ME 6102: Design of Mechatronic Systems

Selection of Sensors and Actuators

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Interfaces for actuator and sensor

- Sensor
  - ADC Analog to digital conversion
  - Digital input
  - Encoder interface
  - Uart
- Actuator
  - PWM
  - DAC
  - Digital output

Important Points

- System requirements → Sensor requirements
- Kinematic/dynamic analysis to get the required sensor specs
- Noise considerations
- Choice of analog vs digital sensor
- Interface compatibility: Example encoder interface, number of bits.
- Use of filters: analog vs digital domain implementation
- Cost implications
- Mathematical model of the system/sensor, preliminary simulation
- Manufacturer Catalogs → proper choice

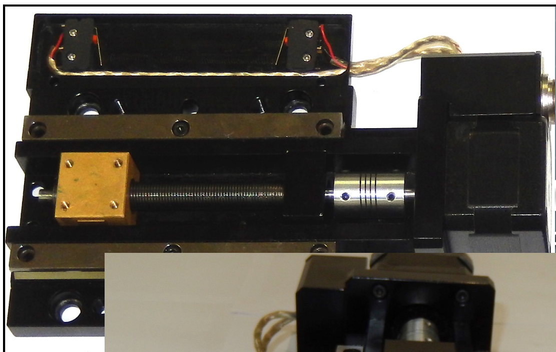
Example: Linear motion stage

Closed loop system for refined control

- Motion stage with lead screw design with spring loaded elements
- Q: We would like to have closed loop control implemented on such spring loaded linear motion stage drive with accuracy of 5 micron and speed of operation to be achieved is 20 mm/sec for total range of 60 mm. What should be sensor and actuator specification.
- Typically this will be broad specification. We need to now get going with design actually getting the moving masses estimated and then proceed to calculations.
- Q: Where to start?
- TIP: A lot of things are based on common sense do not loose your common sense in pursuit of mathematics

Example: Linear motion stage

- Physical construction of system: Sketch and observe kinematic connections and relationships. Based on these sensor resolution and range specifications can be worked out.
- Note important moving elements and give some rough estimates (or keep them as variables in your analysis)
- Determine the equivalent inertia + load on motor.
- Use specifications to get idea of order of magnitude of power in the system (forceXvelocity or TorqueXangular velocity). At this point estimation of ALL forces/ torques is crucial step.



Example: Linear motion stage

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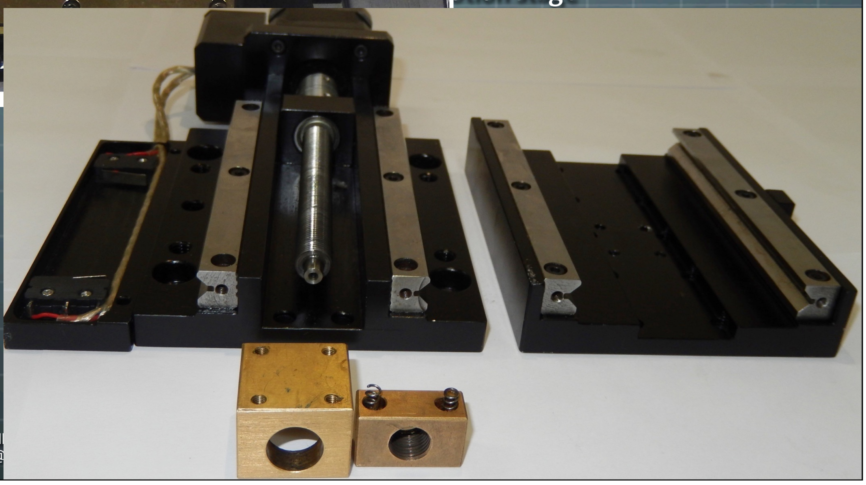


Linear Motion Stage

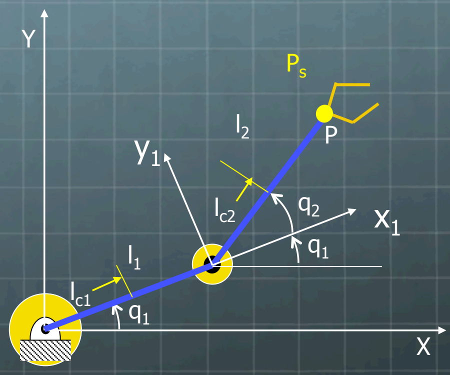
- Selection of sensor: Linear encoder vs rotary encoder, Digital sensor for advantages
- Calculation of resolution of sensor: Kinematics of lead screw, how to decide diameter of lead screw: Manufacturing and tolerance consideration (cost implecations). Easily available dia 8 mm onwards
- Rotary encoder pulses per revolution? Based on speed required dynamic response pulse duration??
- Use range 60 mm to get the total number of counts without overflow and hence the bit accuracy, 8, 12 or 16 bit
- Sensor response should be faster so changes are truly representative of application rather than spurious data (we will see its connection with sampling time later)

Linear Motion Stage

Closed loop system

- Selection of Actuator: Options available
  - DC servormotor: PMDC, BLDC
  - AC servomotor X
  - Servo Hydraulics X
- Think how would you get the power, torque, of the motor?? What do you need to know or need to design.
- Identify variables in system affecting power?
  - Friction Time in which to attain the desired vel
  - Inertia

Examples: 2R manipulator



- Q: If we would like to have circle of radius 70 mm drawn by the end effector at speed of 10 mm/sec and given that the accuracy of drawing is +-0.5 mm on diameter. How do you make choices of link lengths and sensor resolution? What should be specifications on the motors in terms of torque etc.

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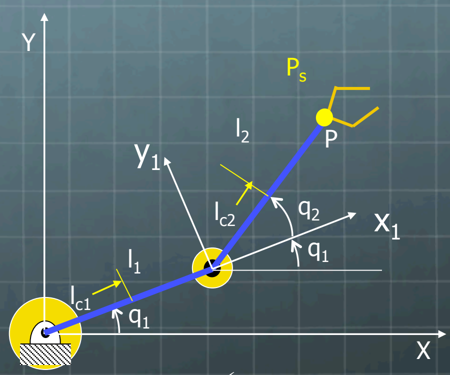
Lagrangian Formulation: 2-R Manipulator



Kinetic energy is computed Using jacobian expression

$$v_{c1} = J_{v_{c1}} \dot{q}$$

$$J_{v_{c1}} = \begin{pmatrix} -l_{c1}\sin q_1 & 0 \\ l_{c1}\cos q_1 & 0 \end{pmatrix}$$

$$v_{c2} = J_{v_{c2}} \dot{q}$$

$$J_{v_{c2}} = \begin{pmatrix} -l_1\sin q_1 - l_{c2}\sin(q_1+q_2) & -l_{c2}\sin(q_1+q_2) \\ l_1\cos q_1 + l_{c2}\cos(q_1+q_2) & l_{c2}\cos(q_1+q_2) \end{pmatrix}$$

2-R Manipulator

$$D(\mathbf{q})\ddot{\mathbf{q}} + C(\mathbf{q},\dot{\mathbf{q}})\dot{\mathbf{q}} + \mathbf{g}(\mathbf{q}) = \tau$$

Using Lagrange equation and arranging the terms

$$d_{11} = m_1 l_{c1}^2 + m_2\left(l_1^2 + l_{c2}^2 + 2 l_1 l_{c2}\cos q_2\right) + I_1 + I_2$$

$$d_{12} = d_{21} = m_2\left(l_{c2}^2 + 2 l_1 l_{c2}\cos q_2\right) + I_2$$

$$d_{22} = m_2 l_{c2}^2 + I_2$$

Element of matrix C

$$C_{111} = \frac{1}{2}\frac{\partial d_{11}}{\partial q_1} = 0$$

$$C_{112} = \frac{\partial d_{21}}{\partial q_1} - \frac{1}{2}\frac{\partial d_{11}}{\partial q_2} = -h$$

$$C_{121} = C_{211} = \frac{1}{2}\frac{\partial d_{11}}{\partial q_2} = -m_2 l_1 l_{c2}\sin q_2 = h$$

$$C_{122} = C_{212} = \frac{1}{2}\frac{\partial d_{22}}{\partial q_1} = 0$$

$$C_{221} = \frac{\partial d_{12}}{\partial q_2} - \frac{1}{2}\frac{\partial d_{22}}{\partial q_1} = h$$

$$C_{222} = \frac{1}{2}\frac{\partial d_{22}}{\partial q_2} = 0$$

2-R Manipulator

$$\frac{\partial V}{\partial q_1} = \left(m_1 l_{c1} + m_2 l_1\right) g\cos q_1 + m_2 l_{c2} g\cos\left(q_1 + q_2\right)$$

$$\frac{\partial V}{\partial q_2} = m_2 l_{c2}\cos\left(q_1 + q_2\right)$$

Final dynamical equations of the system

$$\boxed{\begin{aligned} & d_{11}\ddot{q}_1 + d_{12}\ddot{q}_2 + c_{121}\dot{q}_1\dot{q}_2 + c_{211}\dot{q}_1\dot{q}_2 + c_{221}\dot{q}_2^2 + \frac{\partial V}{\partial q_1} = \tau_1 \\ & d_{21}\ddot{q}_1 + d_{22}\ddot{q}_2 + c_{112}\dot{q}_1^2 + \frac{\partial V}{\partial q_2} = \tau_2 \end{aligned}}$$

Sensor Specs for 2R

- Discussion in class about using the Kinematic relationship to decide based on inverse kinematic analysis specs of resolution of q1 and q2

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