ESBootcamp Day 2: Mechatronics Homework Assignment

Thank you for attending the workshop! The questions listed below are designed to gauge your understanding in mechatronics fundamentals. Please feel free to collaborate with other newbies and don't hesitate to reach out to Vedang or Katie if you have any questions. Have fun!

Sensors and Actuators

Link: https://youtu.be/Gu_1S77XkiM

Watch the video linked above, and find one example of an actuator and one example of a sensor being used. (1 to 2 sentence max)

The video shows a servo motor adjusting the position of a robotic arm, demonstrating an actuator converting electrical signals into mechanical movement. The video also shows how the OptiTrack camera is used to help track the gantry.

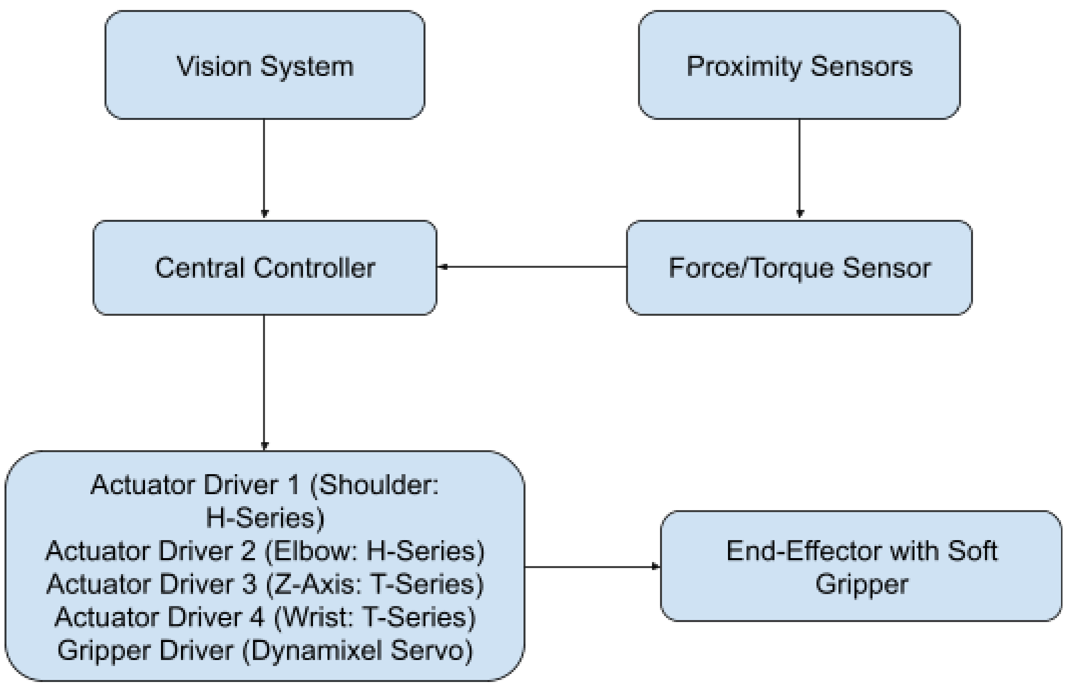
Design Challenges

1) Design a robotic arm for precision pick-and-place operations. The arm must be able to pick up light objects, move them to a target location, and place them with high accuracy. Propose a mechanical design, focusing on actuators and sensors you would include. Draw a block diagram of your proposed system.

Mechanical Design:

- A SCARA (Selective Compliance Assembly Robot Arm), minimizes deflection during high-speed horizontal movements while maintaining precise vertical placement
  - Four Degrees of Freedom:
    - Two rotary joints for X-Y plane positioning.
    - A prismatic Z-axis joint for vertical motion.
    - A rotary wrist joint for end-effector orientation.
  - End-Effector:
    - Two-fingered gripper with servo-driven actuation and soft silicone pads for delicate object handling.
  - Actuators:

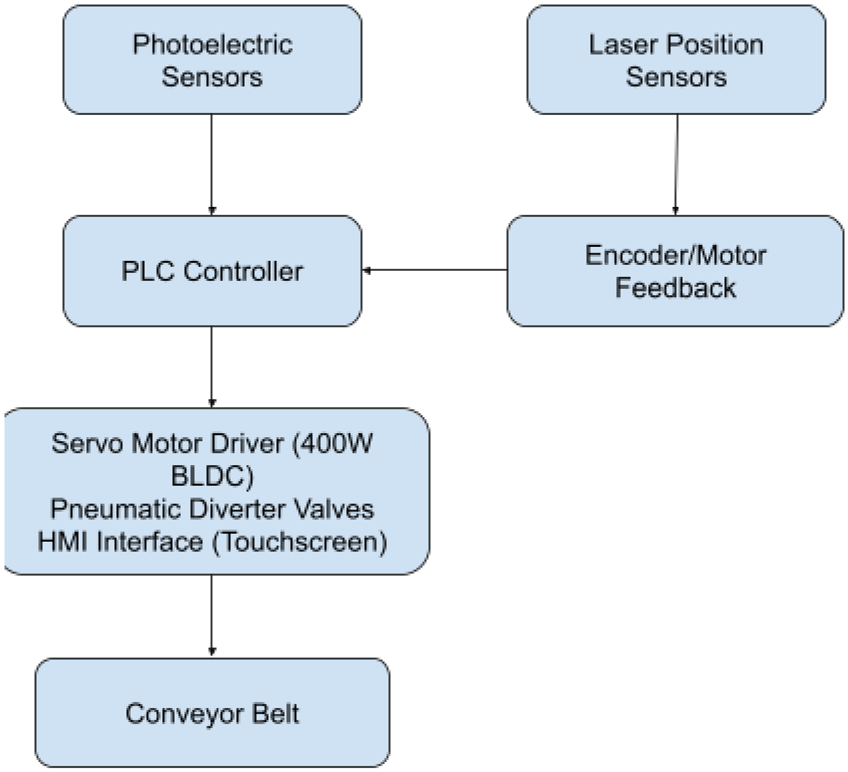
        - High-torque, low-weight actuators for precision and speed
        - Ex: HEBI Robotics H-Series Actuators for joints, Dynamixel servo motors for end-effector
    - Sensors:
        - RGB-D camera mounted at the workspace for object detection and localization.
        - Six-axis F/T sensor at the wrist to monitor grip force and detect contact.
        - Laser distance sensors on the end-effector for sub-millimeter positioning accuracy.
        - Integrated magnetic encoders in actuators for real-time joint angle feedback.



2) Design a mechanical system for a conveyor belt that needs to move products along a production line. The system must allow precise control of speed and direction. Propose a design, considering the mechanical components and their integration with actuators and sensors. Draw a block diagram of the system.

Mechanical Design:

- Frame and Belt Configuration:
    - Modular aluminum frame with adjustable supports for easy length customization.
    - Polyurethane-coated fabric belt for high friction, low stretch, and resistance to wear.
    - Motorized drive roller with a lagged surface to prevent belt slippage.
- Transmission System:
    - Precision helical gearbox coupled to the drive roller for torque amplification.
    - Tensioning mechanism with spring-loaded idler rollers to maintain consistent belt tension.
- Load Handling:
    - Supports payloads up to 50 kg/m with a maximum speed of 2 m/s.
    - Stainless steel side guides for product alignment.
- Actuators:
    - Primary Drive Motor: Back-drivable design allows rapid direction reversal without mechanical stress.
    - Auxiliary Actuators: Pneumatic diverters for product routing (controlled via solenoid valves). Servo-driven lift gates for selective product retention.
- Sensors:
    - Speed/Direction Feedback:
        - Magnetic rotary encoder on the drive roller shaft (direct belt speed measurement).
        - Quadrature encoder on the motor shaft (secondary feedback for redundancy).
    - Product Detection:
        - Retro-reflective photoelectric sensors at entry/exit points for object counting.
        - Laser triangulation sensors for precise product positioning.
    - Condition Monitoring:
        - Strain gauges on the frame to detect overloads.
        - Infrared temperature sensors on motor bearings for preventive maintenance.



Controls:

1) Open-Loop and Closed-Loop Systems
    a) Explain the difference between open and closed-loop systems.
        i) Open-loop systems operate without feedback, the controller sends commands based on a predefined input, and the output has no effect on the control action.
        ii) Closed-loop systems use feedback to compare the output with the desired setpoint, adjusting the input dynamically to minimize error.
    b) Give one practical example of each type of system.
        i) Open-loop: A toaster. The user sets a timer, and the heating element runs for the duration regardless of the toast's actual browning.
        ii) Closed-loop: A car's cruise control. The system adjusts throttle based on real-time speed measurements to maintain the set speed.
    c) Draw a block diagram for an open loop and closed loop system and explain how each block plays a role in the overall system.

Open-Loop System:
[Setpoint] → [Controller] → [Actuator] → [Process] → [Output]

Controller: Generates control signals (timer duration).
Actuator: Converts signals into action (heating element).
Process: Executes the task (toasting bread).

Closed-Loop System:

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[Setpoint] → [Controller] → [Actuator] → [Process] → [Output]
        ↑                      |
        └──────── [Sensor] ←──────── [Feedback] ┘
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Sensor: Measures output (speed sensor).
Feedback: Compares output to setpoint, sending error signals to the controller.

2) What is positive feedback in control systems?
    a) Positive feedback amplifies deviations from the setpoint, causing the system to move away from equilibrium.
3) You are tasked with designing a **closed-loop control system** for controlling the speed of a motor in an electric fan. The motor's speed can be measured using a sensor and the desired speed (setpoint) can be adjusted by the user.

Design Components:

- Compensates for load changes (fan blade resistance).
- Reduces speed fluctuations due to voltage variations.
- Setpoint: User-adjustable speed (e.g., via dial or digital interface).
- Sensor: Optical encoder or tachometer to measure motor RPM.
- Controller: PID controller to compute error (setpoint – actual speed).
- Actuator: Motor driver (e.g., PWM-controlled H-bridge).
- PID Controller: Adjusts motor voltage based on error (Proportional-Integral-Derivative algorithm).
- Encoder Feedback: Provides real-time RPM data for closed-loop adjustments.

Block Diagram:

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[User Setpoint] → [PID Controller] → [Motor Driver] → [Motor] → [Output Speed]
           ↑                      |
           └──────────── [Encoder Feedback] ←──────────┘
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