Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

**CSE-2205: Introduction to Mechatronics**

# Lec-1: Fundamentals of Mechatronics

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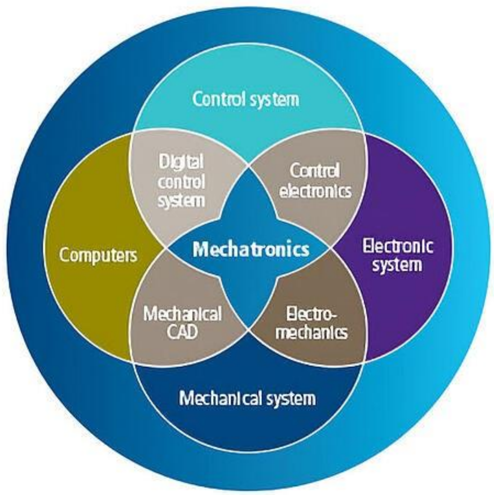
# Fundamentals of Mechatronics

## What is mechatronics?

The term mechatronics was 'invented' by a Japanese engineer in 1969, as a combination of 'mecha' from mechanisms and 'tronics' from electronics. It is the integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes. As a result, mechatronic products have many mechanical functions replaced with electronic ones.




This results in much greater flexibility, easy redesign and reprogramming, and the ability to carry out automated data collection and reporting.

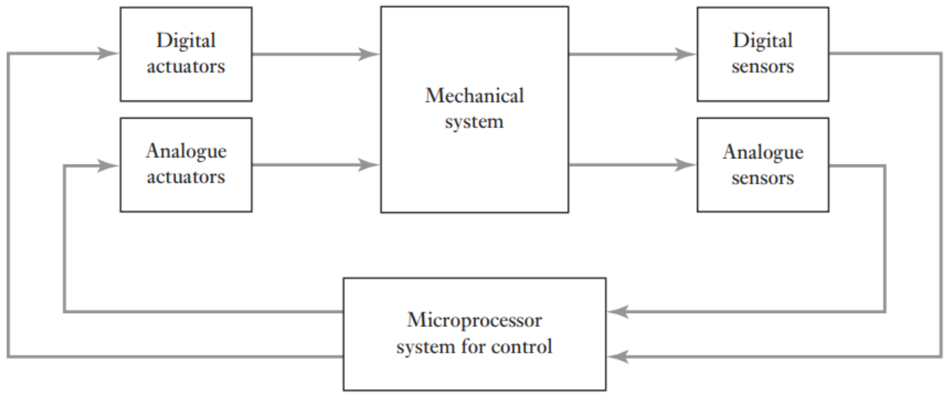
## Basic Elements of Mechatronics Engineering

A mechatronic system is a synergistic combination of mechanical, electronic, computer, and control engineering elements to create a functional and integrated system. The basic elements of a mechatronic system include:

1. **Mechanical Components:**

    **Actuators:** These are responsible for converting electrical signals into mechanical motion. Examples include motors, pistons, solenoids, and valves.

    - **Sensors:** Mechanical sensors detect physical changes such as position, velocity, force, pressure, temperature, and deformation. Examples include encoders, accelerometers, strain gauges, and proximity sensors.
    - **Mechanical Structures:** These form the physical framework of the system, including frames, linkages, gears, belts, and bearings.




2. **Electrical Components:**
    - **Power Supply:** Provides electrical energy to the system. This can range from batteries to external power sources.
    - **Controllers:** Microcontrollers or microprocessors manage the system's operation by processing sensor data and generating control signals.
    - **Wiring and Connectors:** Transmit electrical signals between components, ensuring proper communication and power distribution.
3. **Electronic Components:**
    - **Amplifiers:** Amplify sensor signals or control signals to drive actuators effectively.
    - **Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs):** Convert analog signals (e.g., from sensors) to digital and vice versa.
    - **Interface Modules:** Provide compatibility and communication between different electronic components.
4. **Software and Computing Elements:**
    - **Control Algorithms:** These include PID controllers, state machines, and more to regulate the behavior of the system.
    - **User Interfaces:** Graphical interfaces or command-line interfaces for user interaction and system monitoring.
    - **Programming:** Code that runs on microcontrollers, microprocessors, or embedded systems to execute control algorithms and manage system behavior.
5. **Communication Interfaces:**
    - **Communication Protocols:** Such as UART, SPI, I2C, Ethernet, or wireless protocols like Wi-Fi or Bluetooth for data exchange with external devices or other mechatronic systems.
    - **Networking:** Integration into larger systems or the internet for remote control and data sharing.

6. **Feedback and Control Systems:**
    - **Feedback Loops:** Mechanisms to continuously monitor and adjust system performance based on sensor data and desired outcomes.
    - **Control Algorithms:** Algorithms that process sensor data and generate control signals to achieve specific system goals.
7. **Human-Machine Interface (HMI):**
    - **Displays:** Visual output devices like screens or LEDs to provide feedback and information to users.
    - **Input Devices:** Such as keyboards, touchscreens, or buttons for user interaction.
8. **Power Management and Distribution:**
    - **Voltage Regulators:** Maintain stable voltage levels for electronic components.
    - **Power Distribution:** Routing and managing power to various components as needed.
9. **Safety and Reliability Features:**
    - Redundancy: Backup systems or components to ensure continued operation in case of failure.
    - **Emergency Stop Mechanisms:** Safety measures to quickly halt system operation in case of emergencies.

## Example of Mechatronics System

### Example#1: The modern autofocus, auto-exposure camera

The combination of mechanical components (lenses and actuators), sensors, electronic control systems, and software algorithms allows the camera to automatically adjust focus and exposure settings, making it user-friendly and capable of capturing high-quality photos without requiring manual adjustments.

1. **Mechanical Components:**
    - **Lenses and Focus Mechanism:** The camera has a set of lenses that can move back and forth to adjust the focus. This movement is controlled by an electric motor or actuator.
2. **Electrical Components:**
    - **Actuators:** The electric motor or actuator controls the movement of the lenses for autofocus.
    - **Power Supply:** The camera requires a power source, typically a battery, to operate the electronic components.

3. **Electronic Components:**
    - **Microcontroller or Processor:** This component processes information from sensors and controls various aspects of the camera's operation.
    - **Sensors:** Sensors, such as contrast-detection or phase-detection sensors, detect the sharpness of the image and provide feedback to the microcontroller for focusing.
    - **Light Metering Sensor:** Measures the amount of light entering the camera to determine the appropriate exposure settings.
    - **Control Circuitry:** Manages the autofocus and auto-exposure functions, making decisions based on sensor input.
4. **Software and Computing Elements:**
    - **Control Algorithms:** Algorithms in the camera's software use feedback from sensors to adjust the focus and exposure settings.
    - **User Interface:** The camera often has a display screen where users can see and change settings, though many functions are automated.
5. **Feedback and Control Systems:**
    - **Feedback Loops:** The camera continuously monitors the focus and exposure settings and adjusts them in real-time to ensure the subject is in focus and the image is properly exposed.
6. **Communication Interfaces:**
    - **Buttons or Touchscreens:** These allow users to interact with the camera, including taking pictures and making settings adjustments.
    - **Memory Card Slot:** Allows storage of captured images.
7. **Power Management and Distribution:**
    - **Voltage Regulation:** Ensures that the camera's components receive the correct voltage for optimal operation.
8. **Safety and Reliability Features:**
    - **Redundancy:** Some advanced cameras may have multiple sensors and systems to ensure accurate autofocus and exposure in various conditions.

## Example #2: A truck's smart suspension system

A smart suspension system in a truck is a mechatronic system that combines mechanical components with advanced electronics and control algorithms to provide a comfortable and stable ride, regardless of road conditions, vehicle load, or driving circumstances.

1. **Mechanical Components:**
    - **Suspension Components:** The core mechanical components include springs, shock absorbers, and various linkages that support the truck's weight and absorb shocks from the road.
    - **Load Sensors:** These sensors detect the weight distribution and uneven loading on the truck.
2. **Electrical Components:**
    - **Actuators:** Electric or hydraulic actuators are used to adjust the suspension components in real-time to maintain a level platform and absorb road irregularities.
    - **Load Sensors:** These sensors provide electrical signals to the control system based on the truck's load.
3. **Electronic Components:**
    - **Control Unit:** A central control unit (usually a microcontroller or microprocessor) processes data from various sensors and makes decisions on how to adjust the suspension.
    - **Sensors:** In addition to load sensors, the system may include sensors to measure vehicle speed, wheel speed, steering angle, and accelerometer data.
4. **Software and Computing Elements:**
    - **Control Algorithms:** Sophisticated control algorithms analyze sensor data and determine how to adjust the suspension in real-time to maintain a smooth ride and level platform.
    - **User Interface:** Some systems may offer user-adjustable settings through a digital display or control panel.
5. **Feedback and Control Systems:**
    - **Feedback Loops:** The control system continuously monitors the vehicle's condition and road conditions, adjusting the suspension settings accordingly.

- **Closed-Loop Control:** The system uses closed-loop control to maintain the desired ride quality and level platform.

6. **Communication Interfaces:**

   - **Data Sharing:** In advanced systems, data may be shared with other vehicle systems, such as the engine control unit (ECU) or the anti-lock brake system (ABS), to improve overall vehicle performance and safety.

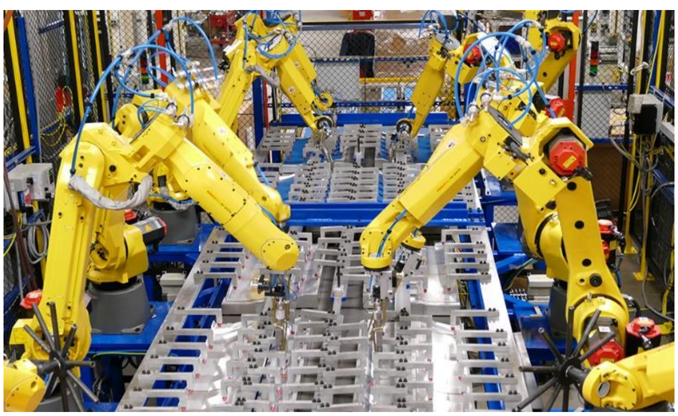
7. **Power Management and Distribution:**

   - **Power Supply:** The system needs a reliable power supply to operate the electronic components and actuators.

8. **Safety and Reliability Features:**

   - **Redundancy:** Some advanced systems may have redundancy in critical components to ensure the suspension can still operate safely in case of a component failure.
   - **Emergency Handling:** The system may have special modes for handling emergency situations, such as rapid adjustments to prevent rollovers.

## Example #3: An automated production line



It is a prime example of a mechatronic system used extensively in manufacturing industries. It combines various mechanical, electronic, and control elements to carry out production processes efficiently and accurately.

1. **Mechanical Components:**

   - **Conveyors and Robotics:** These are used to transport raw materials, workpieces, and products between different production stages.
   - **Machines and Tools:** Various machines and tools are employed for tasks like cutting, welding, assembly, and quality control.

- **Material Handling Systems:** Such as robotic arms, grippers, and conveyor belts are used to move and manipulate parts.
- **Safety Systems:** Mechanical safeguards and emergency stop mechanisms are incorporated to ensure worker safety.

2. **Electrical Components:**
    - **Actuators:** Electric motors and pneumatic actuators are used to move mechanical components, such as robotic arms or conveyor belts.
    - **Sensors:** Sensors detect workpiece positions, quality parameters, and machine statuses. Examples include proximity sensors, photoelectric sensors, and vision systems.
    - **PLCs (Programmable Logic Controllers):** These are industrial-grade computers that control the sequence and operation of machines and processes on the production line.
3. **Electronic Components:**
    - **Control Units:** These control units receive data from sensors and PLCs and issue commands to actuators for precise control.
    - **Human Machine Interface (HMI):** An interface, often a touchscreen or panel, allows operators to monitor and adjust production parameters.
4. **Software and Computing Elements:**
    - **Control Algorithms:** Software programs run on control units to manage the sequencing and coordination of production processes.
    - **Data Logging and Reporting:** Data is collected and logged at each stage of the process, providing real-time feedback and reporting for quality control and process optimization.
    - **Error Handling:** Software can implement error-handling routines and diagnostic procedures to identify and address issues promptly.
5. **Feedback and Control Systems:**
    - **Feedback Loops:** Sensors provide feedback on the status and quality of workpieces, allowing the control system to make real-time adjustments.
    - **Closed-Loop Control:** The system maintains precise control over processes to ensure consistent quality and efficiency.
6. **Communication Interfaces:**
    - **Network Connectivity:** Production lines often have network connections for remote monitoring, data sharing, and integration with other systems like inventory management and order processing.
7. **Power Management and Distribution:**

- **Power Distribution:** Ensures that electrical components receive the appropriate power supply.

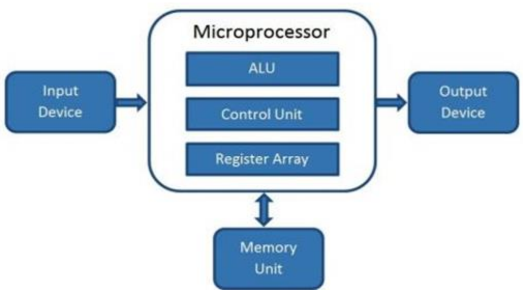
8. **Safety and Reliability Features:**

- **Emergency Stop Systems:** Rapidly halt production in case of emergencies or safety concerns.
- **Redundancy:** Critical components may have backups to prevent production downtime.

## Embedded Systems and Microcontrollers:

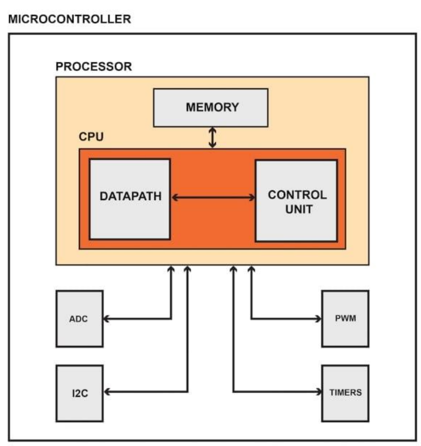
An embedded system is a system where microprocessors or microcontrollers are integrated into devices or machines to control specific functions. These systems are not typically designed to be user-programmable like general-purpose computers.

Microprocessors are essentially collections of logic gates and memory elements that execute instructions defined by software.

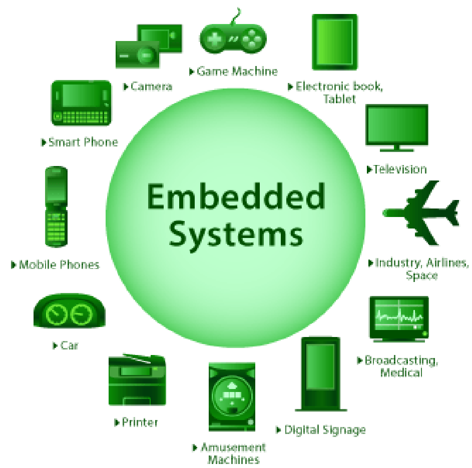



In control systems, microprocessors often require additional components, such as memory for data storage and input/output ports, to interface with the external world.

Microcontrollers are specialized microprocessors that integrate all necessary components (CPU, memory, input/output ports) onto a single chip, making them suitable for embedded systems.

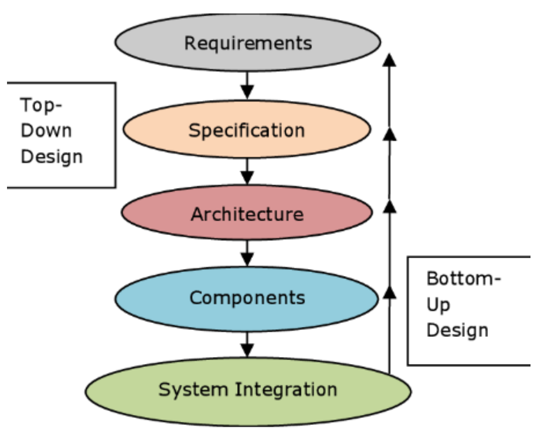


## Examples of Embedded Systems:




- ➢ Modern appliances like washing machines and cars use microprocessor-based control systems to manage various functions, such as washing cycles, engine management, and anti-lock brakes.
- ➢ Other examples of embedded systems include digital cameras, smart cards (used for data storage and processing), mobile phones, printers, televisions, temperature controllers, and various consumer electronics.

## Design Process for Embedded Systems:




The design process for embedded systems typically involves the following steps:

- **Need Identification:** The process starts with identifying the customer or market needs through research.
- **Problem Analysis:** Analyzing the problem accurately is crucial to avoid wasted effort on ineffective designs.
- **Specification:** Preparing a detailed specification outlining the problem, constraints, and quality criteria.

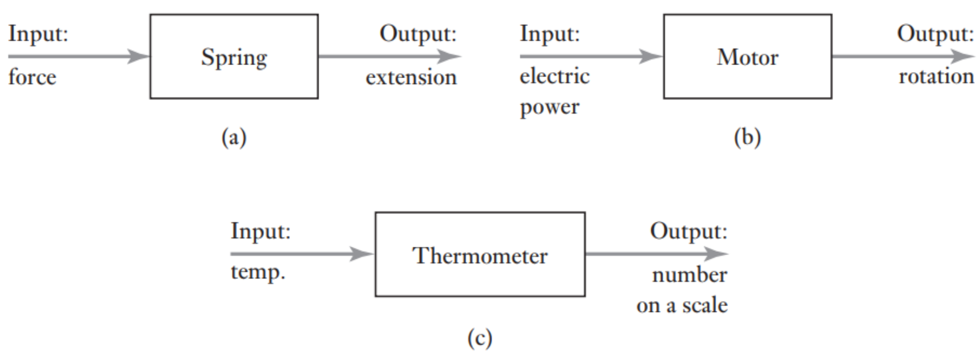
- **Generation of Solutions:** Developing potential solutions, including their approximate size, shape, materials, and costs.
- **Selection of a Solution:** Evaluating and choosing the most suitable solution, often involving modeling and simulation.
- **Detailed Design:** Refining the chosen solution, which may require creating prototypes or mock-ups.
- **Working Drawings:** Translating the selected design into detailed drawings, circuit diagrams, etc., for manufacturing.

## System

In the process of designing mechatronic systems, a crucial step involves constructing a system model. This model serves the purpose of making predictions about how the system will behave when subjected to various inputs.

Visualize a system as a simplified box or block diagram, featuring an input and an output. In this context, our primary concern is not with the internal workings of the system but rather with understanding the relationship that exists between the system's output and the inputs it receives.

The term "modeling" is employed when we seek to represent the behavior of a real-world system using mathematical equations. These equations serve as a means to capture and express the connections and dependencies between the inputs applied to the system and the resulting outputs it produces. This modeling process is a fundamental aspect of designing and analyzing mechatronic systems, enabling engineers to gain insights into system behavior, optimize its performance, and make informed decisions during the design and control processes.




1. **<u>Spring as a System:</u>**

    - Consider a spring as a system with an input force (F) and an output extension (x). When you apply a force to the spring, it extends or compresses in response.
    - To model the relationship between the input force and the output extension, you can use Hooke's Law: F = kx, where:
        - F is the applied force (input).

    - x is the resulting extension or compression (output).
    - k is the spring constant, a measure of the spring's stiffness.
- This equation represents the linear behavior of an ideal spring. It shows how the force applied to the spring relates to the resulting displacement or deformation of the spring.

2. **Motor as a System:**
    - A motor can be viewed as a system with electric power as the input and the rotation of a shaft as the output.
    - When electric power is supplied to the motor, it generates mechanical motion, typically in the form of shaft rotation.
    - The relationship between the input power (P) and the output shaft rotation (θ) can be modeled using various equations, depending on the motor type and characteristics. For example, for a simple DC motor:
        - P = VI, where V is voltage (electric power input) and I is current.
        - The motor's rotation speed (angular velocity) may be related to voltage and current, which can be further linked to the shaft's angular displacement.
    - These equations represent the relationship between the electrical input and the mechanical output of the motor.

3. **Temperature Measurement System (Thermometer):**
    - A temperature measurement system, like a thermometer, serves as an excellent example of a device used to quantify temperature.
    - In this context:
        - **Input:** The input to the thermometer is the temperature of the object or environment being measured. It's the physical quantity you want to assess.
        - **Output:** The output of the thermometer is a numerical value or a position on a scale that corresponds to the temperature. This output provides a quantitative representation of the temperature.

**Operating Principle:**

- A thermometer operates based on a particular physical principle or property that changes with temperature. For example:
    - **Mercury Thermometer:** Uses the expansion and contraction of mercury in a glass tube with temperature changes. The height of the mercury column on a scale represents the temperature.
    - **Digital Thermometer:** Employs electronic sensors, such as thermistors or resistance temperature detectors (RTDs), to measure changes in electrical

resistance with temperature. The device converts this resistance change into a numerical temperature reading displayed on a screen.

**Calibration:**

- To ensure accurate temperature measurements, thermometers are typically calibrated. This involves comparing the thermometer's readings to known temperature standards and adjusting it if necessary to minimize errors.

**Accuracy and Precision:**

- The quality of a temperature measurement system is assessed based on its accuracy (how close the measured temperature is to the true value) and precision (how consistently it provides the same reading for repeated measurements).

**Applications:**

- Temperature measurement systems are widely used in various fields, including weather forecasting, scientific research, industrial processes, medical applications, and everyday household use. They allow us to quantify and monitor temperature, which is critical in many contexts.

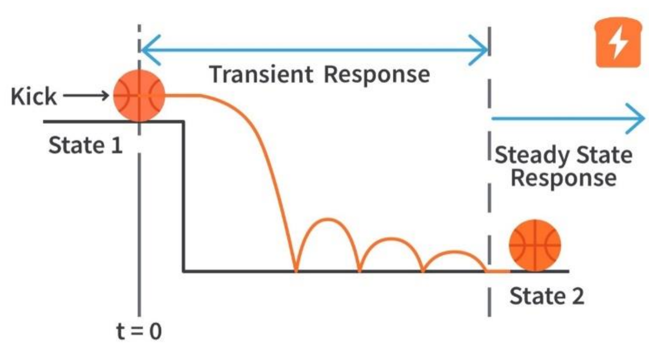
## Modeling Systems

### Transient and Steady-State Response:

When you apply an input to a system, there are two primary phases of response: transient and steady-state.

1. **Transient Response:**

This is the initial phase of the system's response, which occurs as the system transitions from its initial state to a new state due to the applied input. During this phase, the system may exhibit time-dependent behavior, and its output may change rapidly.

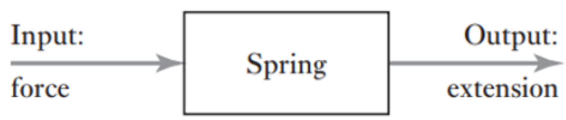


**2. Steady-State Response:**

After the transient response has settled, the system reaches a stable state where its output remains relatively constant or oscillates around a stable value. The steady-state response reflects the system's behavior when it has fully adapted to the input.

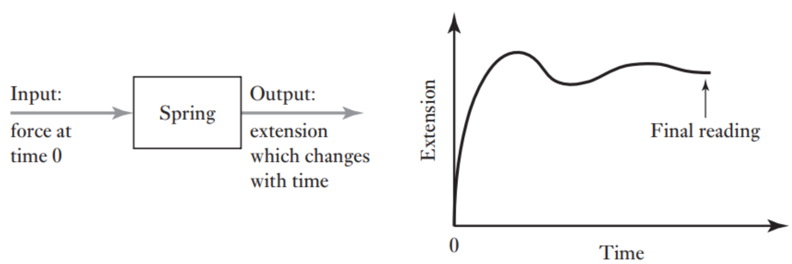
**Example with the Spring System:**

In the case of the spring system described by F = kx, this equation represents the relationship between force (input) and extension (output) when the system has reached a steady-state condition.




(a)

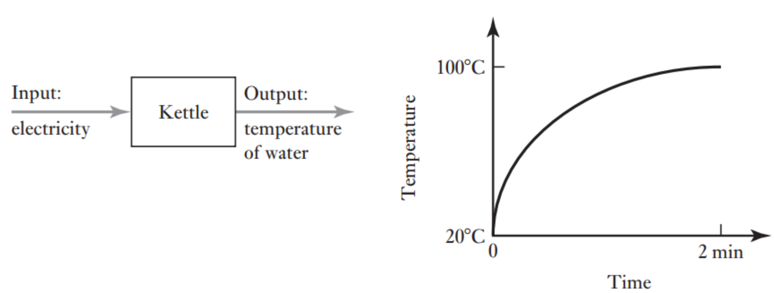
During the transient phase, when you first apply a force to the spring, the spring may undergo temporary deformation and oscillations before settling into a steady-state where F = kx accurately describes its behavior.




The duration and characteristics of the transient phase depend on factors like the system's inertia, damping, and stiffness.

**Kettle Heating Water Example:**

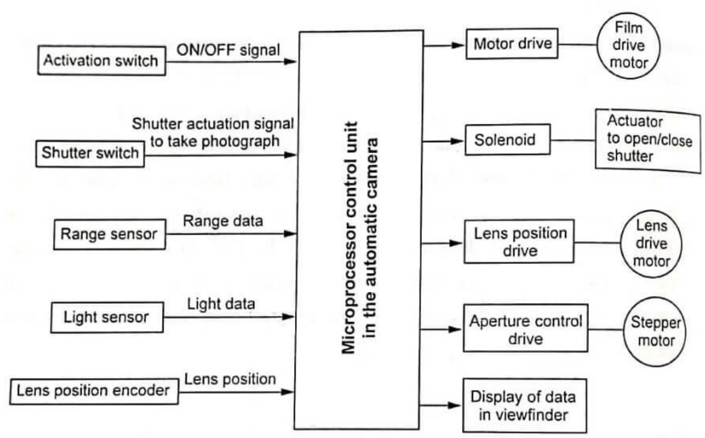
When you switch on an electric kettle to boil water, it's a classic example of a system undergoing transient behavior.




- **Initial State:** At the beginning, the kettle contains cold water, and the heating element is off. The water is at a lower temperature than the desired boiling point.

- **Input:** You switch on the kettle, which applies heat to the water through the heating element.
- **Transient Response:** As the heating element starts warming the water, the water's temperature begins to rise, but it doesn't instantly reach the boiling point. Instead, it goes through a transitional phase during which its temperature gradually increases.
- **Steady-State Response:** Eventually, after some time, the water reaches its boiling point, and you see it boiling and producing steam. At this point, the water has reached a steady-state condition where its temperature remains relatively constant at the boiling point until all the water has evaporated.

**Microprocessor-Controlled Camera Lens Example:**




In modern automatic cameras, microprocessors are often used to control various functions, including lens movement for focusing.

- **Initial State:** The camera lens is in its current position, and you want to focus it on a specific subject.
- **Input:** You initiate a focusing action by giving a signal or command through the camera's controls.
- **Transient Response:** When the microprocessor receives the command, it starts adjusting the lens position. This adjustment does not happen instantaneously. Instead, the lens goes through a transitional phase during which it gradually moves toward the desired focus point. The time it takes to reach the correct focus position can vary based on factors like the lens type, motor speed, and the distance to the subject.
- **Steady-State Response:** Once the lens has moved to the correct position and achieved the desired focus, it enters a steady-state condition where it maintains that focus until further adjustments are needed.

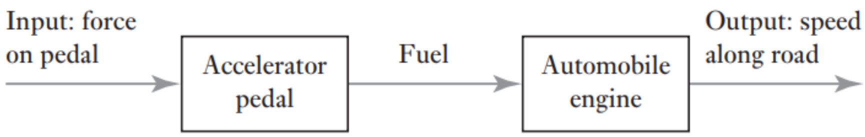
## Connected Systems:

In complex systems, it's often beneficial to view them as a series of interconnected blocks or components, where each block serves a specific function or purpose.

These blocks are connected in a way that allows the output from one block to become the input to the next block, forming a chain of interconnected components.

The lines drawn to connect these blocks represent the flow of information or signals between them, indicating how data or control flows from one part of the system to another.

**<u>Example: Automobile Driving System:</u>**




The example of an automobile's driving system illustrates this concept well:

1. **Accelerator Pedal Block:** This block represents the accelerator pedal, which receives an input force applied by the driver's foot. It controls an output, which is the amount of fuel supplied to the engine.
2. **Engine System Block:** This block represents the engine system, which receives the input of fuel and controls the output, which is the speed of the vehicle along the road.

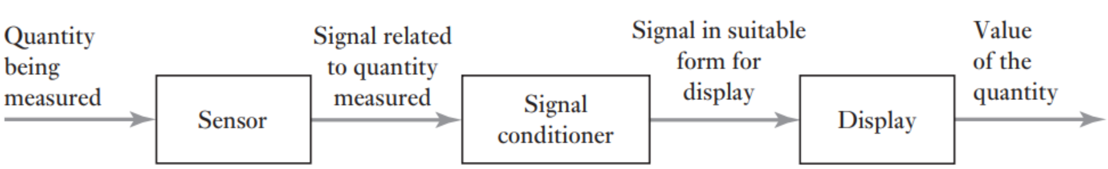
**Interconnected Blocks vs. Physical Connections:**

- It's important to note that the lines connecting these blocks in diagrams represent the flow of information or control signals, not necessarily physical connections like wires or pipes.
- In many systems, the flow of information is vital for the system to function correctly, and understanding how data or control signals pass between blocks helps engineers design and analyze systems effectively.

**Importance:**

- Viewing systems as interconnected blocks simplifies the analysis and design of complex systems. Engineers can focus on the function and behavior of individual blocks, making it easier to understand and optimize the overall system's performance.
- This approach is widely used in various fields, including electrical circuits, control systems, mechanical systems, and many other areas of engineering and technology.

## Measurement System Components:



1. **Sensor:**

A sensor is a device that responds to a physical quantity, such as temperature, by producing an output signal related to that quantity.

Example: A thermocouple is a temperature sensor. When subjected to a temperature change, it generates an electromotive force (e.m.f.) as an output, which is proportional to the temperature.

2. **Signal Conditioner:**

The signal conditioner takes the raw signal from the sensor and processes it to make it suitable for further use, such as display or control.

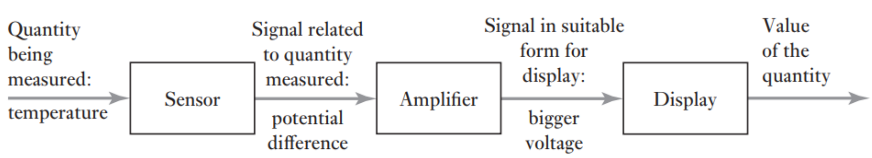
Example: In the case of a thermocouple, the e.m.f. generated is typically small. An amplifier can be used as the signal conditioner to increase the signal's amplitude, making it more usable for further processing.

3. **Display System:**

The display system presents the processed signal in a format that can be easily interpreted by the user.

Example: A digital thermometer takes the conditioned signal and displays the temperature measurement. This display could be in the form of a digital readout, making it easy for users to read the temperature value.

**<u>Digital Thermometer Example:</u>**




In the context of a digital thermometer, here's how it works:

- **Sensor:** The input to the thermometer is the temperature, which is sensed by a semiconductor diode. The diode's voltage across a constant current source is a measure of the temperature.
- **Signal Conditioner:** An operational amplifier is used as a signal conditioner. It amplifies the voltage from the sensor, ensuring that the signal is of sufficient strength for further processing.
- **Display:** The amplified voltage is used to directly drive a digital display, showing the temperature reading.

**Integration on a Silicon Chip:**

It's worth noting that modern digital thermometers often integrate the sensor and operational amplifier on the same silicon chip, making the device compact and efficient.

## Control System Overview:

A control system is a system designed to manage and regulate various aspects, such as variables, sequences of events, or the occurrence of events, to achieve a desired outcome.

Control systems can be classified into different types based on their functions:

1. **Regulating Variables:**

These control systems maintain a specific variable, like temperature, at a particular setpoint. For example, central heating systems regulate room temperature to a desired level.

2. **Sequencing Events:**

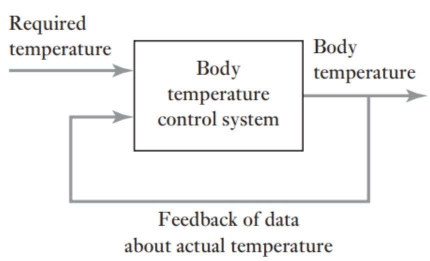
These systems control the sequence of actions or events. For instance, a washing machine follows a specific sequence of events based on the selected wash cycle.

3. **Conditional Control:**

Some systems control whether an event occurs or not based on certain conditions. For instance, a safety lock on machinery prevents operation until a safety guard is properly positioned.

## Human Body Temperature Control:

The human body provides a familiar example of a control system. In this case, the body's temperature control system maintains a nearly constant internal temperature, even when exposed to varying external temperatures.




**Sensors:** The body has sensors that continuously monitor its temperature.

**Comparison:** The sensed temperature is compared to the desired or "normal" temperature.

**Response:** If the sensed temperature deviates from the normal range, the body responds:

- If the temperature is too high, the body initiates sweating to cool down.
- If the temperature is too low, the body initiates shivering to generate heat.

**Feedback Control:** This system operates through feedback control. The body constantly compares the sensed temperature (feedback) with the desired temperature and adjusts its response to maintain the temperature within the desired range.

## Feedback Control

Feedback control is a fundamental principle in control systems. It involves comparing the actual output (feedback) of the system with the desired output and adjusting the system's actions accordingly.

In the example of the human body's temperature control, the body constantly monitors its temperature (feedback) and takes actions to correct any deviations from the desired temperature. This continuous feedback loop helps maintain temperature stability.

A great illustration of feedback control systems and highlighted the difference between manual and automated control. Let's delve into these concepts:

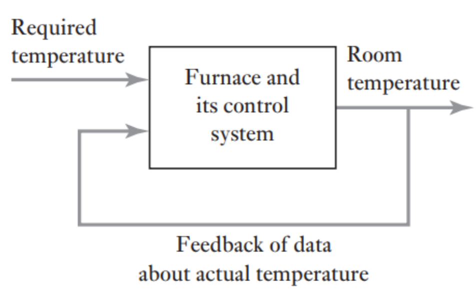
**Manual Control:**

- In the scenario where a human stands near the furnace switch with a thermometer, it represents manual control. Here's how it works:

    1. **Human Operator:** The human acts as the control element or operator. They monitor the temperature using a thermometer.
    2. **Feedback:** The human compares the thermometer reading (feedback) with the desired temperature.
    3. **Control Action:** Based on the comparison, the human manually switches the furnace on or off to adjust the temperature as needed.
    4. **Feedback Loop:** This process involves a feedback loop where the human continuously assesses the temperature and takes action to correct deviations from the desired temperature.

**Automated Feedback Control:**

In a more typical feedback control system with automation, a thermostat or controller is used to automatically regulate the temperature. Here's how it works:




1. **Thermostat/Controller:** The thermostat serves as the control element. It's designed to maintain a specific set temperature.
2. **Sensors:** Temperature sensors continuously measure the actual temperature in the house.
3. **Feedback:** The controller compares the sensed temperature (feedback) with the desired set temperature.
4. **Control Action:** Based on the comparison, the controller automatically switches the furnace on or off to bring the temperature back to the setpoint.

5. **Feedback Loop:** This system also involves a feedback loop, but in this case, it's automated, and the controller adjusts the furnace without human intervention.

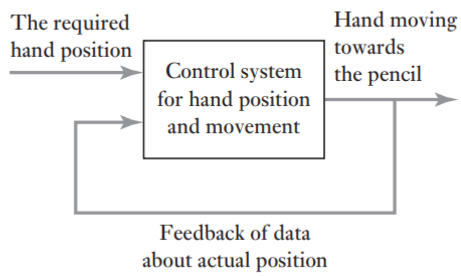
**Feedback Control:**

- In both scenarios, whether manual or automated, the fundamental principle is feedback control. This means that signals, in the form of temperature measurements (feedback), are constantly compared to a reference (the desired set temperature), and actions are taken to correct any discrepancies.

**Advantages of Automated Feedback Control:**

- Automated feedback control systems, such as thermostats, offer several advantages:
  - They can maintain temperature stability without constant human attention.
  - They can respond quickly to temperature changes, ensuring comfort and energy efficiency.
  - They can operate continuously, day and night, without fatigue.

**<u>Picking Up a Pencil Example:</u>**



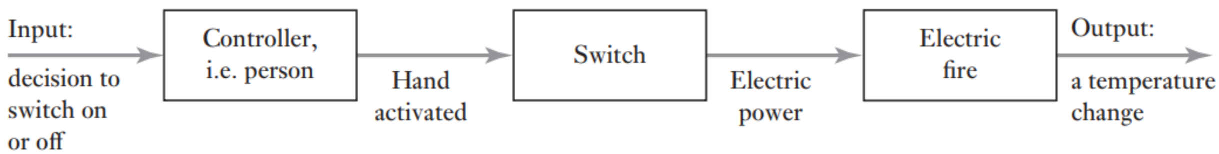

1. **Objective:** The goal is to pick up a pencil from a bench.
2. **Control System:** In this case, your brain and body act as the control system.
3. **Sensors:** Your eyes and proprioceptive senses (sensory feedback from muscles and joints) act as sensors. They provide information about the position of your hand relative to the pencil and the bench.
4. **Feedback:** The sensory input from your eyes and proprioceptive senses serves as feedback. It continuously informs your brain about the actual position of your hand as it moves toward the pencil.
5. **Comparison:** Your brain compares the feedback (actual hand position) with the desired position (where the pencil is) and the intended movement.
6. **Control Action:** Based on this comparison, your brain sends signals to your muscles and motor neurons, instructing them to make precise adjustments in your hand's position and movement.

7. **Feedback Loop:** This process forms a feedback loop. Your senses continuously provide information about your hand's position, enabling your brain to make real-time adjustments to ensure that your hand ends up at the pencil accurately.

**Advantages of Feedback Control:**

- Feedback control in this scenario ensures that you can successfully and precisely pick up the pencil. It accounts for any discrepancies between your intended action and the actual position of your hand, allowing you to make immediate corrections.
- This feedback control system operates seamlessly, enabling you to perform everyday tasks with accuracy and coordination.

## Open-Loop Control




- In an open-loop control system, the control action is determined solely by the initial setup or input, without considering the system's actual output or the need for correction.
- It operates based on a predefined sequence of actions or commands without monitoring the system's performance or making adjustments in response to changes in conditions or disturbances.
- Open-loop systems do not have feedback loops to continuously compare the desired output with the actual output and make corrections.
- Your example of an electric fire with a fixed heating element (1 kW) is a classic open-loop control system. The heating element is turned on based on a person's initial choice, and it operates at a fixed power level without considering room temperature changes or other factors.

## Closed-Loop Control (Feedback Control)

- In a closed-loop control system, feedback is used to continuously compare the actual system output with the desired output (setpoint) and make real-time adjustments to maintain or regulate the output.
- Closed-loop systems have sensors that provide feedback information about the system's performance.
- When there are discrepancies between the desired and actual outputs, the control system takes corrective actions to bring the system back to the desired state.
- Closed-loop control systems are more adaptable and capable of responding to changes and disturbances in the environment.

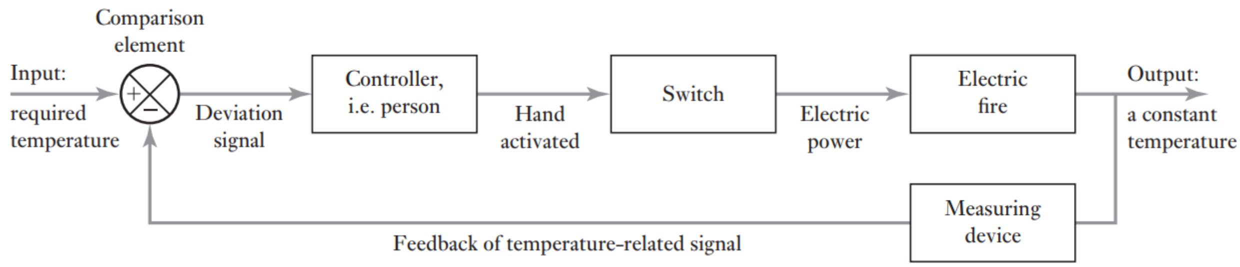
**Electric Fire Example (Open-Loop vs. Closed-Loop):**

- In your example, the open-loop control is represented by the electric fire with a fixed heating element (1 kW). Once it's turned on, it operates at a constant power level, regardless of changes in room temperature.
- In a closed-loop system, the electric fire might have a thermostat that senses the room temperature and adjusts the heating element's power level based on the actual temperature relative to the desired temperature (setpoint). This ensures that the room maintains a constant temperature, even if external conditions change.

**Advantages of Closed-Loop Control:**

- Closed-loop control systems are more robust and adaptable to varying conditions, making them suitable for applications where precise regulation is required.
- They can respond to disturbances and maintain desired setpoints, improving control accuracy and system stability.

**Closed-Loop Heating System:**




1. **Control Element (Person):** In this scenario, the person serves as the control element. They actively monitor the room's temperature using a thermometer and make decisions based on the temperature readings.
2. **Feedback Loop:** The feedback loop is established by continuously comparing the actual room temperature (feedback) to the desired or setpoint temperature.
3. **Comparison Element:** The person acts as the comparison element. They determine the difference between the actual and desired temperatures by observing the thermometer readings.
4. **Control Action:** Based on the comparison of actual and desired temperatures, the person decides whether to switch the 1 kW or 2 kW heating element on or off. The control action is taken to bring the room temperature closer to the desired temperature.

**Advantages of Closed-Loop Control in this Scenario:**

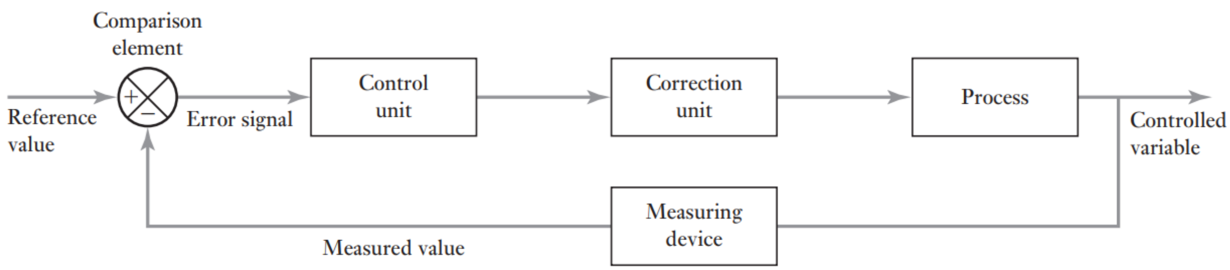
- With this closed-loop system, the room temperature can be maintained much more precisely because the control element (the person) actively responds to temperature changes by adjusting the heating element.

- It allows the system to adapt to variations in room temperature caused by external factors, such as opening windows or doors.
- The closed-loop system provides a level of control accuracy and responsiveness that the open-loop system lacked.

**Feedback Control in Action:**

- The feedback control system continuously assesses the room's actual temperature (feedback) against the desired temperature (setpoint) and takes corrective actions to minimize the temperature difference.
- If the room temperature deviates from the desired temperature, the person makes control decisions to heat or cool the room accordingly.

## Basic Elements of Closed Loop System




1. **Comparison Element:**
    - Function: Compares the desired or reference value (setpoint) with the measured value of the variable being controlled.
    - Action: Produces an error signal based on the difference between the reference value and the measured value.
    - Symbol: Represented by a segmented circle, with inputs going into segments. The feedback input is typically marked as negative, while the reference signal is marked as positive to calculate the error signal.
    - Feedback Type: Negative feedback subtracts from the input value, while positive feedback adds to the input value. Negative feedback is typically used for control systems.
2. **Control Element:**
    - Function: Receives the error signal from the comparison element and decides what action to take to correct the error.
    - Action: It may trigger specific actions, such as operating a switch, opening or closing a valve, or sending control signals to other elements.

- Control Plans: Control plans can vary, from simple on-off control (as in a room thermostat) to proportional control, where the control action is adjusted proportionally to the error's magnitude.

- Implementation: Control elements can be hard-wired, with fixed control plans, or programmable, with control plans stored in memory and alterable by reprogramming.

3. **Correction Element:**

   - Function: Produces changes in the process to correct or modify the controlled condition based on the control element's actions.

   - Action: It may include switches to activate heaters, valves to control fluid flow, or actuators to provide the power needed for control actions.

4. **Process Element:**

   - Function: Represents the system or process that is being controlled. It is the target of the control system's actions.

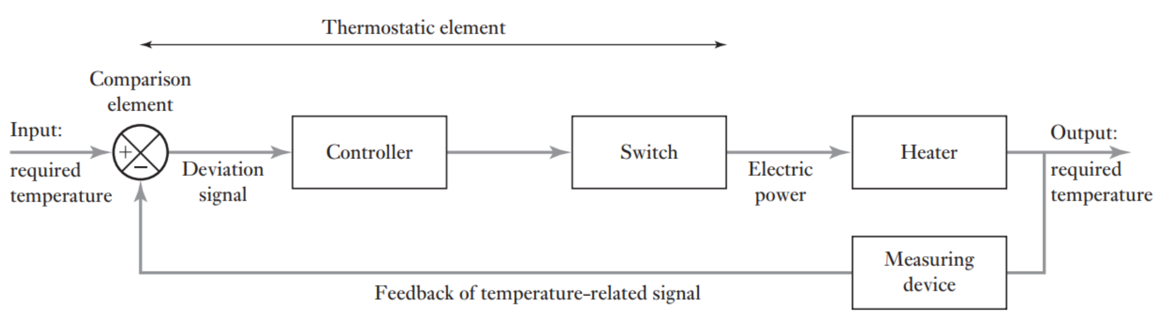
   - Example: The process element could be a room in a house for temperature control or a water tank for level control.

5. **Measurement Element:**

   - Function: Provides feedback to the control system by producing signals related to the variable condition of the process.

   - Action: It may include sensors like switches or thermocouples that produce signals indicating the current state of the controlled variable (e.g., temperature, position, or level).

## Project#1: An automatic control system for the control of the room temperature




1. **Controlled Variable:**

   - The variable being controlled is the room temperature. It represents the actual state or condition that the control system aims to regulate.

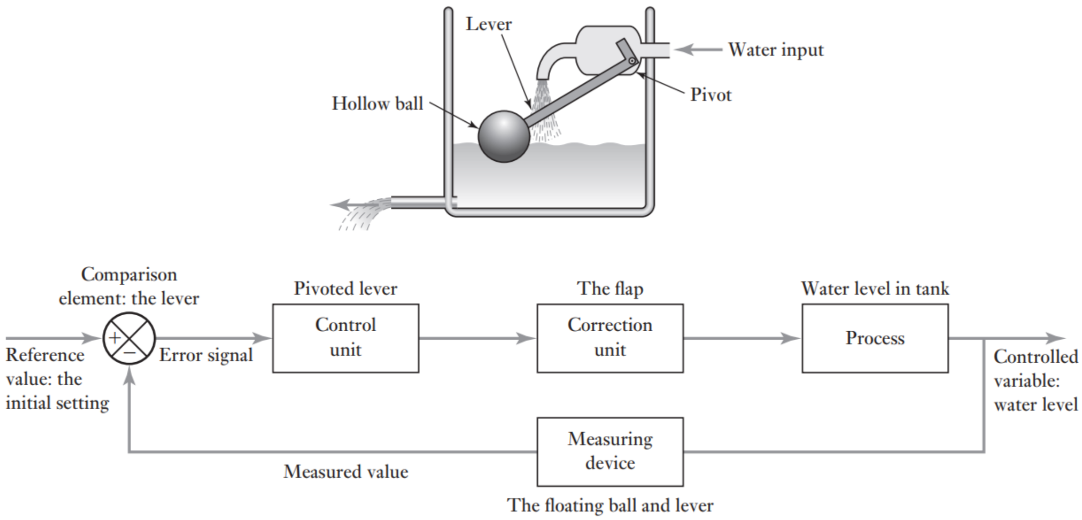
2. **Reference Value:**
    - The reference value is the desired or setpoint temperature that the person wants to maintain in the room. It serves as the target value for temperature control.
3. **Comparison Element:**
    - The comparison element is the person who actively compares the measured room temperature (actual) with the desired room temperature (setpoint).
4. **Error Signal:**
    - The error signal is the difference between the desired room temperature (setpoint) and the measured room temperature. It indicates how far the actual temperature deviates from the desired temperature.
5. **Control Unit:**
    - The control unit can be represented by the thermostatic element. It is sensitive to temperature changes and takes action based on the error signal.
6. **Correction Unit:**
    - The correction unit in this case is responsible for controlling the operation of a switch to activate or deactivate the heater. It receives input from the control unit (thermostatic element).
7. **Process:**
    - The process element represents the physical room or environment whose temperature is being controlled. It is the target of the control system's actions.
8. **Measuring Device:**
    - The measuring device is the thermometer used to measure and provide feedback on the room's actual temperature.

**Automatic Control System:**

- In an automatic control system for room temperature control, the thermostatic element plays a central role. Here's how it works:
    - The thermostatic element is sensitive to temperature changes and serves as both the comparison element and the control unit.
    - When the actual room temperature falls below the set value (reference value), the thermostatic element detects the error (difference) and triggers a switch to turn on the heater.
    - When the room temperature reaches the desired setpoint, the thermostatic element switches off the heater.

- This automatic control system combines the functions of comparison, error detection, and control in a single element (thermostatic element), making it efficient and responsive.

## Project#2: A simple control system used to maintain a constant water level in a tank




1. **Controlled Variable:**
    - The controlled variable is the water level in the tank. This variable represents the actual state or condition that the control system aims to regulate.
2. **Reference Value:**
    - The reference value is the initial setting of the float and lever position. It determines the desired water level in the tank, which serves as the target value for level control.
3. **Comparison Element:**
    - The comparison element is the lever arrangement. It continuously compares the actual water level (float position) with the initial reference value (float and lever position).
4. **Error Signal:**
    - The error signal is the difference between the actual position of the float (water level) and the initial reference position of the float and lever. It indicates how far the actual water level deviates from the desired level.
5. **Control Unit:**
    - The control unit is represented by the pivoted lever connected to the float. It takes action based on the error signal to either open or close the water supply.
6. **Correction Unit:**

- The correction unit in this case is the flap that controls the water supply. It responds to the actions of the control unit to either allow water to enter the tank or cut off the water supply.

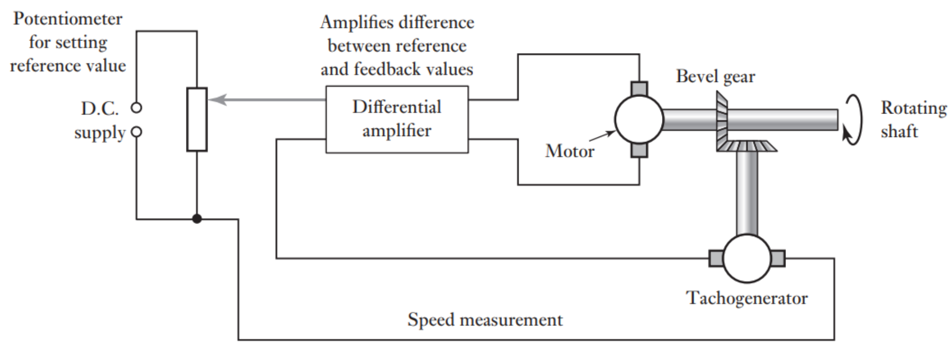
7. **Process:**
   - The process element represents the physical tank containing water. It is the target of the control system's actions.

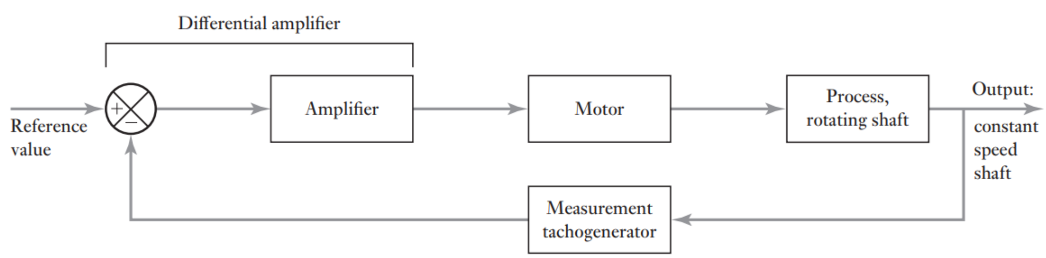
8. **Measuring Device:**
   - The measuring device is the floating ball and lever arrangement. It provides feedback on the current water level in the tank by continuously changing its position as the water level fluctuates.

**System Operation:**

- When water is drawn from the tank, the float moves downward with the decreasing water level.
- The downward movement of the float causes the lever arrangement to rotate, which opens the flap and allows water to enter the tank.
- The water continues to flow until the floating ball has risen to such a height that it moves the lever arrangement back to its initial reference position, cutting off the water supply.
- This closed-loop control system ensures that the water level in the tank remains close to the desired setpoint (initial reference value) by continuously comparing the actual water level (float position) to the reference value and adjusting the water supply as needed.

## Project#3: A simple automatic control system for the speed of rotation of a shaft



1. **Controlled Variable:**
    - The controlled variable is the speed of rotation of the shaft. It represents the actual state or condition that the control system aims to regulate.
2. **Reference Value:**
    - The reference value is set using a potentiometer. It determines the desired speed of rotation, which serves as the target value for speed control.
3. **Comparison Element:**
    - The comparison element is the differential amplifier. It has a dual role:
        - It compares the reference value (set by the potentiometer) with the feedback value (from the tachogenerator).
        - It amplifies the difference (error signal) between the two values.
4. **Error Signal:**
    - The error signal is the amplified difference between the reference value (potentiometer setting) and the feedback value (tachogenerator output). It indicates how far the actual speed deviates from the desired speed.
5. **Control Unit:**
    - The control unit receives the amplified error signal from the differential amplifier. It takes action based on the error signal to adjust the speed of the rotating shaft.
6. **Correction Unit:**
    - The correction unit is represented by the motor. It responds to the actions of the control unit by adjusting the speed of the rotating shaft.
7. **Process:**
    - The process element represents the physical system with the rotating shaft. It is the target of the control system's actions.
8. **Measuring Device:**
    - The measuring device is the tachogenerator, which measures the actual speed of rotation of the shaft. It provides feedback on the current speed to the differential amplifier.

**System Operation:**

- The desired speed of rotation is set using the potentiometer, which acts as the reference value.
- The tachogenerator, connected to the rotating shaft, continuously measures the actual speed of rotation and provides feedback to the differential amplifier.
- The differential amplifier compares the reference value (potentiometer setting) with the feedback value (tachogenerator output) and amplifies the error signal.

- The amplified error signal is then used to control the motor, which adjusts the speed of the rotating shaft.
- The closed-loop control system ensures that the actual speed of rotation closely matches the desired speed set by the potentiometer.