Lecture 32 - Design Considerations

Announcements:

- Exam corrections due Weds
- Office Hours today in Fitz B22
- Robotics talk tomorrow: 1PM in Fitz 258

Today:

- Manipulator Design
- Workspace Analysis
- Metric for workspace usability (Manipulability)

Recap: Fundamentals:

- Forward (direct) kinematics - position & 3D orientation
- Inverse kinematics - closed form & numerical
- Forward differential kinematics - velocity & acceleration
- Jacobian - $v = J\dot{\theta}$ $\quad \tau = J^T f$
- Dynamics $\tau = M\ddot{\theta} + V(\theta,\dot{\theta}) + G(\theta) + J^T f$
  - Recursive Newton Euler
  - Lagrangian

What's Next:

No HW, Short answers on the final

- Design Considerations
- Control

[HW] - Trajectory generation [2 lectures]

[HW, Proj] - Linear & Nonlinear Control [4 lectures]

Manipulator Design

Caveat: A bit Subjective

- Multi-Objective Optimization Problem

Often difficult to quantify

- Cost
- Maintainence
- Time

- End Use (Adoption & Usability, user friendly)
- Performance
  - Workspace
  - Energy usage
- Aesthetics

- All specific to task @ hand

  (But at the same time we want robots to be versatile)

Performance Considerations

- # DOFs (# actuators sets overall cost ≥ $1K / DoF)
  - Often don't need 6 DoF
- Workspace (influenced by prismatic vs. revolute, joint axis selection)
- Load capacity (Actuators & Structural elements)
- Speed
- Repeatability & Accuracy

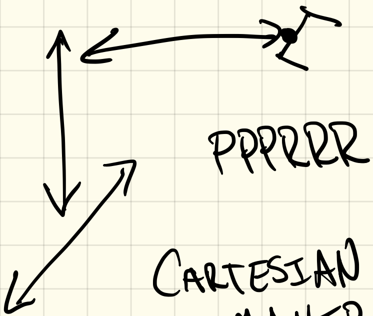
Choosing How to Arrange Your DoFs

Common Approach

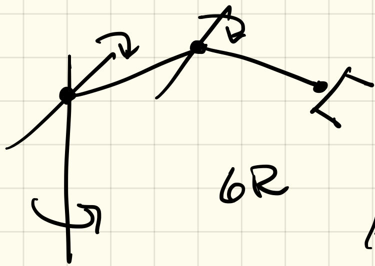
Positioning Structure - 3 inboard joints set position of wrist in a volume of workspace

Orienting Structure - 3 outboard joints orient wrist

↳ successive revolute joints w/ common intersection point called concurrency point



CARTESIAN MANIP



Articulated Manipulator

Maximizing workspace Volume

- Maximize Volume in which concurrency point can be placed for a given "length" of manipulator structure. (Sphere)

3R

Joint 1: Axis 1 vertical

Joint 2: Axis 2 intersects Axis 1 and is $\perp$ to axis 1

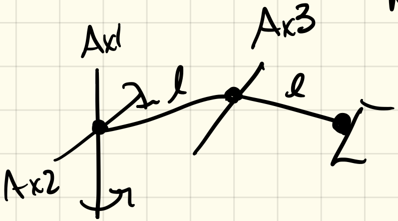
Joint 3: Halfway between Axis 1 and concurrency point

Evaluating Workspace:

$L = \sum a_{i-1} + d_i$ "Structural length sum"

Normalized Volume index: $N = V / \frac{4}{3}\pi L^3$ ← Volume of workspace

(Large N is good)

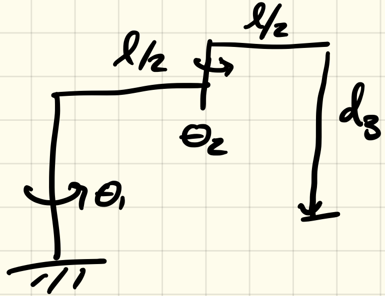


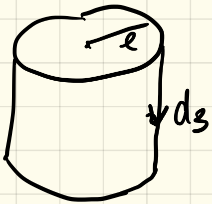
Structural Length index: $L / \sqrt[3]{V} = Q_L$ (Small Q_L is good)

Example: SCARA Manipulator

- What value for d_3 maximizes Normalized Volume index?

- What is the workspace shape?





Volume

$$V = \pi l^2 d_3$$

$$L = \frac{l}{2} + \frac{l}{2} + d_3 = l + d_3$$

$$N = \frac{\cancel{\pi} l^2 d_3}{4/3\, \cancel{\pi} L^3} = \frac{3}{4} l^2 \frac{d_3}{(l+d_3)^3}$$

$$\frac{dN}{dd_3} = \frac{(l+d_3)^{\cancel{3}} - 3\cancel{(l+d_3)^2}\, d_3}{(l+d_3)^{\cancel{6}\,4}} = 0$$

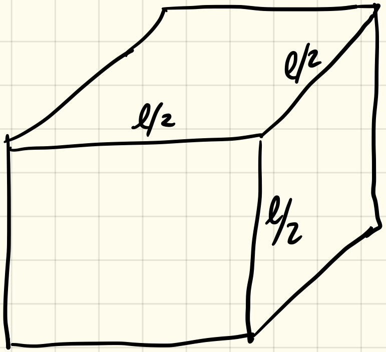
$$l + d_3 - 3d_3 = 0 \Rightarrow \boxed{d_3 = \frac{l}{2}}$$

Symmetry!

Design Comparisson:

$$N = \frac{3}{4} l^2 \frac{d_3}{(l+d_3)^3}\bigg|_{d_3=\frac{l}{2}} = \frac{1}{9}$$

VS. Cartesian Manipulator?



$$N = \frac{(l/2)^3}{4/3\,\pi\left(\frac{3l}{2}\right)^3} = \frac{1}{36\pi}$$