Mechatronics

Week 1 Day 2

Sensors, Actuators, and Systems engineering

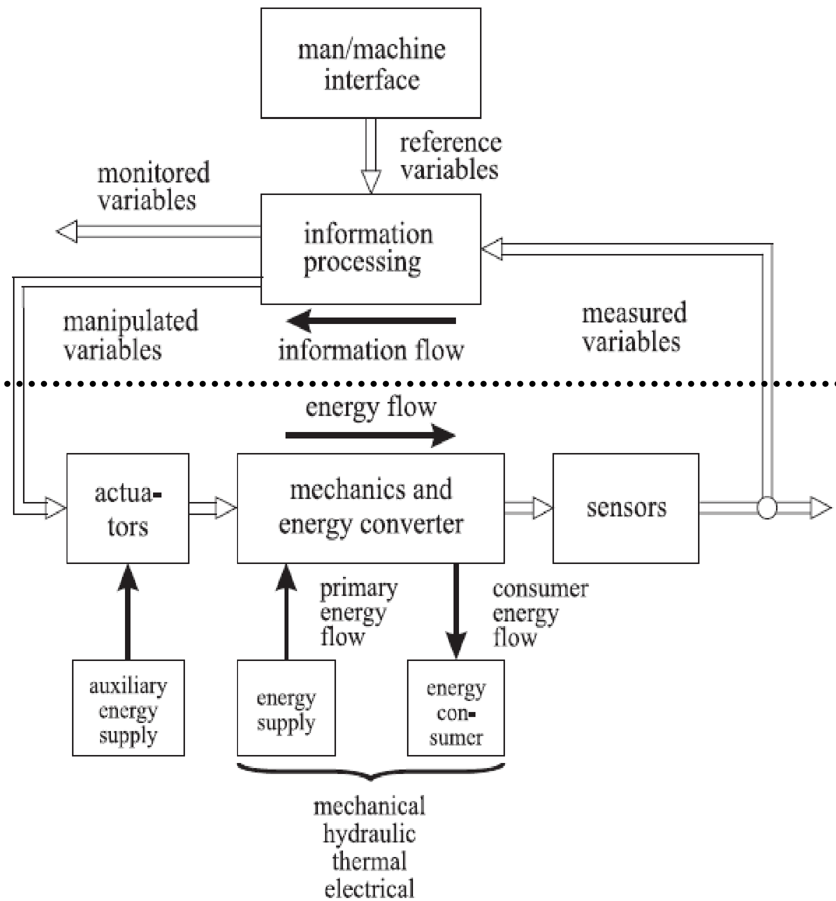
Learning outcomes:

- Identify components of a mechatronics system
- Familiarize with sensors and actuators while appreciating the concepts of a system, inputs, and outputs
- Describe the concept of systems engineering
- Identify role of systems engineering in the design of mechatronic systems

Components of a Mechatronics System

Electronic domain

Mechanical, electrical, hydraulic, or thermal domain



The figure is taken from (Isermann, 2008).

Defining the concept of a system, inputs, and outputs

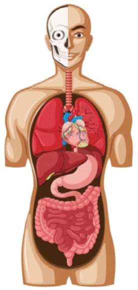
Systems, inputs, and outputs

What is a system?

i. A combination of various components that act together to perform a specific objective.

ii. An entity separable from the rest of the universe (referred to as its environment) through a physical or conceptual boundary.

Some examples of systems are:
- The human body.
- A robotic arm.
- The economy of a country.



Systems, inputs, and outputs

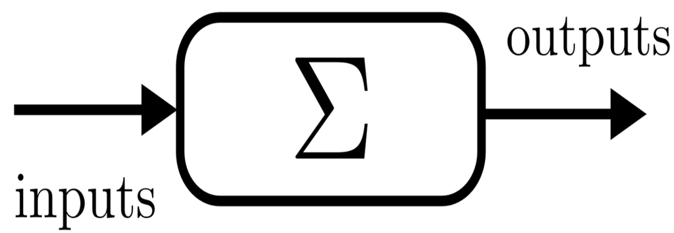
How does the system interact with environment?

Systems, inputs, and outputs

How does the system interact with environment?

Inputs:
Variables that are not directly dependent on what happens in the system.

Outputs:
Variables generated by the system as it interacts with its environment

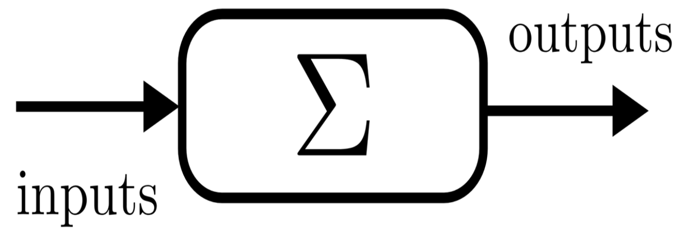


Systems, inputs, and outputs

How does the system interact with environment?

Example: 

A human body is a system equipped with capabilities of sight, voice, hearing, receiving or sending electrical impulses from the brain…



Which are inputs and which are outputs?

Introduction to Sensors and Actuators

Sensors and actuators

Sensors:

- Device that measures the output variable or response
- Device that when exposed to physical phenomena produces a proportional and more suitable signal

Example: Thermocouple.

Physical phenomena: temperature
Measured signal: voltage

- Generally require calibration
- Active or passive (power source or not)

Sensors and actuators

Actuators:

- Device that produces input (action) to the system according to *control signal.*

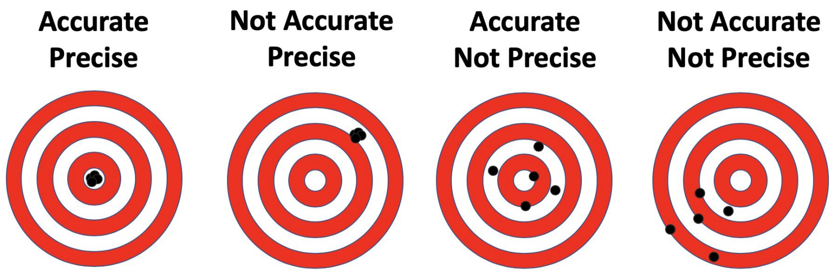
- Device that accepts control command (mostly electrical signal) and acts to produce a desirable and specified change in the physical system by generating force, motion, heat, flow…

Actuators are used in conjunction with a power supply and coupling mechanism.

Sensors and actuators

Sensor and actuator selection criterion, some **definitions**:

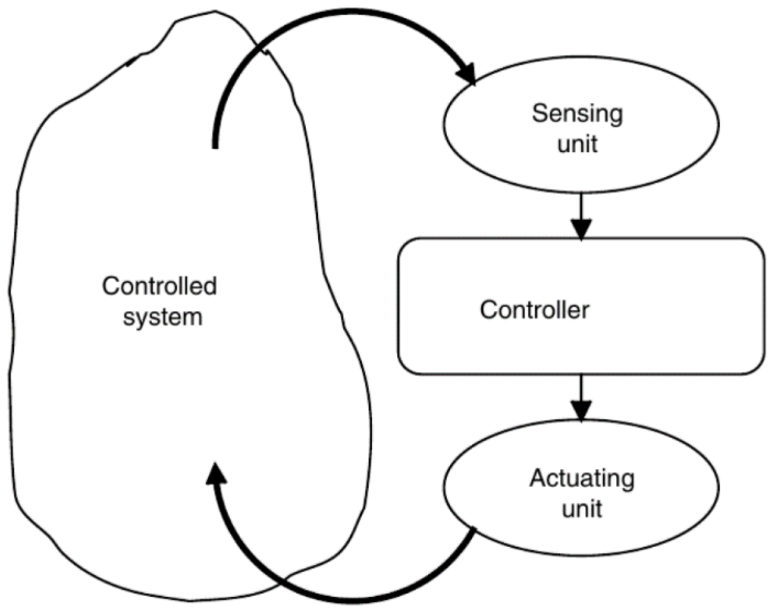
- **Response time:** time lag between input and output
- **Sensitivity:** ratio of change in output to unit change of input
- **Resolution:** smallest change the sensor can differentiate
- **Accuracy:** difference between measured and true value
- **Precision:** ability to repeatedly reproduce a given accuracy



Sensors and actuators

Sensors selection criteria:

- Response time
- Sensitivity
- Accuracy
- Precision
- Resolution



Actuators selection criteria:

- Power requirement
- Accuracy
- Range of motion
- Resolution
- Durability

Introduction to Coupling Devices

Coupling devices

Devices use for conversion from one physical domain to another. For example, from mechanical to electrical (and vice versa) or from fluid to mechanical (and vice versa)

- They involve energy conversion from a type to another
- If very small amount of energy is converted, they are referred to as signal-converting transducers
- Usually couple electrical domain to and from physical domain (mechanical-fluid-thermal)
- Actuators and sensors are considered coupling devices

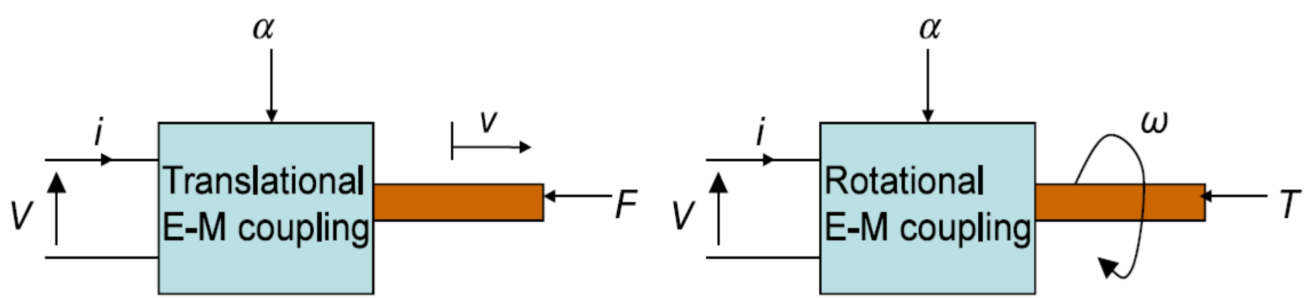
Actuators

Electro-mechanical coupling as an **actuator**

- Coupling between mechanical and electrical elements is provided through a magnetic field
- The magnetic field can be generated by inductors (with coils), or by permanent magnets
- **Motor**: Magnetic field makes mechanical side move
- **Generator:** Mechanical movement changes magnetic field which makes current flow
- Lorentz law is the basis for this

Electro-mechanical coupling as an actuator

Diagram of ideal (power in= power out) electromechanical coupling:



$F = \frac{1}{\alpha} i$

$v = \alpha V$

$T = \frac{1}{\alpha} i$

$\omega = \alpha V$

- Electrical power: V · i
- Mech translational power: F · v
- Mech rotational power: T · w

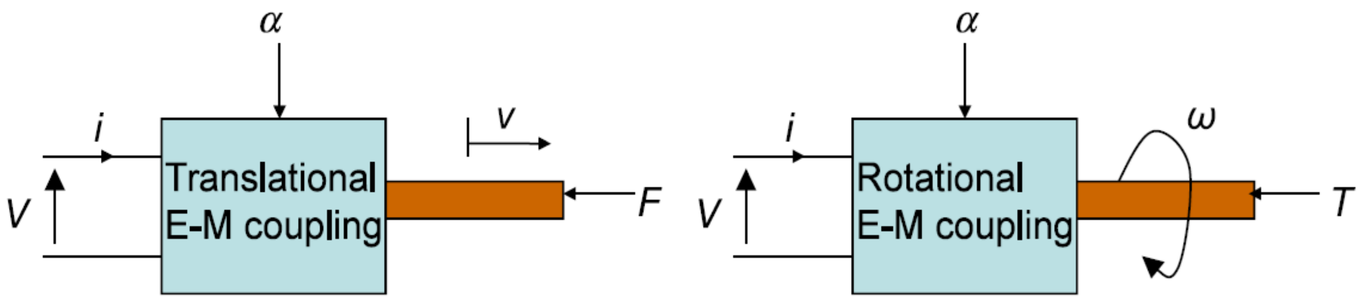
Coupling:

V · i =F ·v

or

V · i = T · w

Electro-mechanical coupling as an actuator



$$F = \frac{1}{\alpha} i$$
$$v = \alpha V$$

$$T = \frac{1}{\alpha} i$$
$$\omega = \alpha V$$

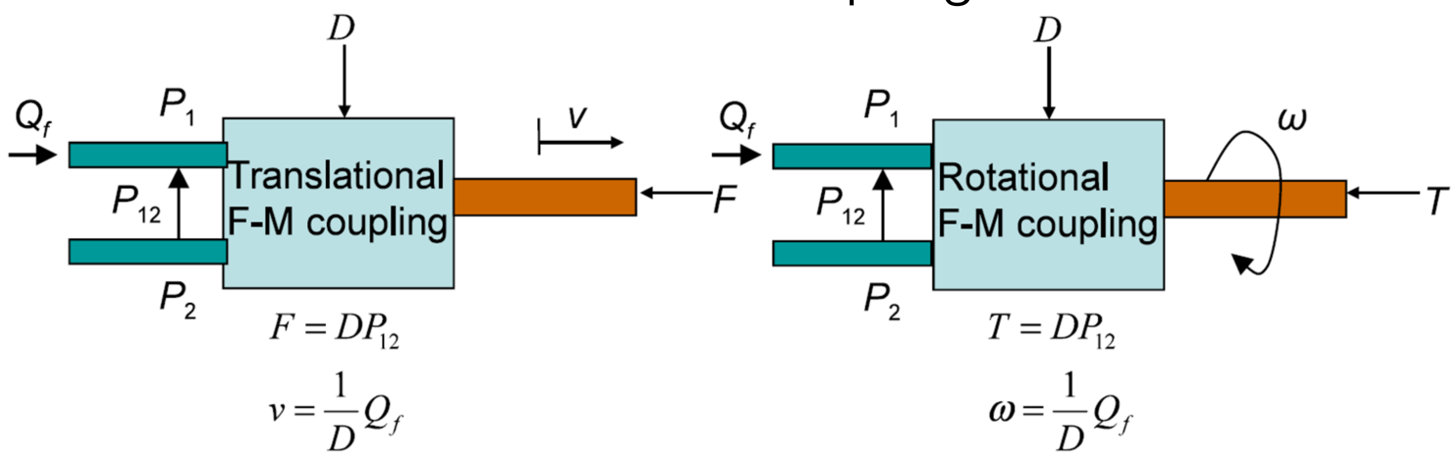
Using above convention for arrows:

- Positive power implies the coupling acts as a motor.
- Negative power makes the coupling a generator.

In DC motor, constant $1/\alpha$ is referred as torque constant.
Constant α is referred to as speed constant.

Fluid-mechanical coupling as an actuator

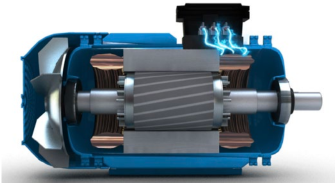
Diagram of ideal fluid-mechanical coupling:



- Constant D is interpreted as the amount of displaced volume per displacement of output shaft. $Q_f = Dv$
- Model only valid when compressibility of the fluid is negligible
- **Coupling** based on static fluid pressure applied to moving parts
- Devices called hydrostatic energy converters

Electro mechanical vs fluid-mechanical coupling

Electric motor:



Electro-mechanical coupling

Electric energy translated to mechanical rotational

- Lower forces
- Smaller (Most compact size together with piezo-electric actuators)

Hydraulic actuator:

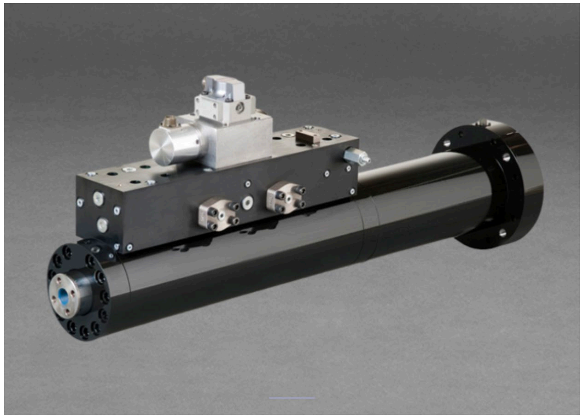
Fluid-mechanical coupling

Hydraulic power translated to mechanical rotational

- Higher forces
- Require pressure sources and/or accumulators
- Bigger

Electrohydraulic servo actuator

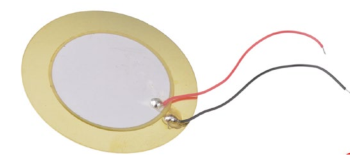
- Used to control powerful hydraulic cylinders with a small electrical signal
- Controls how hydraulic fluid is sent to an actuator
- Used in aerospace and robotic systems
- Servo valves can provide precise control of position, velocity, pressure and force



Hydraulic: a liquid moving in a confined space under pressure

Smart material actuators

- Piezoelectric and electrostrictive actuators: convert electrical signal into physical displacement.

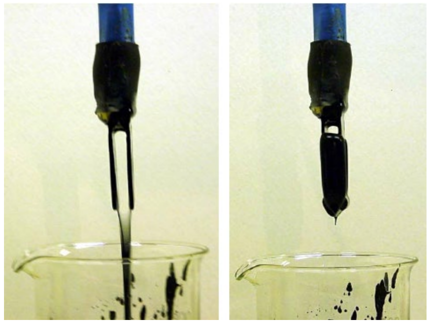


- Magnetostrictive actuators: convert electromagnetic energy into mechanical energy. Example material: Terfenol-D

- Shape memory alloys: electrically powered, can enable movement of soft robots. Example: copper-aluminium-nickel

Smart material actuators

- Electrorheological fluids: change of viscosity due to electrical field. Example: cornflour + vegetable oil



Uncharged vs charged

- Ultrasonic piezo-motors: create rotary or linear motion by electrical excitation of piezo elements. Example material: lead zirconate titanate

Sensors

Sensor classification

Classified according to measurement objectives

Temperature
(Thermocouple. Thermistor, RTD, thermo-diode, infrared…)

Thermocouple: temperature change measured as change on resistance

Light
(photoresistor, photodiode, phototransistors, photoconductors, charge coupled diodes

Linear/ Rotational
LVDT/RVDT, optical encoder, tachometer, hall-effect sensor, capacitive transducer…

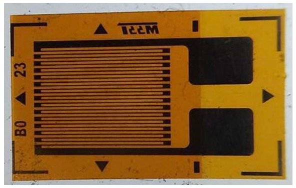
LVDT: measure linear displacement as electrical current

Photoresistor: decrease resistance with light

Sensor classification

Classified according to measurement objectives

Force, torque, pressure
Strain gauge dynamometer, piezoelectric load cell, tactile sensor, ultrasonic stress sensor…



Strain gauge: measure strain on object from electrical conductance

Flow
(Pitot tube, orifice plate, dlow nozzle, rotameter, turbine flow meter…)

Pitot tube: measure difference between stagnation and static pressure

Acceleration
Seismic accelerometer, piezoelectric accelerometer

Seismic accelerometer
charge is generated proportional to the vibration of machine or structure

Proximity
(inductance, Eddy current, hall effect…

Inductive sensor

Systems Engineering

Systems Engineering

An interdisciplinary approach and means to enable the successful realization of (complex) systems [1]

[1]Systems Engineering Handbook, version 2a. INCOSE. 2004.

Systems Engineering

An interdisciplinary approach and means to enable the successful realization of (complex) systems [1]

- Focuses on defining user demands and functional requirements early in the design cycle

Remember previous lecture... Design of Artificial Limb

- User demands: walk on two legs, no pain...
- Functional requirements: nervous system actuate leg, lifetime...

[1]Systems Engineering Handbook, version 2a. INCOSE. 2004.

Systems Engineering

An interdisciplinary approach and means to enable the successful realization of (complex) systems [1]

- Focuses on defining user demands and functional requirements early in the design cycle
- Integrates several disciplines and specialized groups into a team effort

Remember previous lecture... Design of Artificial Limb
Integrates mechanical, electrical, biomedical engineers, robotics experts, doctors...

[1] Systems Engineering Handbook, version 2a. INCOSE. 2004.

Systems Engineering

An interdisciplinary approach and means to enable the successful realization of (complex) systems [1]

- Focuses on defining user demands and functional requirements early in the design cycle
- Integrates several disciplines and specialized groups into a team effort
- Considers both the business and technical needs of the customers

Remember previous lecture... Design of Artificial Limb

- Business: market, cost, regulatory compliance
- Technical: biomechanics, ergonomics, safety, weight...

[1] Systems Engineering Handbook, version 2a. INCOSE. 2004.

Main Ideas Systems Engineering

- Understand the whole problem before trying to solve it

Main Ideas Systems Engineering

- Understand the whole problem before trying to solve it
- Translate the problem into measurable requirements

Main Ideas Systems Engineering

- Understand the whole problem before trying to solve it
- Translate the problem into measurable requirements
- Examine all feasible alternatives before selecting a solution

Main Ideas Systems Engineering

- Understand the whole problem before trying to solve it
- Translate the problem into measurable requirements
- Examine all feasible alternatives before selecting a solution
- Make sure the total system life cycle is being considered. Birth to death concept extends to maintenance, replacement and decommission.

Main Ideas Systems Engineering

- Understand the whole problem before trying to solve it
- Translate the problem into measurable requirements
- Examine all feasible alternatives before selecting a solution
- Make sure the total system life cycle is being considered. Birth to death concept extends to maintenance, replacement and decommission.
- Make sure to test the total system before delivering it

Main Ideas Systems Engineering

- Understand the whole problem before trying to solve it
- Translate the problem into measurable requirements
- Examine all feasible alternatives before selecting a solution
- Make sure the total system life cycle is being considered. Birth to death concept extends to maintenance, replacement and decommission.
- Make sure to test the total system before delivering it
- Document everything

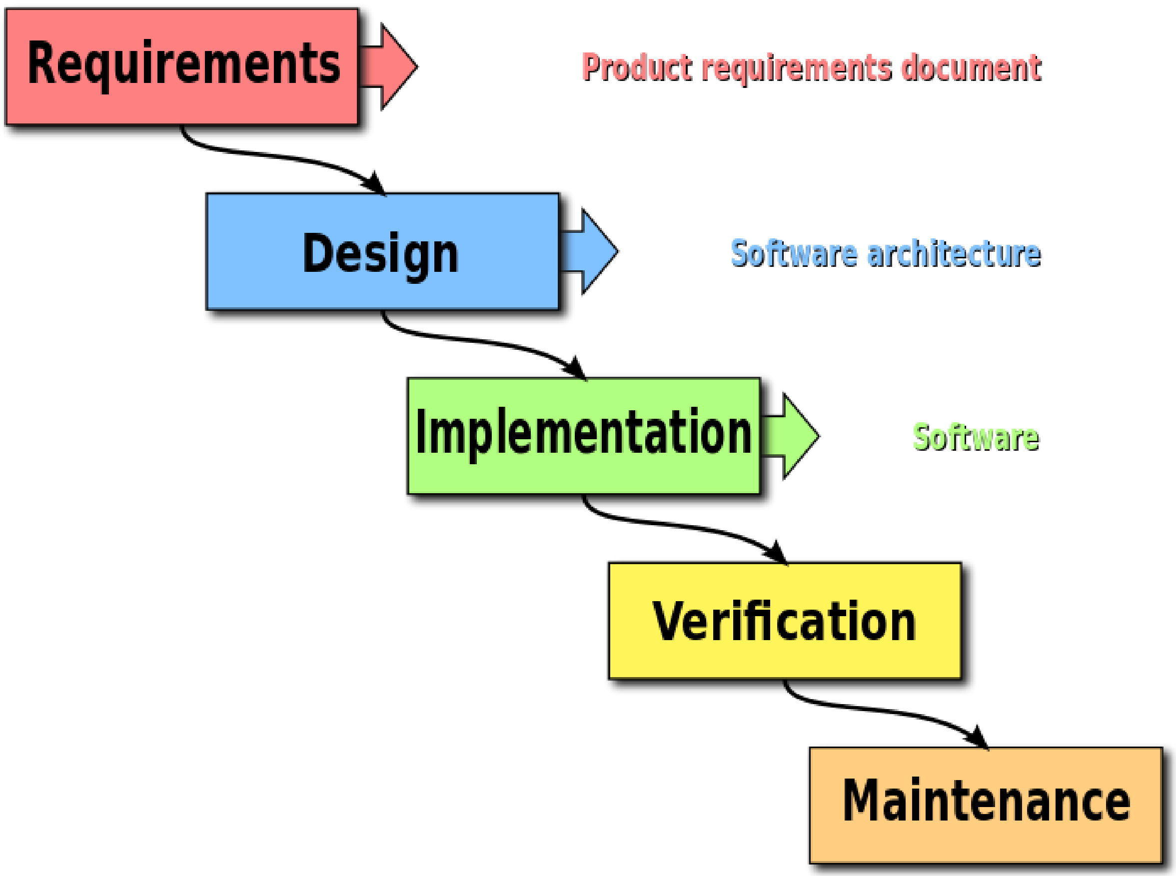
Main Issues of Design

Client knows *partially or informally* what they want.

but

Designer requires *detailed and complete* specifications.

Classical waterfall design approach



Classical waterfall design approach

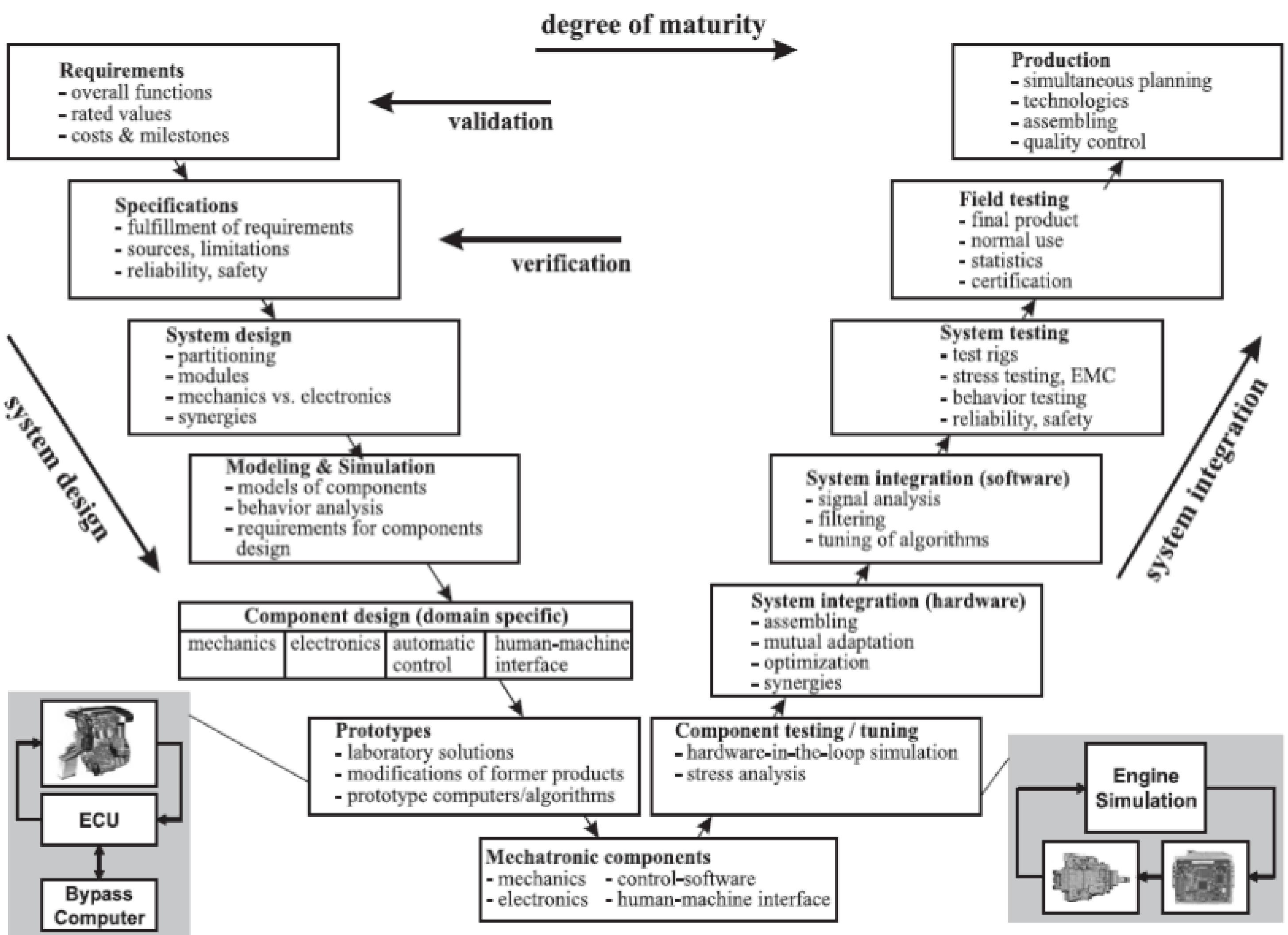
Advantages:

- ✓ Natural, sequential Flow
- ✓ Simple structure
- ✓ Well identified schedules
- ✓ Easily explainable phases
- ✓ Easily identifiable milestones
- ✓ Suitable for projects with well established goals and clear technological needs

Disadvantages:

- Clients usually do not have clear picture of their wants
- Distinct phases of the design may be unaware of needs of others
- Difficult to foresee future issues
- Major costs for late redesign and redevelopment

Improved model: V-model of System Engineering Process



V-model of System Engineering Process

Two key elements:

1. Validation: does the system/product/service meet the needs for customer or stakeholder?

2. Verification: are imposed requirements/specifications fulfilled?

university of groningen / faculty of science and engineering

Mechatronics and its relationship with systems Engineering

Design challenges in mechatronics

- Mechatronics combines all fields of mechanical and electrical engineering

Design challenges in mechatronics

- Mechatronics combines all fields of mechanical and electrical engineering
- Mechatronics systems are employed in various fields, including power systems, transportation, optical telecommunications and biomedical engineering

Design challenges in mechatronics

- Mechatronics combines all fields of mechanical and electrical engineering
- Mechatronics systems are employed in various fields, including power systems, transportation, optical telecommunications and biomedical engineering
- Preliminary design of mechatronic systems is an extremely important step in the development process of multi-disciplinary products

Design challenges in mechatronics

- Mechatronics combines all fields of mechanical and electrical engineering
- Mechatronics systems are employed in various fields, including power systems, transportation, optical telecommunications and biomedical engineering
- Preliminary design of mechatronic systems is an extremely important step in the development process of multi-disciplinary products
- Great challenge lies in the multidisciplinary optimization of a complete system with various physical phenomena related to interacting heterogeneous subsystems

Mechatronics…

- is highly interdisciplinary

Mechatronics…

- is highly interdisciplinary
- is interactive

Mechatronics…

- is highly interdisciplinary
- is interactive
- conveys expertise of several fields, each of which has its own set of ‘toolboxes’

Mechatronics…

- is highly interdisciplinary
- is interactive
- conveys expertise of several fields, each of which has its own set of ‘toolboxes’
- requires a well defined set of user and functional requirements and design parameters

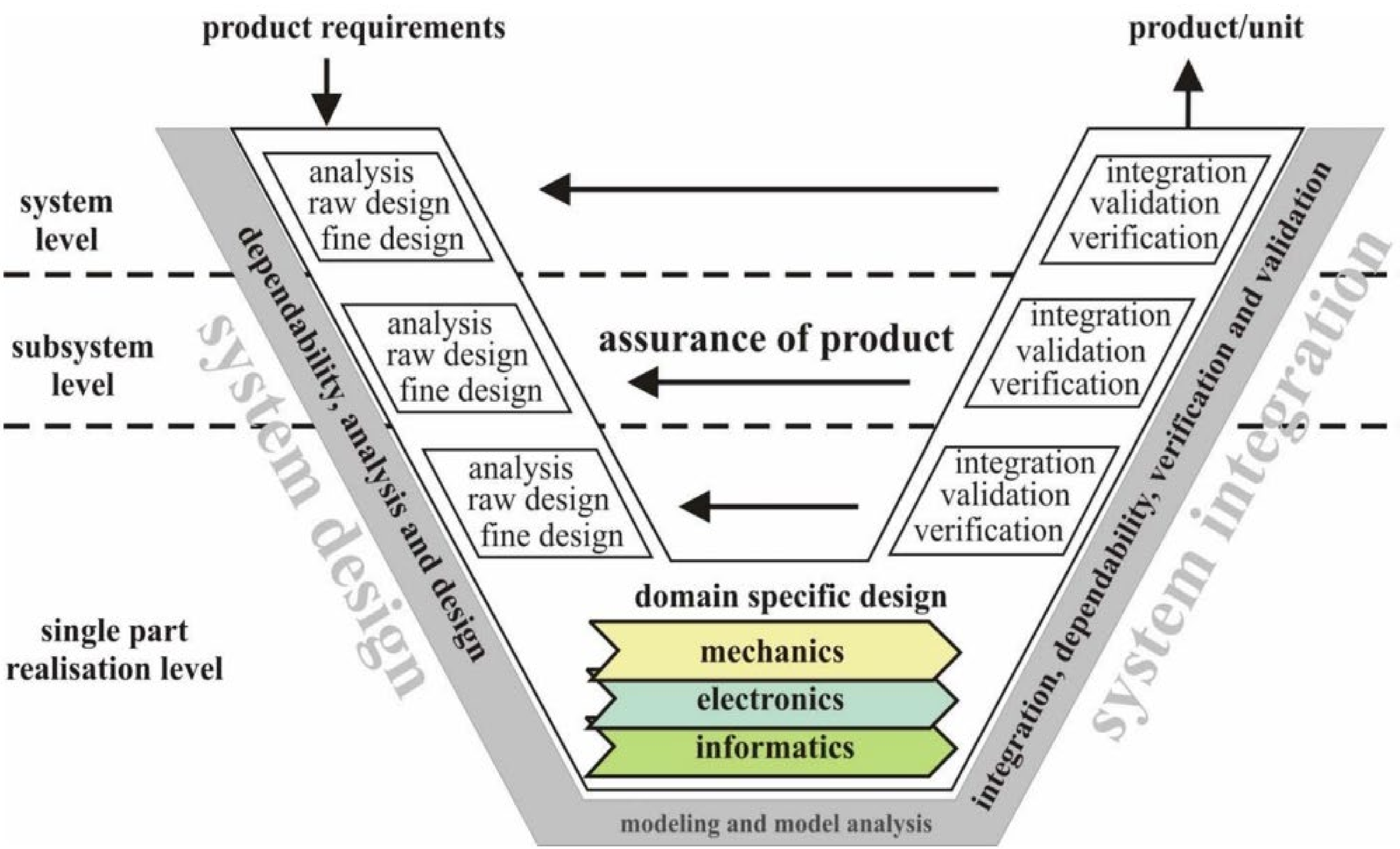
Mechatronics…

- is highly interdisciplinary
- is interactive
- conveys expertise of several fields, each of which has its own set of ‘toolboxes’
- requires a well defined set of user and functional requirements and design parameters
- is flexible

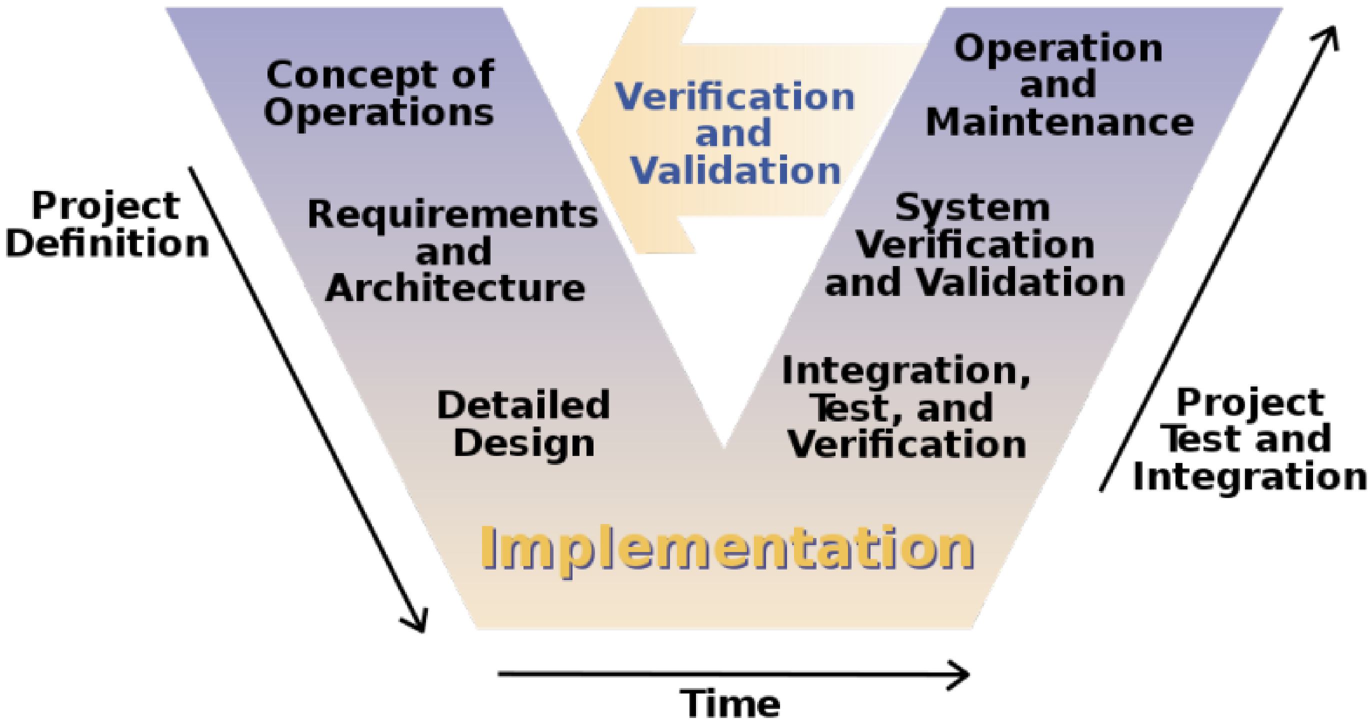
Mechatronics…

- is highly interdisciplinary
- is interactive
- conveys expertise of several fields, each of which has its own set of 'toolboxes'
- requires a well defined set of user and functional requirements and design parameters
- is flexible
- looks for the optimal design and solution to a problem

Mechatronics design cycle



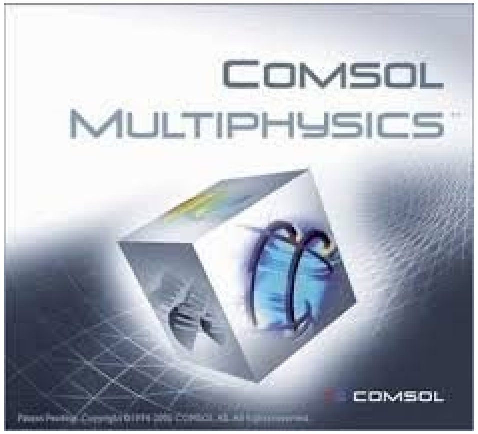
Mechatronics design cycle



Some computational tools

MATLAB

ANSYS



SOLIDWORKS

Some companies

ASML

ALTEN

VDL

Rockwell Automation

ABB

BOSCH
Technologie voor het leven

Summary

- Systems interacts with its environment through sensors and actuators which are related to inputs and outputs of the system

Summary

- Systems interacts with its environment through sensors and actuators which are related to inputs and outputs of the system
- There exists different classification and selection criteria for sensors and actuators

Summary

- Systems interacts with its environment through sensors and actuators which are related to inputs and outputs of the system
- There exists different classification and selection criteria for sensors and actuators
- Systems Engineering provides an interdisciplinary approach that focuses on design, integration and management of complex system.

Summary

- Systems interacts with its environment through sensors and actuators which are related to inputs and outputs of the system
- There exists different classification and selection criteria for sensors and actuators
- Systems Engineering provides an interdisciplinary approach that focuses on design, integration and management of complex system.
- In Systems Engineering the design process, the design methodology and the organizational structure are considered simultaneously

Summary

- Systems interacts with its environment through sensors and actuators which are related to inputs and outputs of the system
- There exists different classification and selection criteria for sensors and actuators
- Systems Engineering provides an interdisciplinary approach that focuses on design, integration and management of complex system.
- In Systems Engineering the design process, the design methodology and the organizational structure are considered simultaneously
- The Systems Engineering approaches eases the design of Mechatronic systems

Next

Next Lecture:

- Introduction to modeling of dynamical systems