# Introduction to Mechatronics

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CSE-2205: Introduction to Mechatronics [2.0 credits, 30 hours lecture]

(Prerequisite Courses: EEE-1103, EEE-1202)

**Introduction:** Definition and applications of Mechatronics, relationship amongst different disciplines. Basics of Electronics: Fundamental concepts of circuits and electrics. Basics of Mechanical Engineering: Fundamental concepts of Mechanics, measurement systems, control systems, mechanical design, discrete linear systems. Sensors and Transducers: Sensors for displacement, proximity, motion, sound, light, temperature, fluid Level and flow, force, etc. Actuation Systems: Basics of pneumatic and hydraulic systems, mechanical actuation systems, electrical actuation systems, servos. System Models and Controllers: Fundamentals of electrical, mechanical, fluid and thermal systems, electromechanical systems, process controllers, control modes, PID and digital controllers, velocity, adaptive, digital logic, microprocessor control. Programmable Logic Controllers: Fundamentals of PLCs, mnemonics and timers, relays and counters, master and jump control, data control, analog I/O control. Design of Mechatronics Systems: Steps of mechatronics system design, possible design solutions, case study.

# What is mechatronics?

- **Mechatronics**, also called **mechatronics engineering**, is an interdisciplinary branch of engineering that focuses on the integration of mechanical, electronic and electrical engineering systems.
- It also includes a combination of robotics, electronics, computer science, telecommunications, systems, control, and product engineering.
- The term "mechatronics" was coined by Tetsuro Mori, the senior engineer of the Japanese company Yaskawa in 1969.

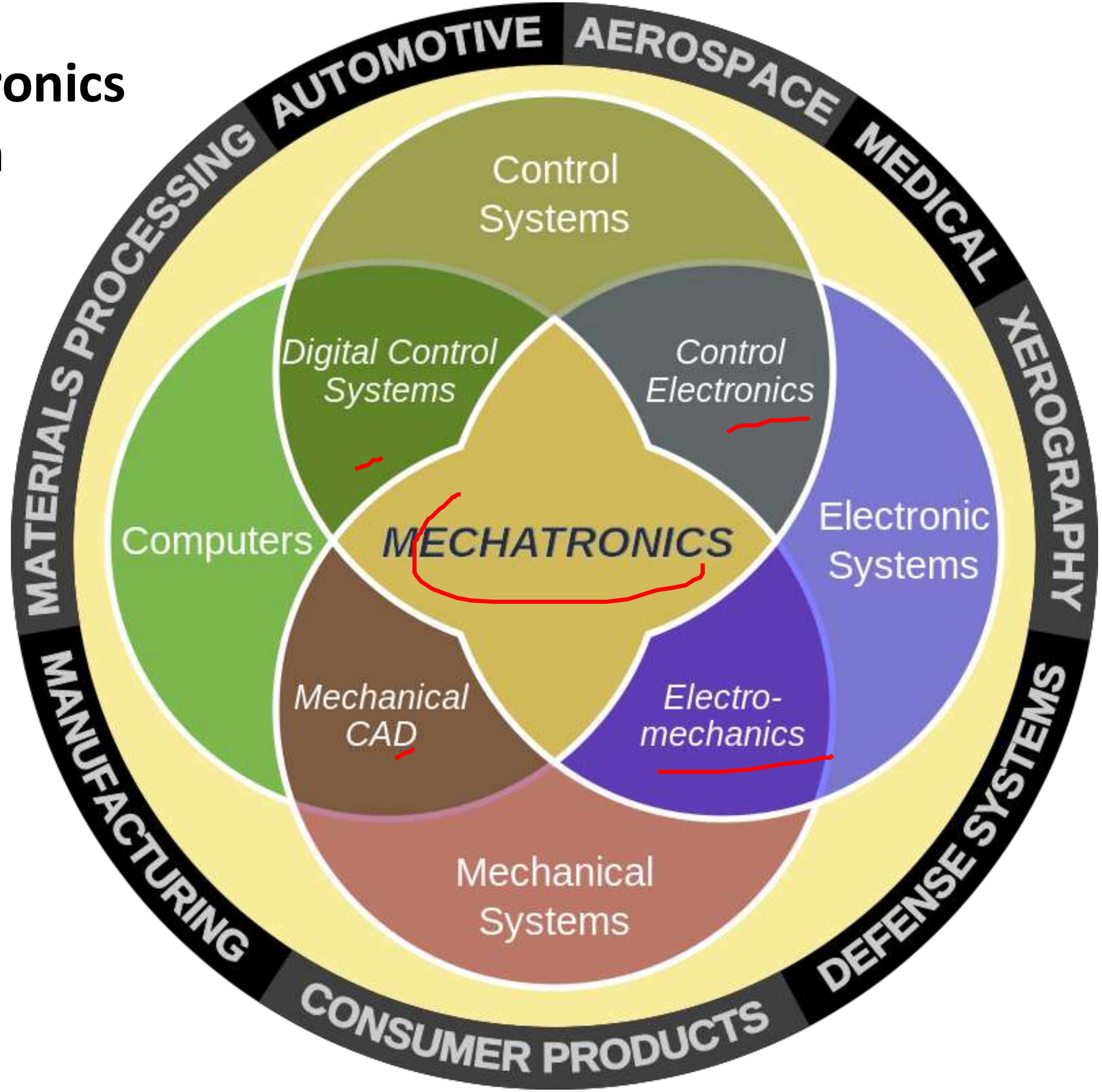
# The Evolution of Mechatronics Engineering

- Mechatronics is a crossover form of engineering born out of the need for engineers with both electrical and mechanical knowledge.
- Before 1970, most household products relied on mechanical engineering alone in their design.
- Even large manufacturing plants were powered by people controlling mechanically driven devices.
- The early 1970s saw a shift towards incorporating electrical power with mechanical features into our tools and machines.
- In the 1980s, with the boom in microprocessors, mechatronics grew more popular.

# The Evolution of Mechatronics Engineering

- By the 90s, the field began to incorporate aspects of computer science and programming, creating almost endless possibilities to the usefulness of mechatronics engineering.
- With all of that crossover knowledge, mechatronics engineers have brought amazing features into the products they work on.
- Cars are a great example. Backup cameras, sensors, and anti-lock breaks all required crossover engineering skills to design and implement.
- Areas like automation and robotics are also full of mechatronics engineers.
- “If you build a mechanical thing that is controlled by electrical components that needs software to make it work, then you need mechatronics.”

# Relationship between mechatronics and other disciplines with applications



## The objectives of mechatronics:

1. To improve products and processes.
2. To develop novel mechanisms.
3. To design new products.
4. To create new technology using novel concepts.

# Basic Elements of Mechatronics System

(i) Actuators and sensors

(ii) Signals and conditioning

(iii) Digital logic Systems

(iv) Software and data acquisition systems

(v) Computers and display devices.

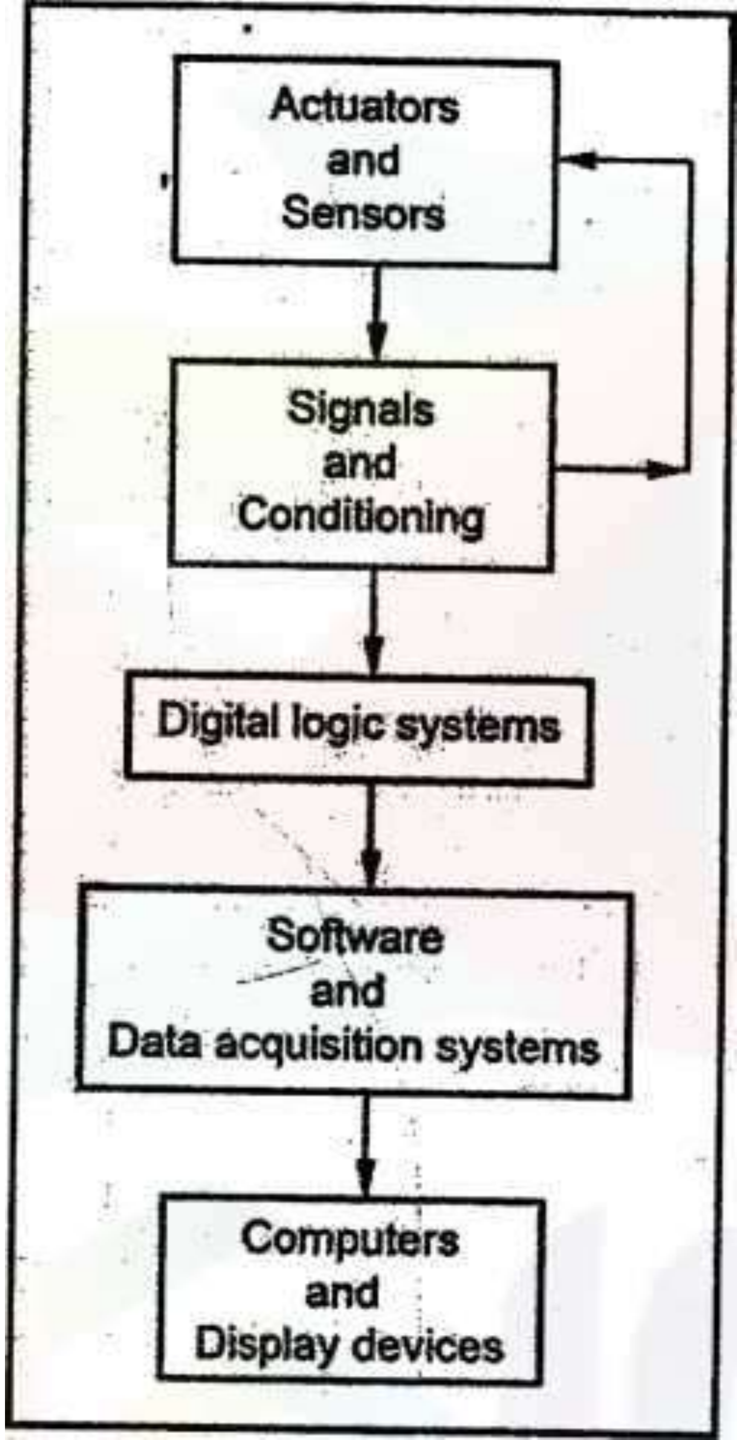



Fig. Various elements in typical mechatronic systems.

# (i) Sensors and Actuators

- Sensors and actuators mostly come under mechanical systems.
- The actuators produce motion or cause some action.
- The sensors detect the state of the system parameters, inputs, and outputs.
- The various types of sensors used in the mechatronic system are linear and rotational sensors, acceleration sensors, force, torque and pressure sensors, flow sensors, temperature sensors, proximity sensors, light sensors etc.
- The various actuators used in the mechatronic system are pneumatic and hydraulic actuators, electro-mechanical actuators, electrical motors etc.

## (ii) Signals and conditioning

- The mechatronic systems deal with two types of signals and conditioning such as – input and output.
- The input devices receive input signals from the mechatronic systems via interfacing devices and sensors.
- Then it is sent to the control circuits for conditioning or processing.
- The various input signal conditioning devices are discrete circuits, amplifiers, Analog to digital (ADC) and Digital-to-Digital (DZD) convertors.
- The output signals from the system are sent to output/display devices through interfacing devices.
- The various output signal conditioning devices are DA converters, Display Decoders (DD), amplifiers, power transistors, power op-amps etc.

## (iii) Digital logic systems

- Digital logic devices control overall system operation.
- The various digital logic systems used in the mechatronic system are logic circuits, microcontrollers, programmable logic controllers, sequencing and timing controls, and control algorithms.

PLC

## (iv) Software and data acquisition systems

- The data acquisition system acquires the output signals from sensors in the form of voltage, frequency, resistance etc. and it is inputted into the microprocessor or computer.
- Software is used to control the acquisition of data through DAC board.

- The data acquisition system consists of a multiplexer, amplifier, register, and control circuitry and DAC board.
- The various data acquisition systems used in the mechatronic system is data loggers, computer with plug-in boards etc.

## (v) Computers and display devices

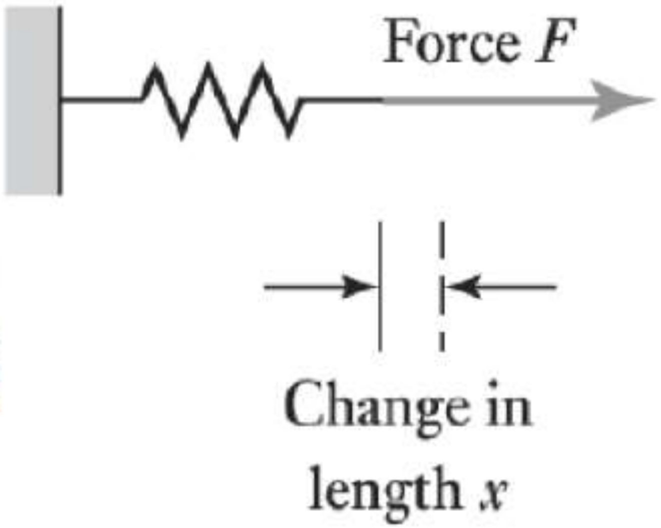
- Computers are used to store a large number of data and process further through software.
- Display devices are used to give visual feedback to the user.
- The various display devices used in the mechatronic system are LEDs, CRT, LCD, digital displays, etc.

# Building Blocks of Mechanical Systems

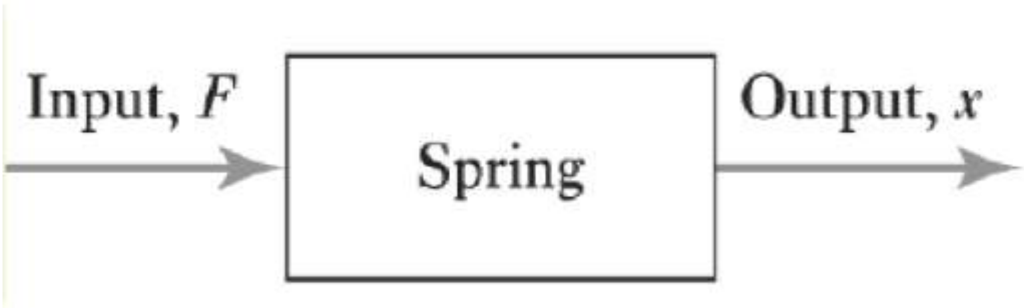
- ***Spring:*** Represents the stiffness of a system.
- ***Dashpot:*** Dashpots are the forces opposing motion i.e. friction or damping.
- ***Mass:*** The inertia or resistance to acceleration.

# Building Blocks of Mechanical Systems

## Spring




k is the stiffness constant

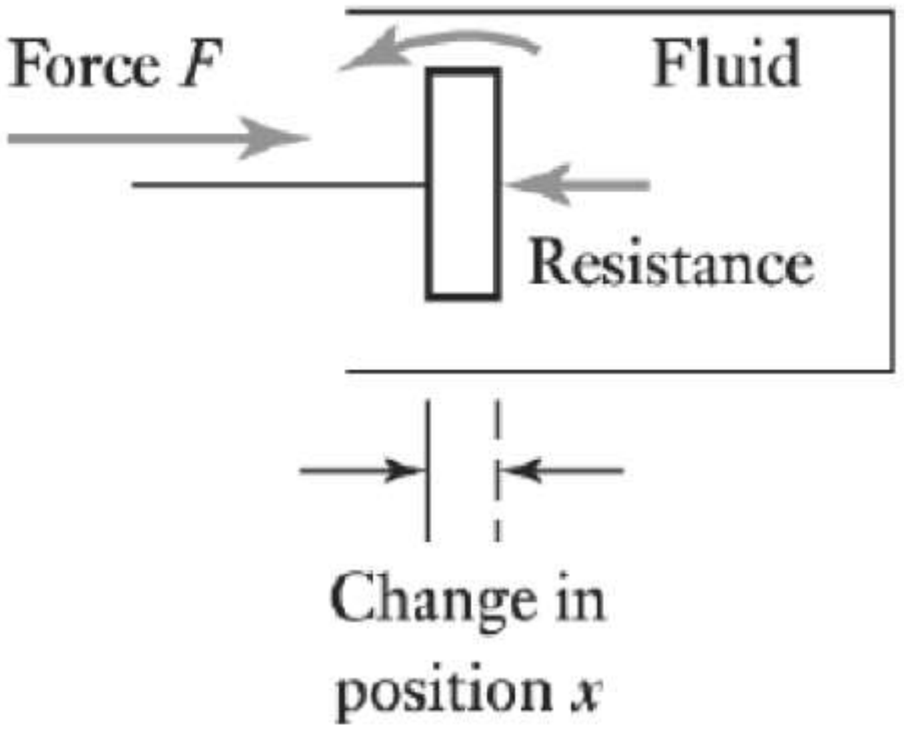


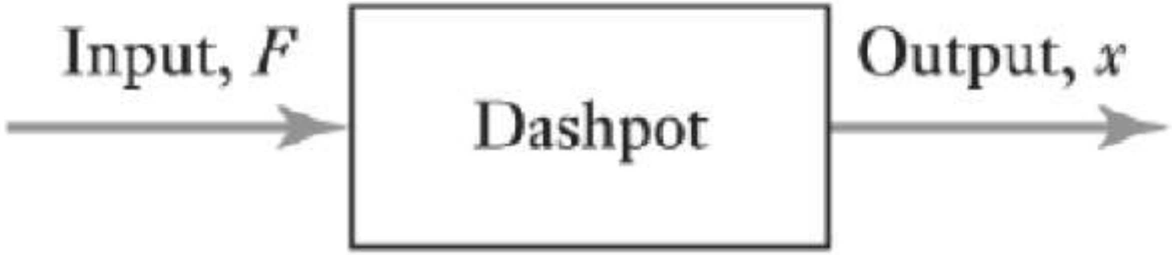

The stiffness of a spring is described by:

**F = kx**

The object applying the force to stretch the spring is also acted on by an equal force acting in the opposite direction (Newton's third law).

# Building Blocks of Mechanical Systems



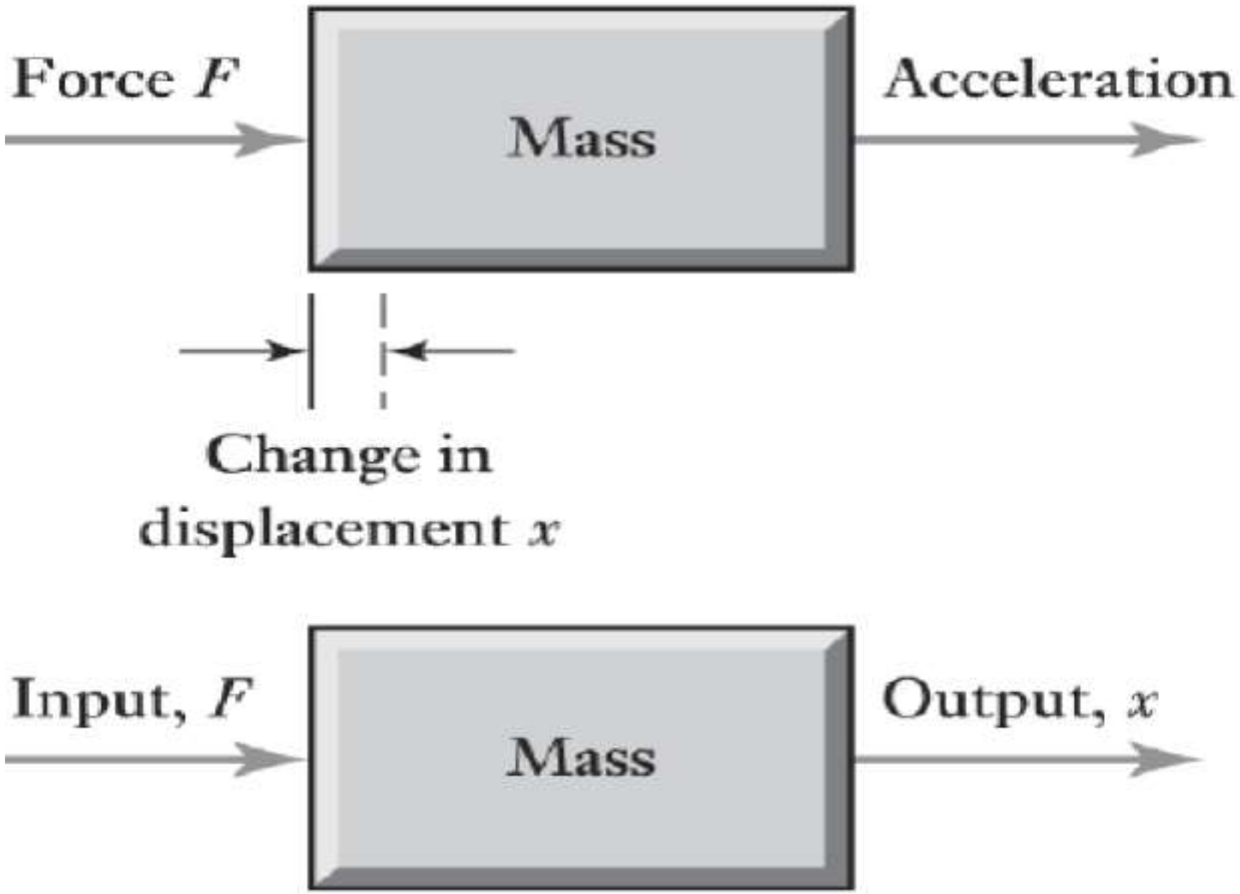

## Dashpot

It is a type of force, which acts when we push an object through a fluid or move an object against friction forces.

$$F = c\frac{dx}{dt} = cv$$

# Building Blocks of Mechanical Systems

## Mass




$$F = m\frac{d^2x}{dt^2} = m\frac{dv}{dt}$$

| Building block | Describing equation | Energy stored or power dissipated |
|---|---|---|
| *Translational* | | |
| Spring | $F = kx$ | $E = \frac{1}{2}\frac{F^2}{k}$ |
| Dashpot | $F = c\frac{dx}{dt} = cv$ | $P = cv^2$ |
| Mass | $F = m\frac{d^2x}{dt^2} = m\frac{dv}{dt}$ | $E = \frac{1}{2}mv^2$ |
| *Rotational* | | |
| Spring | $T = k\theta$ | $E = \frac{1}{2}\frac{T^2}{k}$ |
| Rotational damper | $T = c\frac{d\theta}{dt} = c\omega$ | $P = c\omega^2$ |
| Moment of inertia | $T = I\frac{d^2\theta}{dt^2} = I\frac{d\omega}{dt}$ | $E = \frac{1}{2}I\omega^2$ |

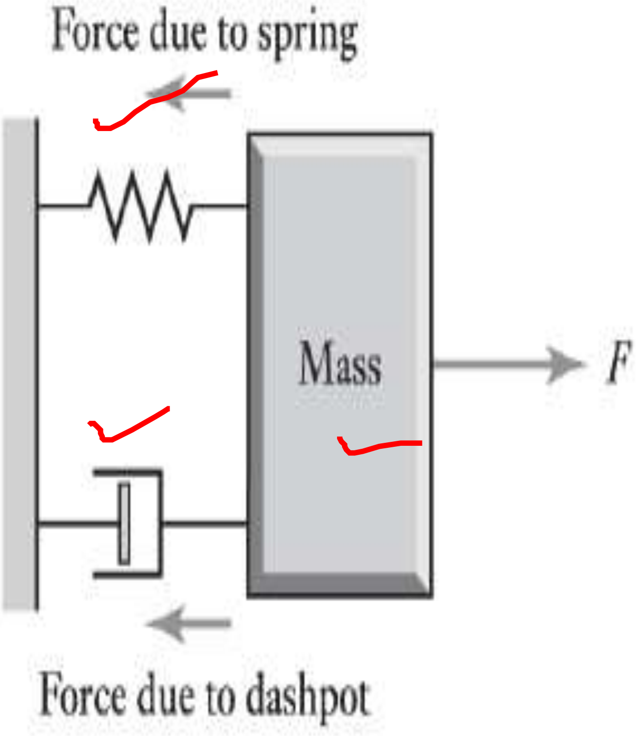
# Building Up Mechanical Systems: Translational Systems


(b)

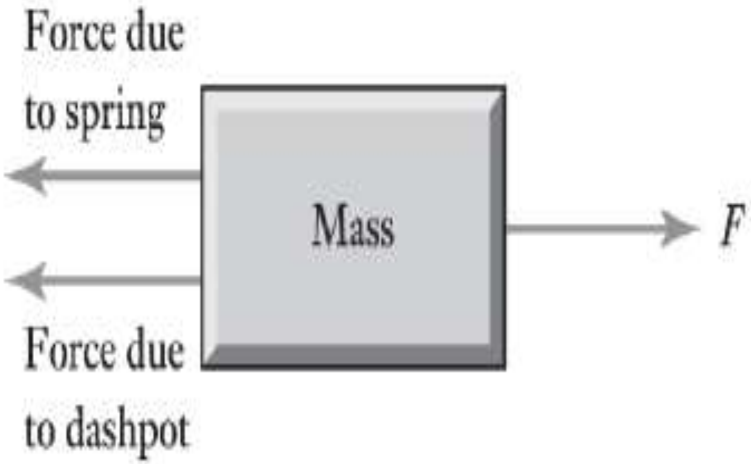
$$F - kx - c\frac{dx}{dt} = m\frac{d^2x}{dt^2}$$

$$or \quad m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F$$

**Derive the system model**




(a)




(c)

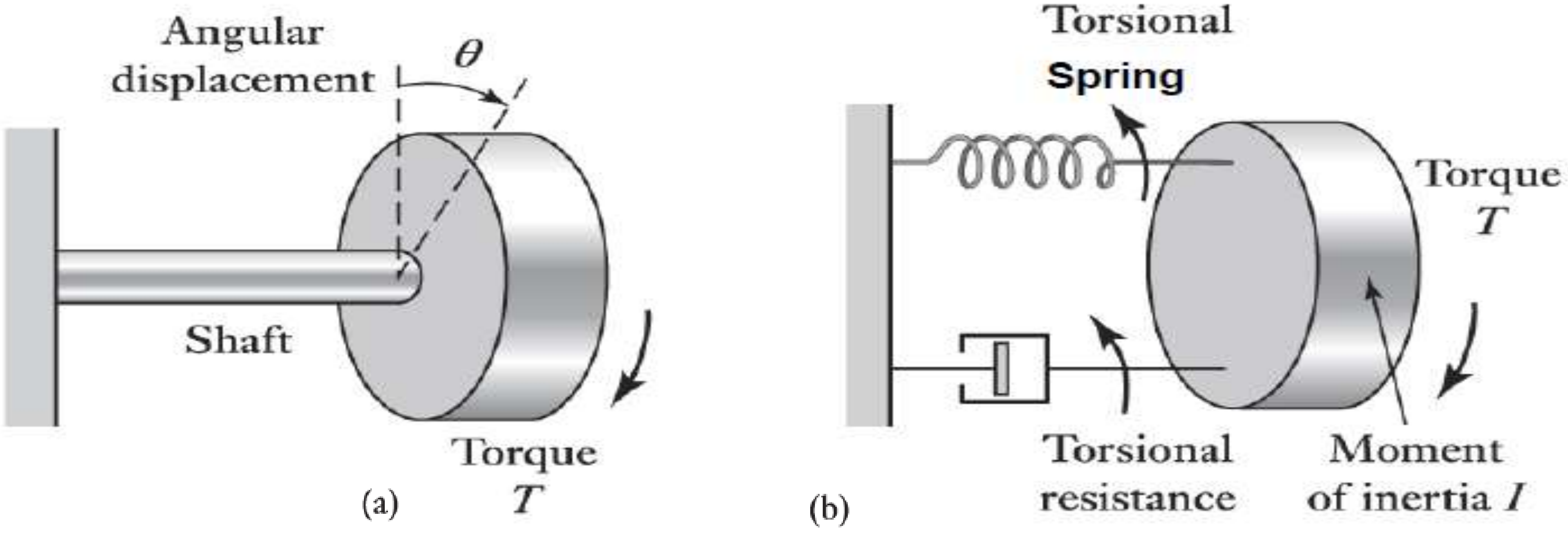
# Rotational Systems

The equivalent three building blocks of rotational system are:

1. **Torsional spring**: With a torsional spring the angle θ rotated is proportional to the torque: $T = k\theta$
2. **Rotary damper**: With a rotary damper a disc is rotated in a fluid and the resistive torque T is proportional to the angular velocity ω.
3. **Moment of inertia** ( the inertia of a rotating mass): The moment of inertia block exhibit the property that the greater the moment of inertia J the greater the torque needed to produce an angular acceleration

$$T = c\omega = c\,d\theta/dt\ ; \quad T = Ja$$

# Building Up Mechanical Systems: Rotational Systems




$$I\frac{d^2\theta}{dt^2} + c\frac{d\theta}{dt} + k\theta = T$$

# Advantages of mechatronic systems:

- It is cost effective and it can produce high quality products.
- Production of parts and products of international standards gives better reputation and return.
- It serves effectively for high dimensional accuracy requirements.
- It provides high degree of flexibility to modify or redesign the systems.
- It provides excellent performance characteristics.
- It Results in automation in production, assembly and quality control.

- Mechatronic systems provide the increased productivity in manufacturing organization.
- Reconfiguration feature by pre supplied programs facilitate the low volume production.
- It provides the possibility of remote controlling as well as centralized monitoring and control.
- It has greater extend of machine utilization.
- Higher life is expected by proper maintenance and timely diagnosis of the fault

# Disadvantages of mechatronics

- The initial cost is high.
- Maintenance and repair may workout costly.
- Multi-disciplinary engineering background is required to design and implementation.
- It needs highly trained workers to operate.
- Techno-economic estimation has to be done carefully in the selection of mechatronic system.
- It has complexity in identification and correction of problems in the systems.
- Such systems also require more parts than others, and involve a greater risk of component failure.

# 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.

# Applications

## Machine vision (MV) :

- It is the technology and methods used to provide imaging based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance, usually in industry.
- The machine vision process includes planning the details of the requirements and project, and then creating a solution.
- During run-time, the process starts with imaging, followed by automated analysis of the image and extraction of the required information.

## Automation and Robotics:

- **Automation** describes a wide range of technologies that reduce human intervention in processes.
- Human intervention is reduced by predetermining decision criteria, subprocess relationships, and related actions — and embodying those predeterminations in machines.
- **Robotics** is interdisciplinary branch of computer science and engineering.
- Robotics involves design, construction, operation, and use of robots.
- The goal of robotics is to design machines that can help and assist humans.
- Robotics develops machines that can substitute for humans and replicate human actions.

## Servo-Mechanics:

- In control engineering a **servomechanism**, usually shortened to **servo**, is an automatic device that uses error-sensing negative feedback to correct the action of a mechanism.

## Sensing and Control systems:

- A **sensor** is a device that produces an output signal for the purpose of sensing of a physical phenomenon.
- A **control system** manages, commands, directs, or regulates the behavior of other devices or systems using control loops.

## Automotive engineering:

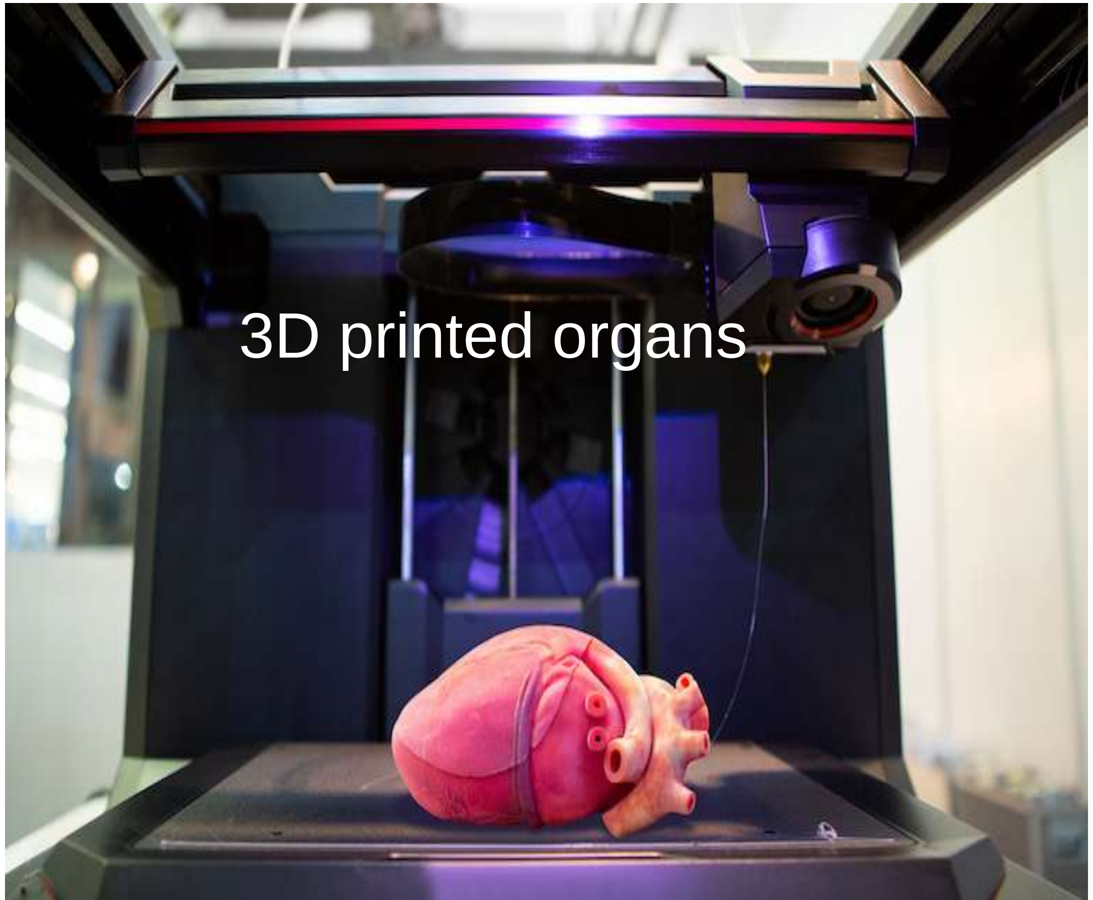
- Along with aerospace engineering and naval architecture, is a branch of vehicle engineering.

## Building/Home automation:

- **Building automation** is the automatic centralized control of a building's HVAC (heating, ventilation and air conditioning), electrical, lighting, shading, Access Control, Security Systems, and other interrelated systems through a Building Management System (BMS) or Building Automation System (BAS).
- **Home automation** or **domotics** is building automation for a home, called a **smart home** or **smart house**.
- A home automation system will monitor and/or control home attributes such as lighting, climate, entertainment systems, and appliances.
- It also control access and alarm systems.

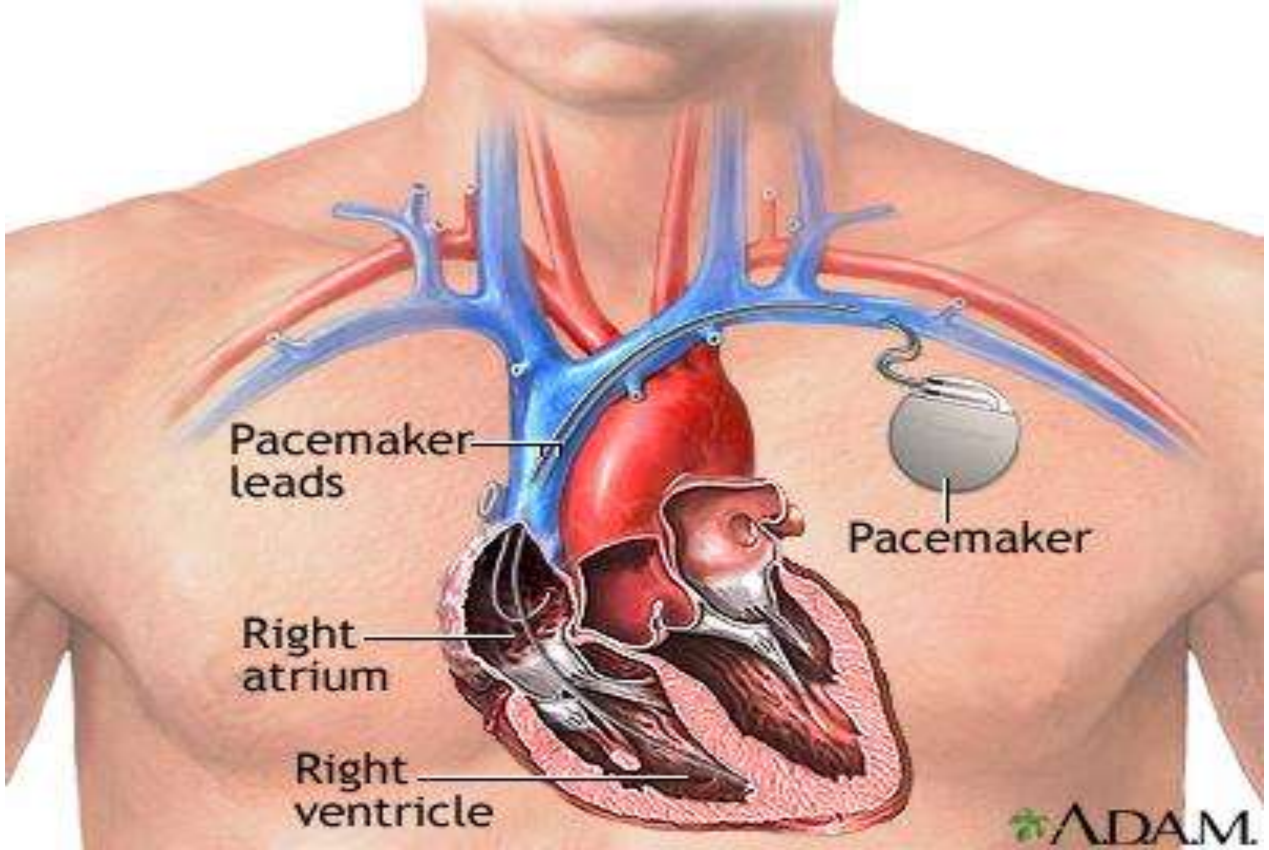
# Smart home systems

- Computer-machine controls, such as computer driven machines like CNC (computer numerical control) milling machines, CNC waterjets, and CNC plasma cutters
- Expert systems
- Industrial goods
- Medical mechatronics
- Structural dynamic systems
- Transportation and vehicular systems



- Computer aided and integrated manufacturing systems
- Engineering and manufacturing systems
- Packaging
- Microcontrollers / PLCs
- Microprocessors
- Biomechatronics

Implant devices



# Computer-aided design

- **Computer-aided design** (**CAD**) is the use of computers to aid in the creation, modification, analysis, or optimization of a design.
- This software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.
- CAD output is often in the form of electronic files for print, machining, or other manufacturing operations.
- The terms **computer-aided drafting** (**CAD**) and **computer aided design and drafting** (**CADD**) is also used.

# Illustrative Examples

## Example 1

- An electrical switch is a man-made mechatronic system, used to control the flow of electricity.
- The toggle of the switch is a mechanical system and the human brain or a control system used to actuate the switch acts as an informatics system.
- The brain or informatics system decides whether we need to turn on the switch. If we do, the brain controls the movement of our limbs and we turn on the switch.
- When the switch is on, the resistance of contact is nearly zero and energy flow takes place.
- When the switch is off, the resistance is infinity and no current flows.

# Illustrative Examples

## Example 2:

- A thermostatically controlled heater or furnace is a mechatronic system.
- The input to the system is the reference temperature.
- The output is the actual temperature.
- When the thermostat detects that the output is less than the input, the furnace provides heat until the temperature of the enclosure becomes equal to the reference temperature.
- Then the furnace is automatically turned off.
- Here, the bimetallic strip of the thermostat acts as informatics since it automatically turns the switch on or off.
- The lever-type switch is mechanical system, heater acts as an electrical system.

# Illustrative Examples

## Example 3:

- The washing machine is an ideal example of a mechatronic system.
- After the clothes to be washed have been put in the machine, the soap, detergent, bleach, and water are put in required amounts.
- The washing and wringing cycle time is then set on a timer and the washer is energized. When the cycle is completed, the machine switches itself off.
- When the required amount of detergent, bleach, water, and appropriate temperature are predetermined and poured automatically by the machine itself, then the machine is a mechatronic system.
- The microprocessor used for this purpose acts as the informatics system.
- The electrical motor actuated for wriggling is an electrical system.
- The agitator and timer are mechanical systems.

# Illustrative Examples

## Example 4:

- The automatic bread toaster is a mechatronic system, in which two heating elements supply the same amount of heat to both sides of the bread.
- The quality of the toast can be determined by its surface colors.
- When the bread is toasted, the color detector sees the desired colors, and the switch automatically opens and a mechanical lever makes the bread pop up.
- Mechanical, electrical, and informatics systems are involved in the operation of the bread toaster.