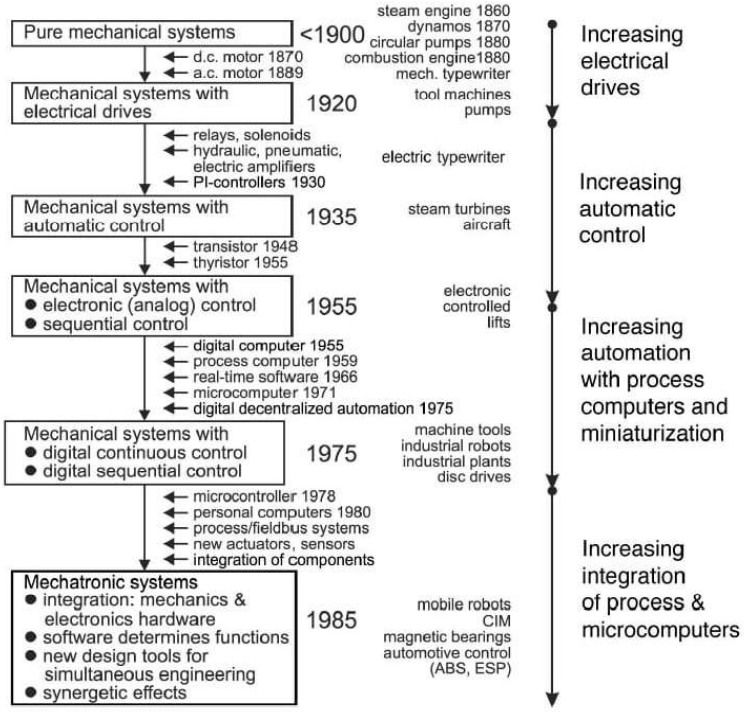
1. Definition of flows
   - energy flow (electrical, mechanical, thermal conductance)
   - energy and material flow (fluidic, thermal transfer, thermodynamic, chemical)
2. Definition of process elements: flow diagrams
   - sources, sinks (dissipative)
   - storages, transformers, converters
3. Graphical representation of the process model
   - multi-port diagrams (terminals, flows, and potentials, or across and through variables)
   - block diagrams for signal flow
   - bond graphs for energy flow
4. Statement of equations for all process elements
   (i) Balance equations for storage (mass, energy, momentum)
   (ii) Constitutive equations for process elements (sources, transformers, converters)
   (iii) Phenomenological laws for irreversible processes (dissipative systems: sinks)
5. Interconnection equations for the process elements
   - continuity equations for parallel connections (node law)
   - compatibility equations for serial connections (closed circuit law)
6. Overall process model calculation
   - establishment of input and output variables
   - state space representation
   - input/output models (differential equations, transfer functions)

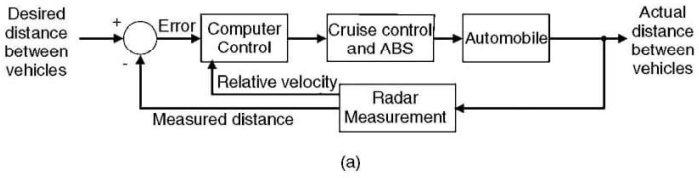
TABLE 2.3 Steps in the Design of Mechatronic Systems

	Precision Mechanics	Mechanical Elements	Machines
Pure mechanical system	●	●	●
1. Addition of sensors, actuators, microelectronics, control functions	○	○	○
2. Integration of components (hardware integration)	○	○	○
3. Integration by information processing (software integration)	○	○	○
4. Redesign of mechanical system	○	○	○
5. Creation of synergetic effects	○	○	○
Fully integrated mechatronic systems	●	●	●
Examples	Sensors actuators disc-storages cameras	Suspensions dampers clutches gears brakes	Electric drives combustion engines mach. tools robots

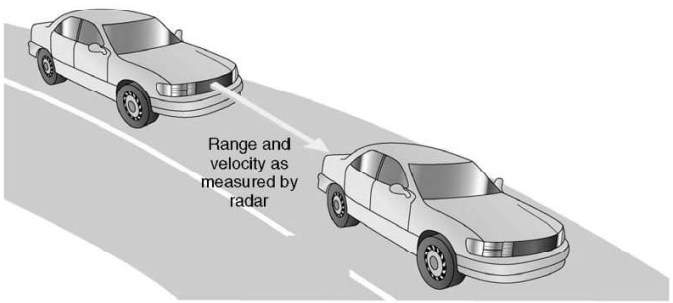
The size of a circle indicates the present intensity of the respective mechatronic development step. ● large, ◯ medium, ○ little.

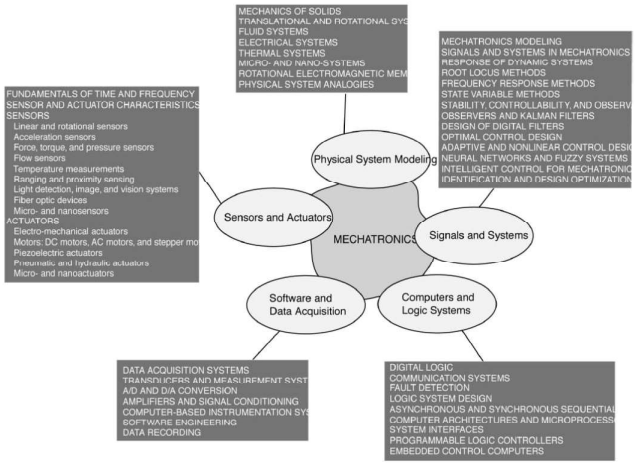

micro electronics
power electronics
sensors
actuators
electronics
information technology
MECHATRONICS
mechanics
system theory
modeling
automation-technology
software
artificial intelligence
mechanical elements
machines
precision mechanics


Pure mechanical systems
<1900
steam engine 1860
dynamos 1870
circular pumps 1880
combustion engine1880
mech. typewriter
d.c. motor 1870
a.c. motor 1889
Mechanical systems with electrical drives
1920
tool machines
pumps
relays, solenoids
hydraulic, pneumatic, electric amplifiers
PI-controllers 1930
electric typewriter
Mechanical systems with automatic control
1935
steam turbines
aircraft
transistor 1948
thyristor 1955
Mechanical systems with
electronic (analog) control
sequential control
1955
electronic controlled lifts
digital computer 1955
process computer 1959
real-time software 1966
microcomputer 1971
digital decentralized automation 1975
Mechanical systems with
digital continuous control
digital sequential control
1975
machine tools
industrial robots
industrial plants
disc drives
microcontroller 1978
personal computers 1980
process/fieldbus systems
new actuators, sensors
integration of components
Mechatronic systems
integration: mechanics & electronics hardware
software determines functions
new design tools for simultaneous engineering
synergetic effects
1985
mobile robots
CIM
magnetic bearings
automotive control (ABS, ESP)
Increasing electrical drives
Increasing automatic control
Increasing automation with process computers and miniaturization
Increasing integration of process & microcomputers


Desired distance between vehicles
+
-
Error
Computer Control
Cruise control and ABS
Automobile
Actual distance between vehicles
Relative velocity
Radar Measurement
Measured distance

(a)


Range and velocity as measured by radar


MECHANICS OF SOLIDS
FLUID SYSTEMS
ELECTRICAL SYSTEMS
THERMAL SYSTEMS
PHYSICAL SYSTEM ANALOGIES
FUNDAMENTALS OF TIME AND FREQUENCY
SENSOR AND ACTUATOR CHARACTERISTICS
SENSORS
Linear and rotational sensors
Acceleration sensors
Force, torque, and pressure sensors
Flow sensors
Temperature measurements
Ranging and proximity sensing
Light detection, image, and vision systems
Fiber optic devices
Micro- and nanosensors
ACTUATORS
Electro-mechanical actuators
Piezoelectric actuators
Micro- and nanoactuators
MECHATRONICS MODELING
SIGNALS AND SYSTEMS IN MECHATRONICS
RESPONSE OF DYNAMIC SYSTEMS
ROOT LOCUS METHODS
FREQUENCY RESPONSE METHODS
STATE VARIABLE METHODS
OBSERVERS AND KALMAN FILTERS
DESIGN OF DIGITAL FILTERS
OPTIMAL CONTROL DESIGN
NEURAL NETWORKS AND FUZZY SYSTEMS
Physical System Modeling
Sensors and Actuators
MECHATRONICS
Signals and Systems
Software and Data Acquisition
Computers and Logic Systems
DATA ACQUISITION SYSTEMS
A/D AND D/A CONVERSION
AMPLIFIERS AND SIGNAL CONDITIONING
SOFTWARE ENGINEERING
DATA RECORDING
DIGITAL LOGIC
COMMUNICATION SYSTEMS
FAULT DETECTION
LOGIC SYSTEM DESIGN
SYSTEM INTERFACES
PROGRAMMABLE LOGIC CONTROLLERS
EMBEDDED CONTROL COMPUTERS

- design and testing of the control hardware and software without operating a real process ("moving the process field into the laboratory");
- testing of the control hardware and software under extreme environmental conditions in the laboratory (e.g., high/low temperature, high accelerations and mechanical shocks, aggressive media, electro-magnetic compatibility);
- testing of the effects of faults and failures of actuators, sensors, and computers on the overall system;
- operating and testing of extreme and dangerous operating conditions;
- reproducible experiments, frequently repeatable;
- easy operation with different man-machine interfaces (cockpit-design and training of operators); and
- saving of cost and development time.