Robotics Terminology

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Parts of Stationary Robot

- Mechanisms (Mechanical Structure)
- End Effecters
- Tools
- Controllers
- Actuators
- Sensors
- Programming Interface
Mechanism Anatomy
Links and Joints

- Links are rigid parts
- Joints permit relative motion between links
Types of Joints
Prismatic Joint
Revolute Joint

Diagram showing a revolute joint with an input link and an output link, which can rotate around a fixed axis. The joint motion is indicated by arrows for both the input and output links.
Degrees of Freedom in Mechanisms

How many degrees of freedom (DOF) are needed to position and orient an object in space?
Desired Degrees of Freedom

- 3 Dimensional Case
  - 3 DOF for positioning (x, y, z)
  - 3 DOF for orientation (pitch, yaw, roll)

- 2 Dimensional Case (Planar case)
  - 2 DOF for positioning (x, y)
  - 1 DOF for orientation (tilt)
Mechanism Types

- Two different category
  - Arm
    - Two to three degrees of freedom
  - Wrist
    - One to three degrees of freedom
Arm: Cartesian Configuration
Arm: Cylindrical Configuration
Arm: Polar Configuration
Arm: SCARA Configuration
Arm: Articulated Configuration
Comparison of Arm Configurations

More Revolute Joints
3 DOF Wrist

Attached to robot arm

Pitch

Roll

Yaw
End Effectors

- Mechanical grippers
- Vacuum gripper
- Magnetic gripper
- Gripper with Adhesive strips
Tools

- Welding guns
- Spray paint guns
- Spindle for drilling and milling
- Screw drivers
- Heating torch
Robot Controllers

- Limited Sequence Control
  - Run one Joint at a time
- Point to Point Control
  - No synchronization of joint motion
- Continuous Path Control
  - Synchronized motion of joints
Commonly Used Actuators

- Electric motors
  - Most commonly used
- Pneumatic cylinders
  - Used in small compact robots
- Hydraulic cylinders
  - Used in very large robots
Commonly Used Sensors

- Proximity sensor (also sometimes called range sensor)
- Tactile sensor (also sometimes called contact sensor)
- Machine vision
Robot Programming

- Manual lead through
- Powered lead through
- Motion programming
A Typical Task
What do we need?

- How to move the robot through space to complete the specified task
- What torques and forces to apply on the joints?
Modeling

- The underlying mathematical model that describes the robot behavior
  - Will be needed to support off line programming
  - Will be needed to design robots
    - Selecting motors, link lengths and cross sections
Forward Kinematics

- Given joint parameters, determine the final end effector location
Inverse Kinematics

- Given desired end effector position and orientation determine the joint parameters
Inverse Kinematics Solutions

- Inverse kinematics may produce
  - One solution
  - Multiple solution
  - No solution
Multiple Solution Case

Elbow Up

Elbow Down
No Solution Case

The selected location is outside the robot workspace
Workspace

- The set of locations that can be reached by the robot
Example

\[ x = a_1 \cos \theta_1 + a_2 \cos(\theta_1 + \theta_2) \]
\[ y = a_1 \sin \theta_1 + a_2 \sin(\theta_1 + \theta_2) \]
Jacobian: Relating Velocities with Joint Velocities

Given joint velocities determine the desired end effector velocities
Example

Recall

\[ x = a_1 \cos \theta_1 + a_2 \cos(\theta_1 + \theta_2) \]
\[ y = a_1 \sin \theta_1 + a_2 \sin(\theta_1 + \theta_2) \]

\[
\begin{pmatrix}
\dot{x} \\
\dot{y}
\end{pmatrix} =
\begin{pmatrix}
-a_1 \sin \theta_1 - a_2 \sin(\theta_1 + \theta_2) & -a_2 \sin(\theta_1 + \theta_2) \\
a_1 \cos \theta_1 + a_2 \cos(\theta_1 + \theta_2) & a_2 \cos(\theta_1 + \theta_2)
\end{pmatrix}
\begin{pmatrix}
\dot{\theta}_1 \\
\dot{\theta}_2
\end{pmatrix}
\]

\[ \dot{x} = J \dot{\Theta} \]
Achieving Desired End Effector Velocities

- Jacobian matrix needs to be inverted to determine the joint velocities to achieve the desired end effector velocity
- This is not always possible
  - Matrix may not be invertible

\[
\dot{\theta} = J^{-1} \dot{x}
\]
Singularity

\[ \dot{\Theta} = J^{-1} \dot{x} \]

Can it be guaranteed that \( J \) is always invertible?

\[ \det(J) = a_1 a_2 \sin(\theta_2) \]

At \( \theta_2 = 0 \) or 180 degrees, \( J \) can’t be inverted.
Singularity

- Losing effective degrees of freedom
  - Cannot specify desired velocity
- Two types of singularities
  - Work-space boundary
  - Workspace-interior

At elevation of zero degrees no effect of changing azimuth

Craig, 2005
Dynamics

What forces and torque need to be applied to joints to achieve the desired velocities and accelerations?
Trajectory Generation

- How to trace a path through the space at the specified velocities
Open Loop vs Closed Loop Control

- If we have a perfect model, then we can just position motors at the desired location with no feedback
- But this does not work in practice
Position Control

- How to compensate for errors and inaccuracies
Force Control

- Control force to ensure that robot can handle delicate objects and move more constrained surfaces
Serial Mechanisms vs Closed Loop Mechanisms
Accuracy vs Repeatability

- Accuracy is a measure of how close the robot reaches to the programmed point in the workspace.
- Repeatability is a measure of how close the robot reaches to the point previously reached by the robot (for the same programmed point).