MECH 420
Sensors and Actuators

Presentation Part 1

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Part 1: Preliminaries & Introduction

- Preliminaries
- Introduction of the Subject
- Sensors and Actuators
- Mechatronics and Instrumentation
- Instrumentation Process
- Examples

Preliminaries

MECH 420: SENSORS AND ACTUATORS

3 Credits, First Semester, 2020/21

Lectures (On-line, Recorded and URL posted on Canvas):
Wednesdays and Fridays, 3:00 to 4:00 pm

Instructor
Dr. Clarence de Silva, Professor, UBC Department of Mechanical Engineering

E-mail: desilva@mech.ubc.ca

On-line Office Hours: Tuesdays 3:00 to 4:00 p.m; and 11:00 pm to 12:00 midnight

Course Format and Assessment

(a) Course Format

Two Lectures per week (on-line): Will present fundamentals, theory, methods, applications, and examples. Recorded and URL posted on Canvas

Homework Assignments : Solutions will be posted after a sufficient time; Your work will not be graded

Intermediate Exam: Typically two questions. on Friday, Nov. 06, followed by a face-to-face interview on the subject material, if needed

Laboratory: Four recorded experiments will be provided with experimental data (different for each student). Each student must submit a complete and comprehensive lab report within one week, which should include data analysis, presentation and discussion of results, and exploration on practical issues, modifications, and improvements of the experiments.

Final Exam: Will follow the University schedule; typically 4 questions, followed by a face-to-face interview on the subject material, if needed

Resources Needed by the Students for the Exams:

A good web cam, ruled papers and pen; Reliable Internet connection

(b) Assessment

Laboratory work (individual reports)	**=**	**25%**
Intermediate exam	**=**	**25%**
Homework assignments	**=**	**0%**
Final exam	**=**	**50%**
Total	**=**	**100%**

Lab Schedule

Lab	Data Provided on	Experiment (Lab Report) Title
# 1	Nov. 02 2019	Data Acquisition and Proximity Sensors for Object Detection
# 2	Nov. 09 2019	Optical Encoder and Torque Sensor
# 3	Nov. 16 2019	Dynamic Transducer Transfer Characteristics – Time Domain
# 4	Nov. 23 2019	Dynamic Transducer Characteristics – Frequency Domain
# 5	Nov. 30 2019	Hydraulic System with Servo Valves and Sensors

Please see Canvas for the lab manuals, recordings and other details

Course Topics

Sensors, Actuators, and Controls: Instrumentation Problem; Mechatronic Systems
Component Interconnection: Component matching, Impedance/Loading Issues
Signal Conditioning: Filtering, Amplification, etc.
Performance Specification: Instrument Ratings, (Time domain, frequency domain, practical), Sampling, Bandwidth Issues; Error Combination/Analysis

Why are ratings important?

Analog Sensors: Torque, Force and Tactile Sensors; Fluid and Thermal Sensors
Digital Sensors and Encoders
Mechanical Transmission Components
Stepper Motors
DC and AC Motors
Hydraulic Actuators

Group these topics into categories such as: Sensors, Actuators, Any other (e.g., signal conditioning, signal conversion, signal modification , interfacing)

Course Resources

The following material will be provided:

- **Lecture presentations (ppt) and recordings**
- **Worked Examples (In-class, interactive)**
- **Homework Assignments and Solutions**
- **Example Exam Questions and Solutions**
- **Lab Manuals, lab recordings, and individual lab data**

Resources Needed by the Students for the Exams:

A good web cam, ruled papers and pen; Reliable Internet connection

Textbook

De Silva, C.W., *Sensors and Actuators—Engineering System Instrumentation*, 2nd Edition, Taylor & Francis, CRC Press, Boca Raton, FL, 2016. (E-book available from the UBC library)

Course Plan

Week	Starts	Topic	Read
1	Sept. 04	Introduction	Chapter 1
2	Sept. 11	Component Interconnection	Chapter 2
3	Sept. 18	Signal Conditioning, Conversion, Modification	Chapter 2
4	Sept. 25	Performance Specification and Instrument Rating Parameters	Chapter 3
5	Oct. 02	Bandwidth Issues, Error Considerations	Chapter 3
6	Oct. 09	Analog Motion Sensors	Chapter 5
7	Oct. 16	Torque, Force, and Tactile Sensors, etc.	Chapter 5
8	Oct. 23	Digital Motion Transducers	Chapter 6
9	Oct. 30	Mechanical Transmission Components **Intermediate exam on November 06**	Chapter 7
10	Nov. 06	Stepper Motors	Chapter 8
11	Nov. 13	DC Motors	Chapter 9
12	Nov. 20	AC Motors	Chapter 9
13	Nov. 27	Hydraulic Actuators	Chapter 9

Course Overview

Course Approach

- Treat general and fundamental topics of sensing, actuation, and instrumentation
- Consider specific examples and their solution, and practical applications in engineering systems
- Take into account the fact that system components have to function as an interconnected and interdependent group, with dynamic interactions.

Why?

Course Coverage:

- Fundamental and practical issues of sensors, actuators and instrumentation

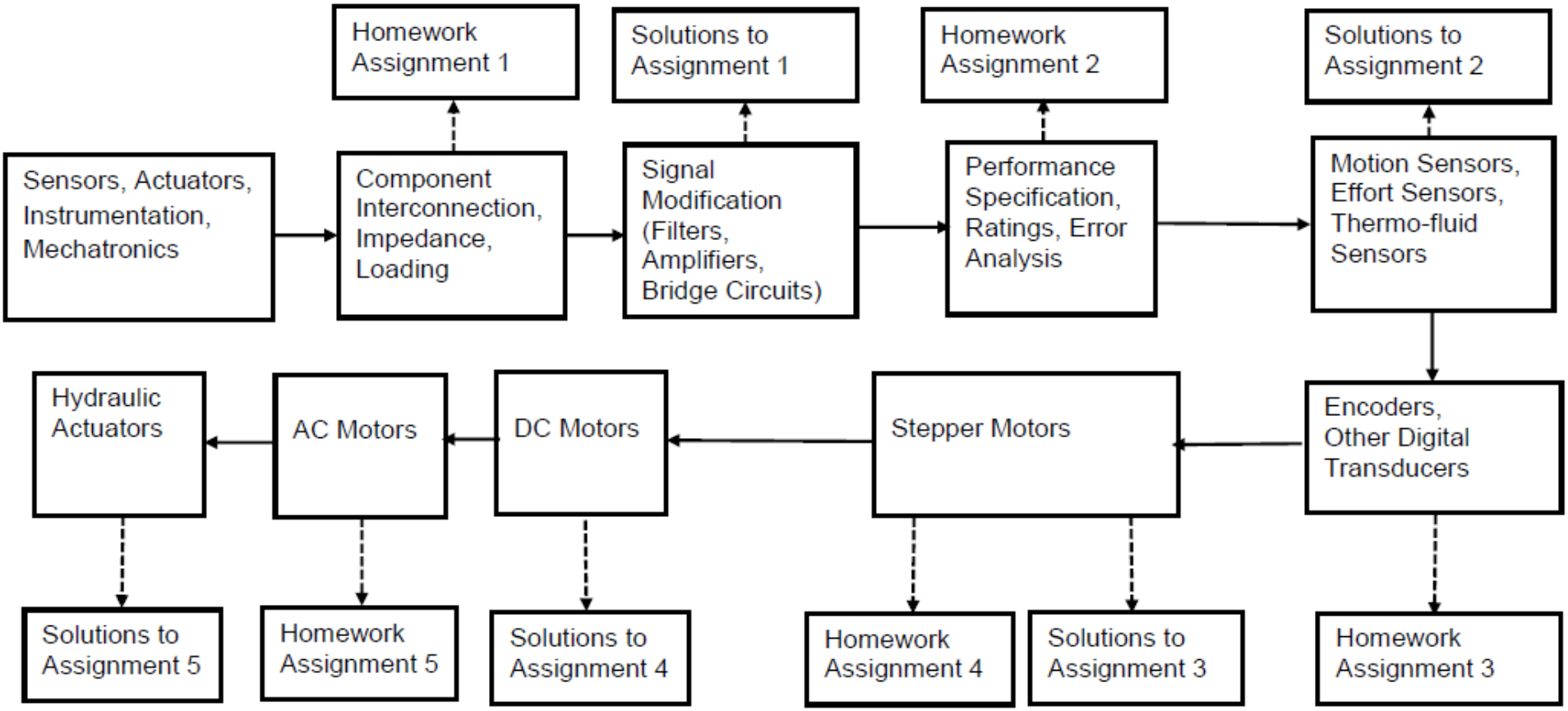
What is instrumentation?

- Operating principles, modeling, analysis, design considerations

What if an analytical model is not possible?

- Component selection, ratings, specifications, interconnection
- Different types of typical sensors, their principles, characteristics, selection, and applications
- Different classes of typical actuators, their principles, characteristics, selection, and applications

MECH 420 Roadmap



MECH 420 Laboratory

Lab	Lab Data Sent On	Title
# 1	Nov. 02, 2020	Data Acquisition and Proximity Sensors for Object Detection
# 2	Nov. 09, 2020	Optical Encoder and Torque Sensor
# 3	Nov. 16, 2020	Dynamic Transducer Transfer Characteristics – Time Domain
# 4	Nov. 23 2019	Dynamic Transducer Characteristics – Frequency Domain
# 5	Nov. 30 2016	Hydraulic System with Servo Valves and Sensors

***Note*: The lab report (individual by each student) should be sent to a TA no later than 1 week after receiving the data for the experiment.**

Introduction

Instrumentation

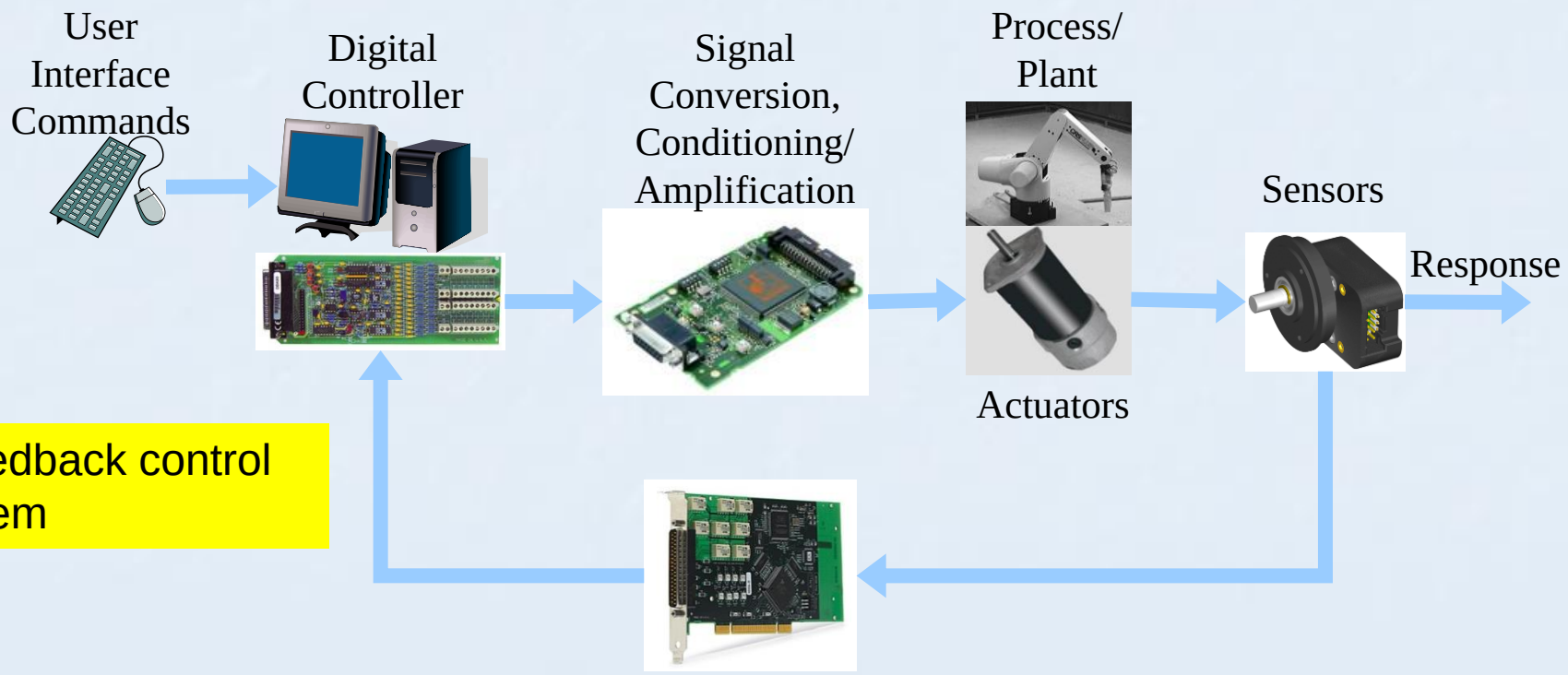
- Identify components for “instrumenting” a system **(consider: type, functions, operation, interaction, etc.)**
- Address component interfacing **(interconnection)**
- Decide parameter values **(component sizing, system tuning, accuracy, etc.)** to meet performance requirements **(specifications)**

Typically, the instruments (devices) are commercially available (a finite set)

Applications: **Processing; production; motion; monitoring; testing and qualification; product quality assessment; fault prediction, detection and diagnosis; warning generation; surveillance; model identification; control (direct, supervisory, etc.)**

Components of Instrumentation

- Sensors and Transducers
- Actuators (including Control Actuators)
- Controllers
- Signal Conditioning/Conversion/Modification Devices
- Power Supplies
- Protection Devices



A feedback control system

Example 2.0

Ear cleaning using a cotton swab:

- Self-cleaning
- Cleaning by another person

Questions:

- What are sensors, actuators, and controllers?
- How are they interacting?

Sensors

What are variables?
What are parameters?

- **Sensor:** Measures (senses) unknown signals and parameters of a plant and its environment

  (Sensors are needed to monitor and "learn" about the system)

What categories of things may be sensed in our context?

- **Useful in:** Process monitoring; testing and qualification; product quality assessment; fault prediction, detection and diagnosis; warning generation; surveillance; model identification; control; general operation of a system
- **Sensor System:** May mean, 1. Multiple sensors, sensor/data fusion (one sensor may not be adequate for the particular application) **or,** 2. Sensor and its accessories (signal processing, data acquisition, display, etc.)

Commercial Sensors

Motion Sensors: Potentiometer, differential transformer (LVDT), magnetostrictive (temposonic) displacement sensor, magnetic induction proximity sensor, tachometer, resolver, synchro, gyro, piezoelectric accelerometer, laser ranger, ultrasound ranger

Force/Torque Sensors: Semiconductor strain gauge, motor current sensor

Fluid Flow Sensors: Coriolis velocity meter, pitot (pee-toh) tube, rotameter, orifice flow meter

Pressure Sensors: Manometer, Bourdon tube, diaphragm type

Temperature Sensors: Thermocouple, thermistor, resistance temperature detector (RTD)

Note: Pressure and flow are correlated →pressure sensing can be used for flow sensing

Sensor Examples

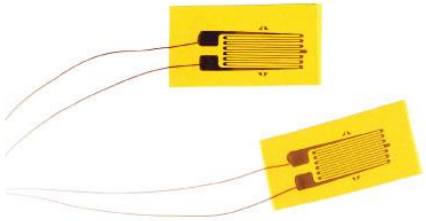
Potentiometers

Piezoelectric Accelerometers

LVDTs

Thermocouples

Resolvers



Strain Gauges

Which of these are you familiar with?

Tachometers

Servovalves

Actuators

Stepper Motor

- **Needed to "drive" a plant**

Examples: Stepper motors, solenoids, dc motors, hydraulic rams, pumps, pneumatic actuators, valves, relays, switches, heaters/coolers

Why are these actuators?

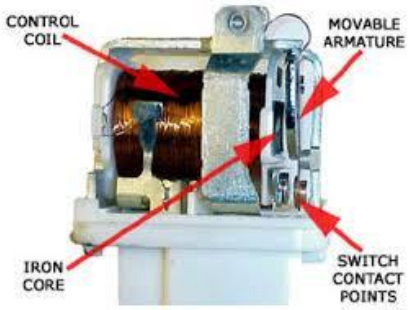
Control Actuators: Perform control actions; they drive control devices. (e.g., control valves)

Solenoid Valve Actuators

Eccentric DC Motor

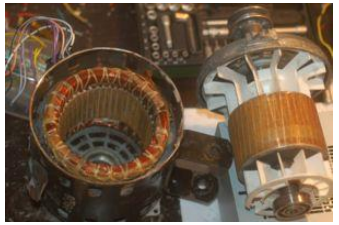
Rotary Hydraulic Actuator

Hydraulic Ram



Relay

Which of these are you familiar with?



AC Motor

What is a relay?

DC Motor

Mechanical Components

Mechanical Sensors:

- **Springs (displacement measures force)**
- **Mechanical limit switches**

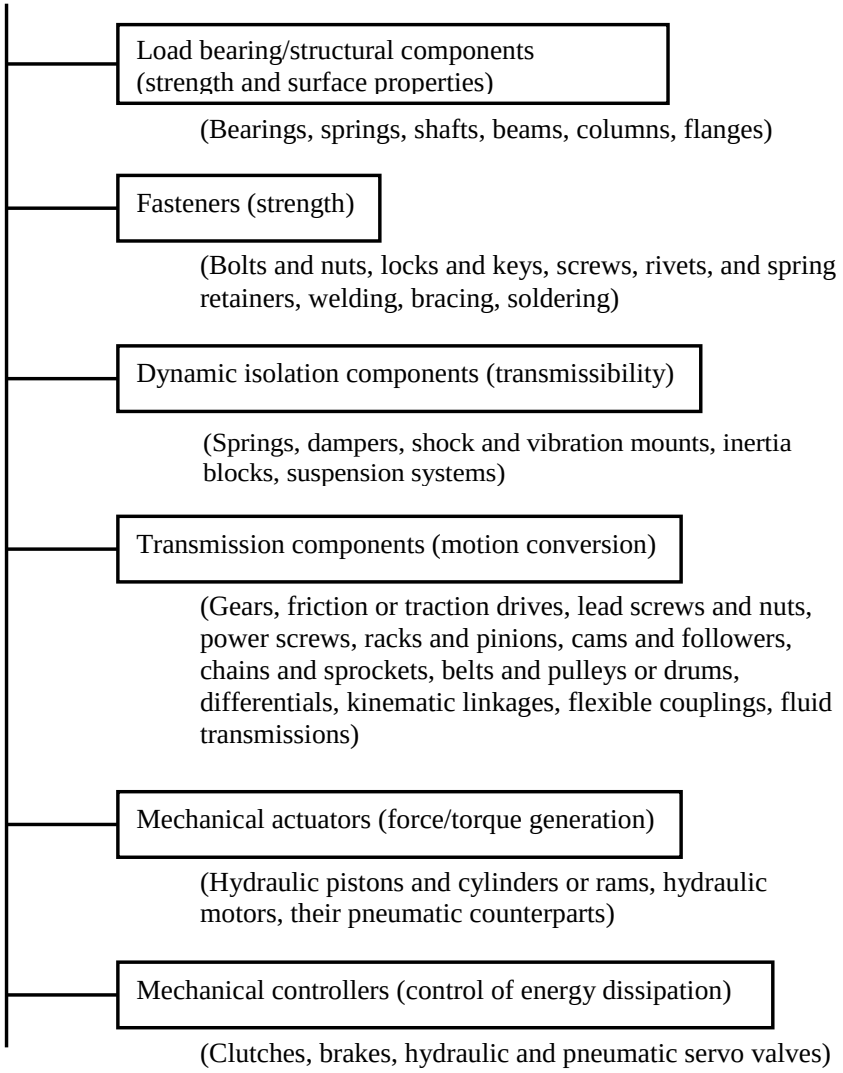
  (contact indicates position limit)
- **Indentation type hardness sensors**

  (size of surface indentation → hardness)
- **Pendulum-based mass/inertia sensors**

  (period of oscillation → inertia)
- **Mechanical flow meters**

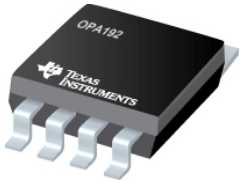
  (count rotations over a time period)

Advantages and disadvantages of mechanical components compared to electronic components?



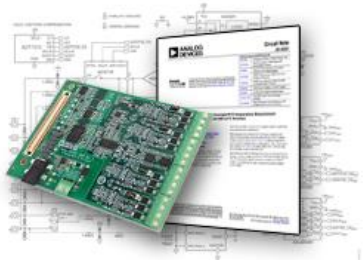
Other Components

- **Controller:** Generates control signals according to which the plant (and control devices) are driven
- **Signal Conditioning/Conversion Devices**
  - **Filters:** Low-pass, high-pass, band-pass, notch, tracking
  - **Amplifiers:** Charge amps, power amps, voltage amps, power amps (all use op amps)
  - **Modulators/Demodulators**
  - **Voltage-Current-Frequency Converters**
  - **ADC, DAC, Data Acquisition (DAQ) Boards**
- **Power Supplies**
- **Protection Devices**



Op Amp

Instrumentation Filter/Amp


DAQ Board

Which are “signal conditioning,” which are “signal conversion,” which are signal modification?

White Board Discussion

In the present subject, why is it not enough to just learn everything about sensors and actuators?

Questions on Instrumentation Paper

- **Meaning of Instrumentation?**
- **What are pertinent hardware in the context of Instrumentation?**
- **Key objectives of instrumentation?**
- **Main steps of instrumentation?**

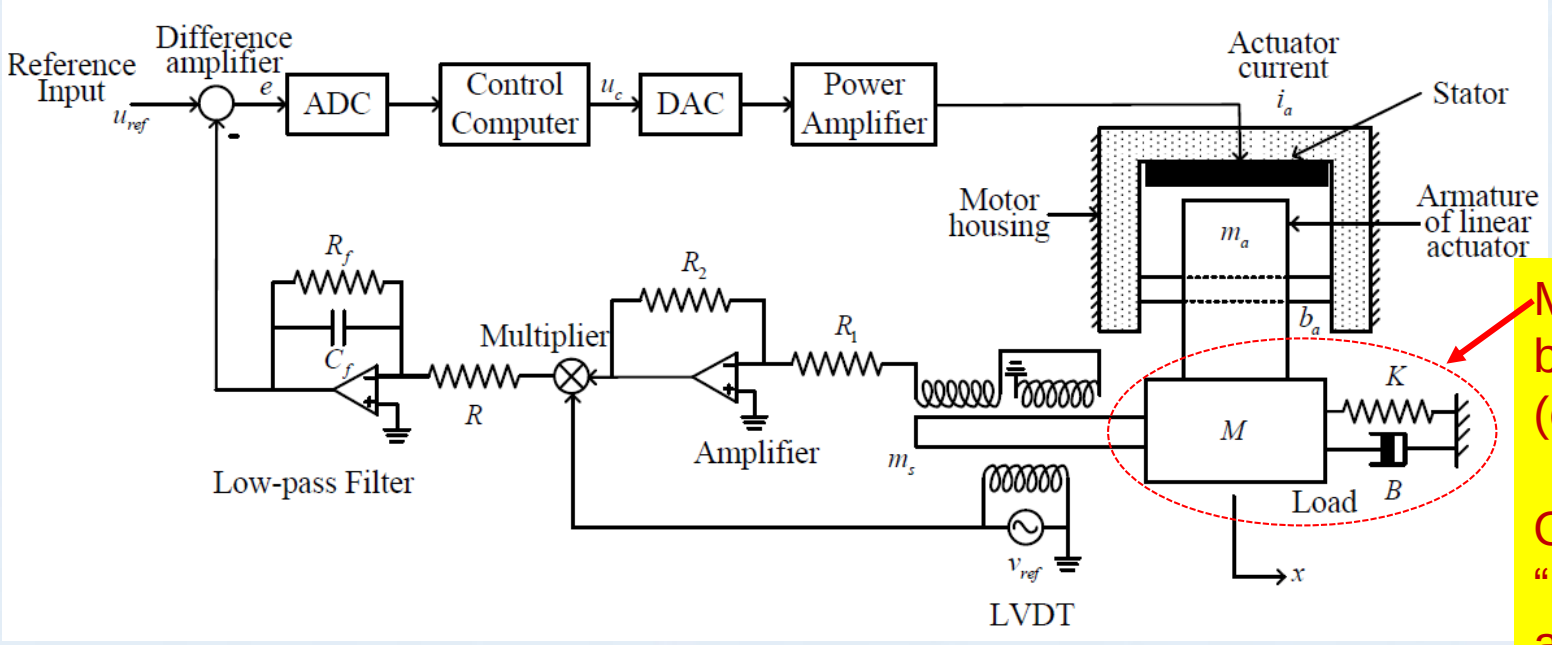
Micro-electromechanical Systems (MEMS)

- Use microminiature sensors and actuators
- Their scientific principles are often the same as those of their "macro" counterparts (E.g., Piezoelectric, capacitive, electromagnetic and piezoresistive principles)

Benefits of MEMS Devices: Small size and light weight (negligible loading errors), high speed (high bandwidth), and convenient mass-production (low cost)

Meaning of "loading"?

Illustrative Example (See Paper): A Plant Driven by a Linear Actuator



May have to be designed (continuous)

Other "instruments" are commercially available

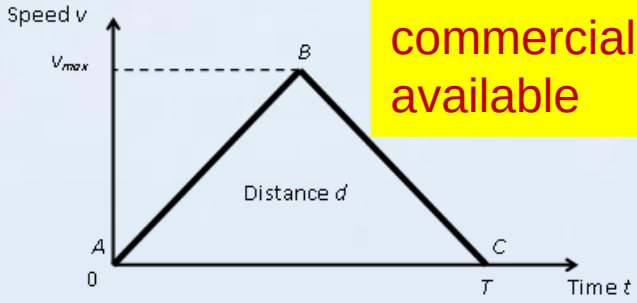
M = 1.0 kg, $m_s = 0.01$ kg

B = 20N/m/s, K = 2500.0 N/m, d = 0.02 m, T = 1.0 s

LVDT voltage amplifier gain = 10.0;

Low-pass filter gain = 1.0;

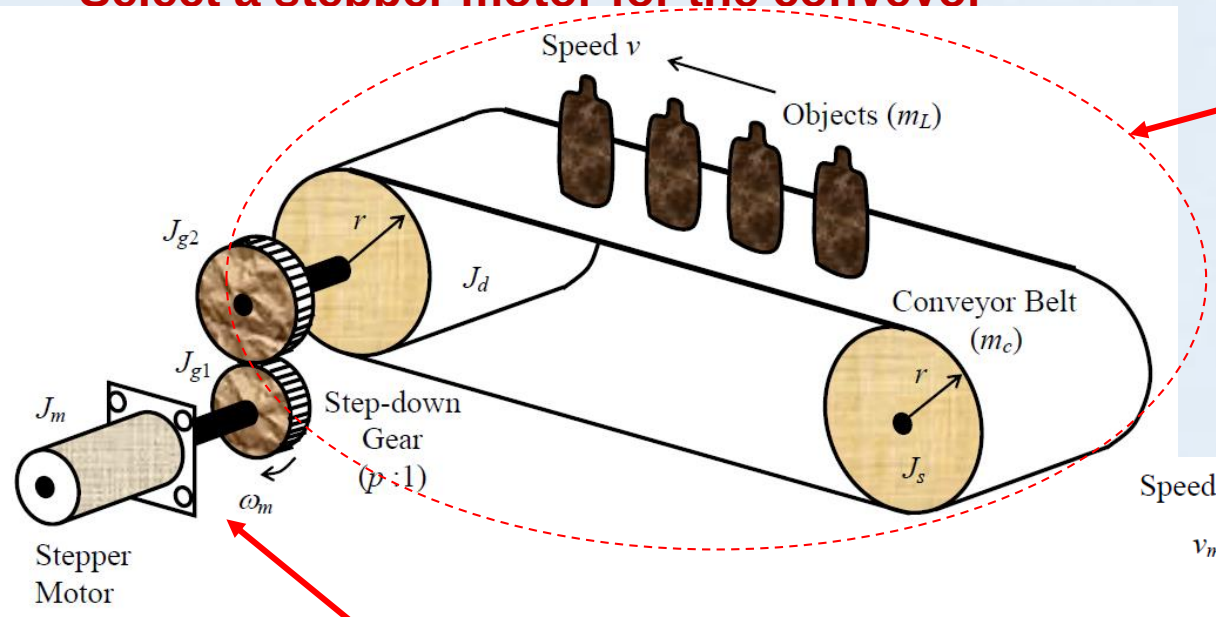
$R_1 = 1.0$ kΩ; $R = 10.0$ kΩ



Note: T = intermittent motion period

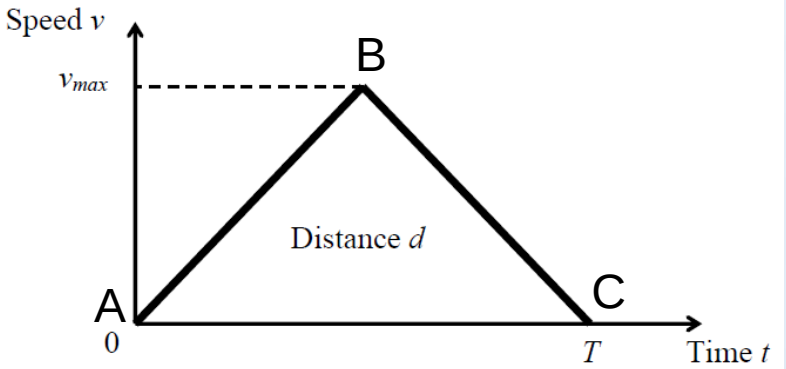
Illustrative Example: Product Conveyor

- Industrial conveyor for product completion, inspection, movement
- Conveyor moves intermittently at a fixed rate ➔ indexes objects through distance *d* in time period *T*
- A triangular speed profile is used for each motion interval, with equal acceleration and a deceleration
- A gear unit with step-down speed ratio *p*:1, *p* > 1, may be used if necessary
- Select a stepper motor for the conveyor



May have to be designed (continuous)

Commercially available "instruments" (motor, gear)



Application Scenarios

Applicable Engineering Fields

Aeronautical and Aerospace Engineering: Aircraft, spacecraft

Civil Engineering: Monitoring of civil engineering structures (bridges, buildings, etc.)

Chemical Engineering: Monitoring and control of chemical processes and plants

Electrical and Computer Engineering: Development of electronic hardware and computer-integrated devices, hard drives, etc.; control and monitoring of electrical and computer systems

Materials Engineering: Material synthesis processes

Mechanical Engineering: Monitoring and control of vehicles and transit systems, robots, manufacturing plants, industrial plants, jet engines, thermo-fluid systems, etc.

Mining and Mineral Engineering: Mining machinery and processes

Nuclear Engineering: Nuclear reactors; testing and qualification of components

Add other examples to each field

High-Speed Ground Transit

The Sky Train in Vancouver, Canada—An Automated Transit System

What are the sensors, what the are actuators?

Automobile Sensors

Powertrain (Engine & Transmission) →

- Air flow
- Air-fuel ratio
- Camshaft motion
- Coolant fluid level
- Crankshaft motion
- Detonation
- Exhaust Oxygen
- Manifold pressure
- Oil level
- Oil temperature
- Throttle position
- Transmission output speed
- Transmission temperature

In each situation, how is the sensed information used?

What is the best sensor for a task? You should be able to answer at the end of the course

Driving Aid →

- Accelerator position
- Antilock braking (ABS)
- Cameras
- Radar/Ultrasonic/ Infrared (parking, object detection)
- Steering rate
- Tactile (haptic-touch)
- Vehicle speed

Develop another example of sensor use, in this format

Safety and Comfort →

- Brake fluid
- Compartment temperature/humidity
- Door position
- Electronics monitoring and diagnosis
- Outside conditions
- Ride comfort (acceleration for active suspension control)
- Tire pressure
- Washer fluid level

Automobile Actuators

Powertrain (Engine & Transmission) →

- Brushless dc motors
- Fluid pumps and blowers
- Linear actuators for valves
- Lubrication oil pumps
- Transmission actuators
- Stepper motors for cooling fans
- Throttle valve actuators

Select one scenario (e.g., active suspension). Draw a schematic diagram to show how sensor, actuator, and controller are interconnected and operated to achieve the objective

Driving Aid →

- Automated action devices
- Antilock braking system (ABS) actuators
- Cruise control actuators
- Electric parking brakes
- Headlight movement actuators
- Piezoelectric actuators
- Solenoids
- Switches and relays
- Torque motors

Develop another example of actuator use, in this format

What is the best actuator for a task? You should be able to answer at the end of the course

Safety and Comfort →

- Active suspension actuators (e.g., hydraulic)
- Heating-ventilation-air conditioning (HVAC) actuators
- Stepper motors
- Sunroof movement actuators
- Windshield wiper actuators
- Window movement actuators

Sensors and Actuators in Engineering Applications

Why is a “heat source” considered as an “actuator”?

Process	Typical Sensors	Typical Actuators
Aircraft	Displacement, speed, acceleration, elevation, heading, force pressure, temperature, fluid flow, voltage, current, global positioning system (GPS)	DC motors, stepper motors, relays, valve actuators, pumps, heat sources, jet engines
Automobile	Displacement, speed, force, pressure, temperature, fluid flow, fluid level, vision, voltage, current, GPS, radar, sonar	DC motors, stepper motors, valve actuators, linear actuators, pumps, heat sources
Home Heating System	Temperature, pressure, fluid flow	Motors, pumps, heat sources
Milling Machine	Displacement, speed, force, acoustics, temperature, voltage, current	DC motors, ac motors
Robot	Optical image, displacement, speed, force, torque, tactile, laser, ultrasound, voltage, current	DC motors, stepper motors, ac motors, hydraulic actuators, pneumatic actuators
Wood Drying Kiln	Temperature, relative humidity, moisture content, air flow	AC motors, dc motors, pumps, heat sources

Human Sensory System

Five Senses: Sight (visual); Hearing (auditory); Touch (tactile); Smell (olfactory); Taste (flavor)

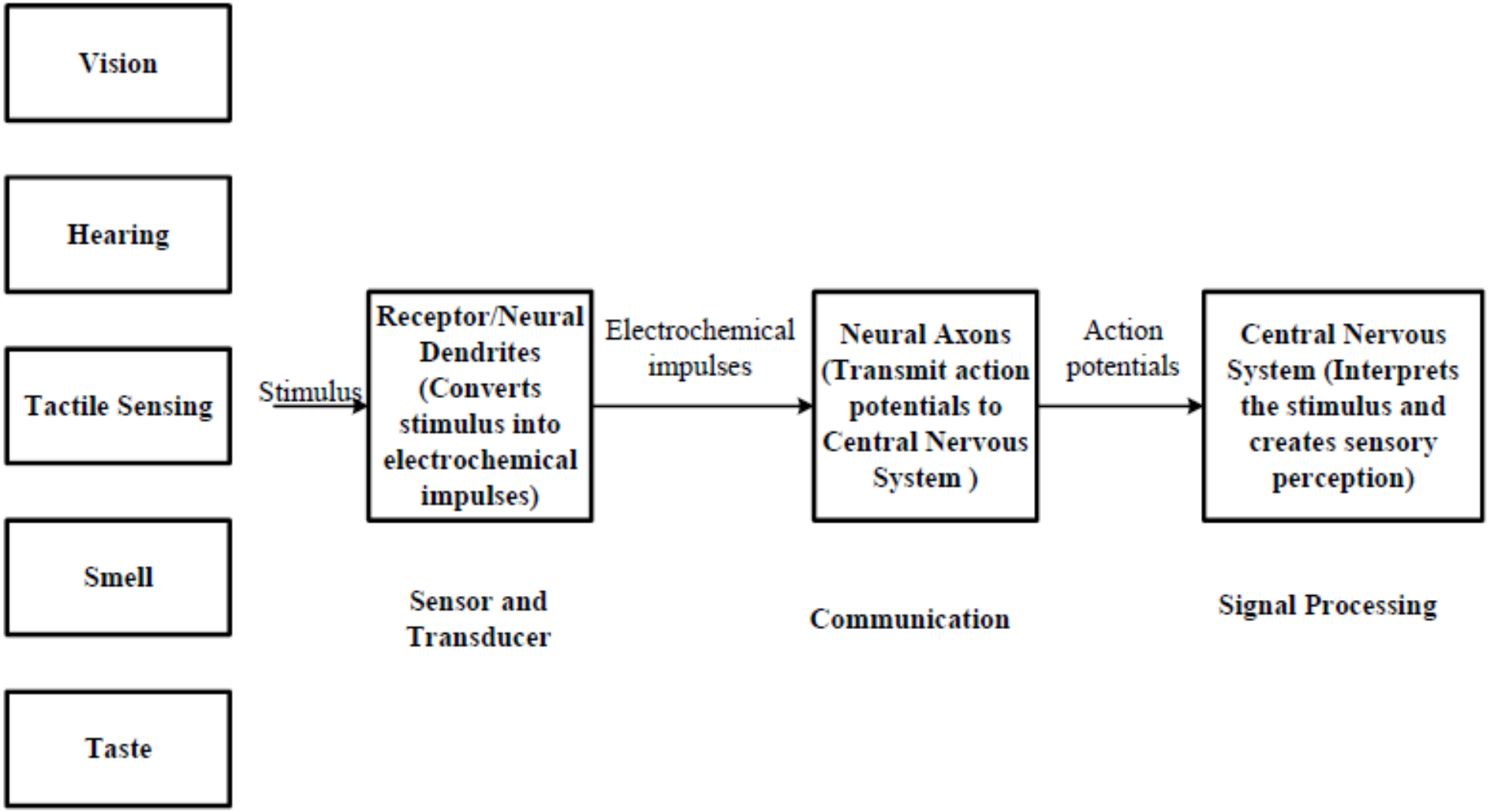
Technology Area: "Intelligent" robots that can mimic characteristics of natural sensing and intelligence

***Note*: Sensors in the first three categories are more advanced (started with basic sensors such as cameras, microphones, and tactile sensors)**

Humans have other types of sensory features too: E.g., sense of balance, pressure, temperature, pain, and motion

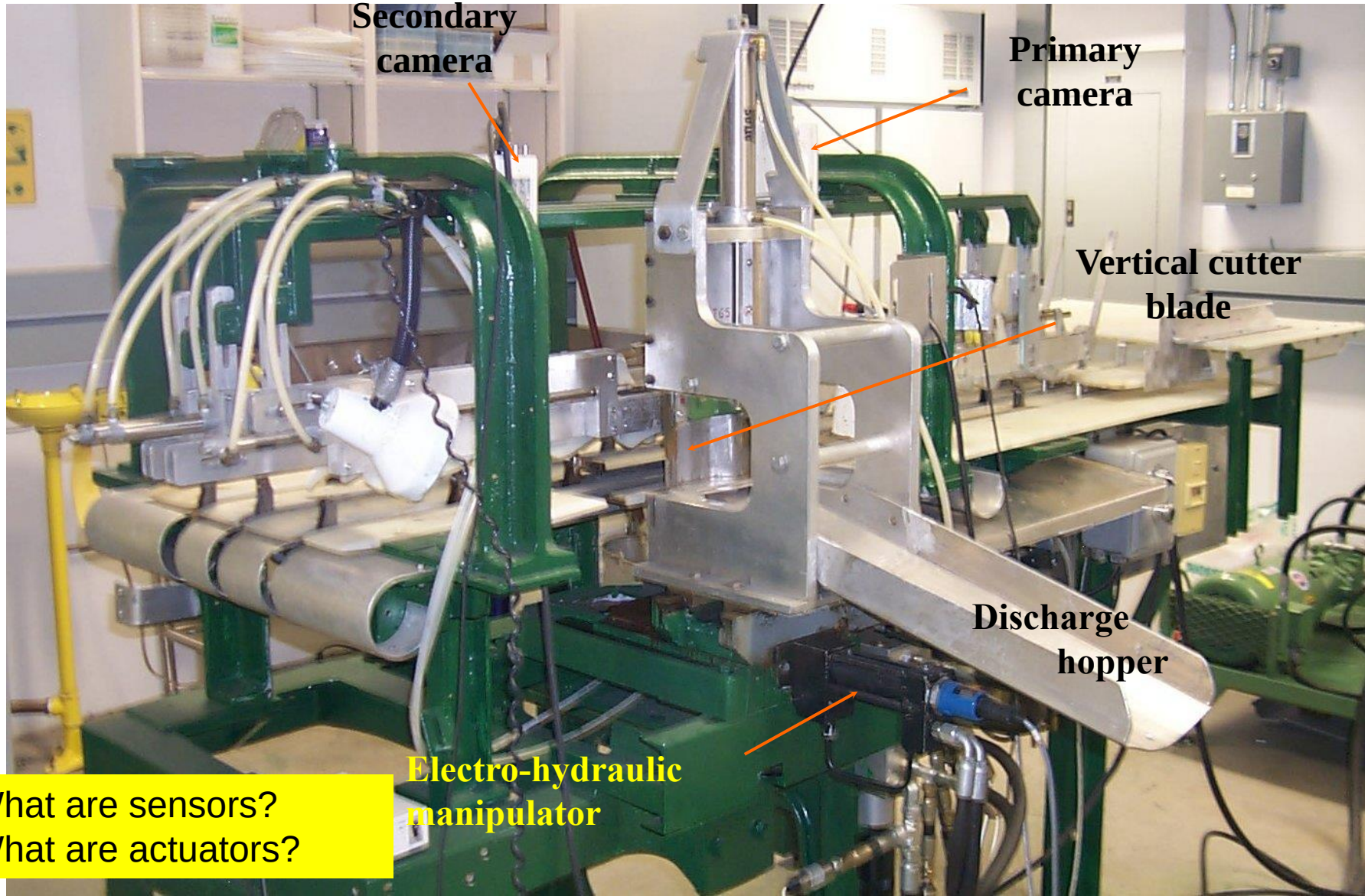
***Note*: Some of them will involve using more than one basic five senses, simultaneously through the central nervous system (CNS)**

Human Sensory System (Analogy to Engineering Sensing)



Intelligent Iron Butcher

Is this an instrumentation problem or a design problem?



What are sensors?
What are actuators?

Operation of the Intelligent Iron Butcher

Questions on Iron Butcher (IB)

- In IB, what are the sensors?
- In IB, what are the actuators?
- In IB, what are other key hardware?
- What other types of sensor may be used to replace the exiting ones or to improve performance? Why?
- What other types of actuators may be used to replace the exiting ones or to improve performance? Why?

"Education is just the progressive Realisation of our ignorance"

Albert Einstein