

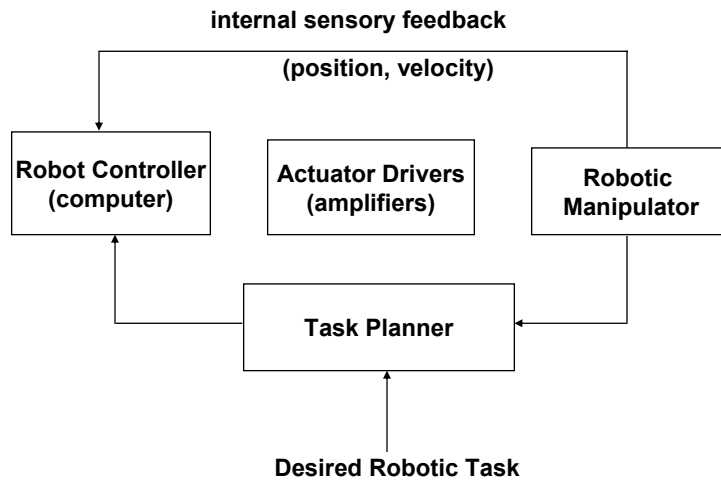
Introduction

- **Robotic System Components**
- **Manipulator Configurations**
- **Robot Specifications**
- **Robot Kinematics**
- **Robot Dynamics**
- **Trajectory Generation**
- **Manipulator Design**
- **Robot Control**
- **Robot Programming**

Definition

- **A Robot is a Programmable, multi-function manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.**
- **Key points:**
 - machine
 - repeated tasks
 - programmability
 - intelligence (e.g., decision making capabilities)
 - articulated motion
 - adapt to environment
 - senses the environment

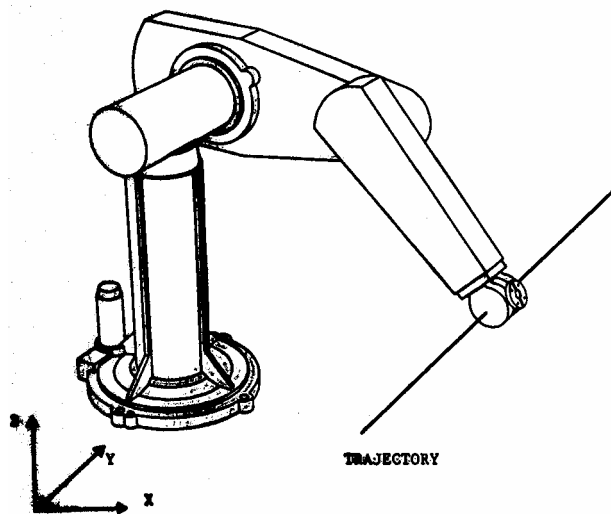
System Components



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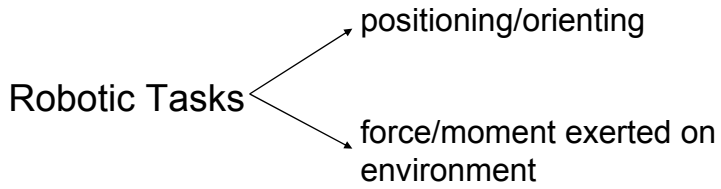
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Robotic Manipulator

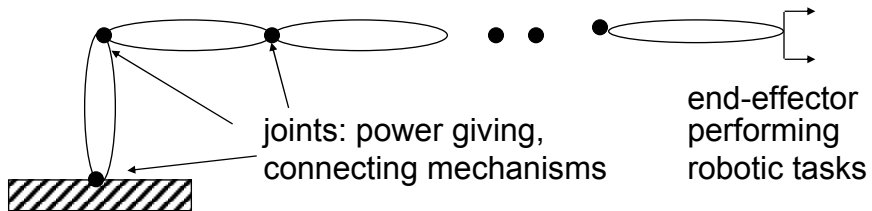


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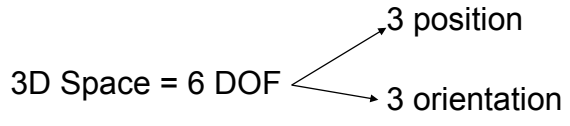
An Open Kinematic Chain, Serially Connected



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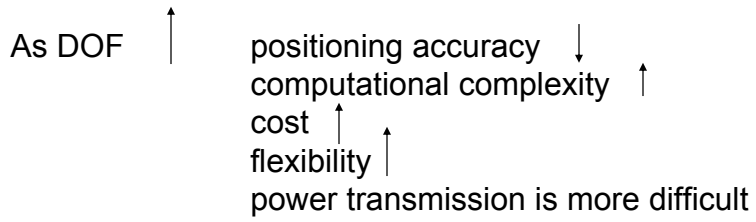
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Degrees-of-Freedom



In robotics,

DOF = number of independently driven joints

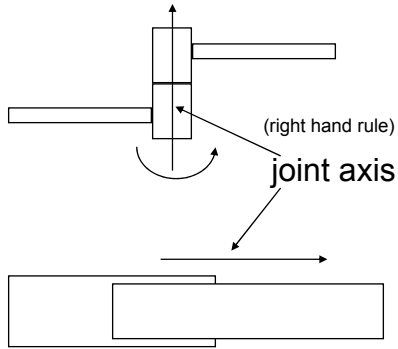


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Robot Joints

Two Basic Types:



Rotational

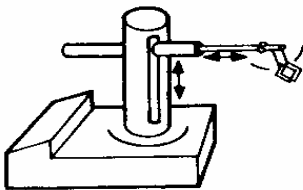
Translational
(Prismatic)

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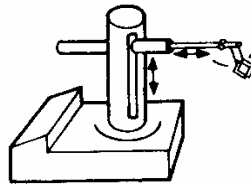
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Manipulator Configurations

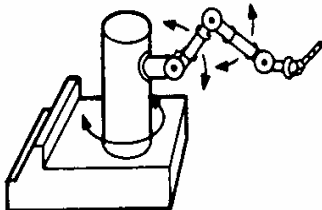
Cartesian



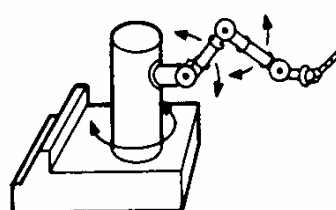
Cylindrical



Spherical



Articulated



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SCARA

- **Selective Compliance Robot Arm**
- Joints 1 and 2 are not gravity loaded
- Joints are direct-drive motors
- End-effector compliance can be controlled to a certain extent

figure of scara

Robot Joints

	<i>Rotational</i>	<i>Translational</i>
Accuracy	Non-Uniform	Consistent
Kinematics	Complex	Simple
Control	Coupled, Difficult	Decoupled, Easy
Link Design	Simple	Complex
Dexterity	Good	Bad

As the number of rotational joints increase,

- task planning complexity ↑
- control algorithm complexity ↑
- dexterity ↑
- accuracy ↓

Drive Technologies

Source of power to drive joints:

Pneumatic:

- energy efficient
- hard for feedback control

Electric:

- clean
- choice of today

Hydraulic:

- can deliver large forces
- bulky, leakage problems

End-effectors = often are pneumatic tools

Note: air-activated tools have built in compliance
→ important when manipulating objects to prevent damage

Motion Control Methods

• Point to Point

- path between points not explicitly controlled
- Applications
 - » spot welding
 - » pick and place
 - » loading and unloading

• Continuous Path

- end-effector must follow a prescribed path in 3D space
- speed may vary or may need to be accurately controlled
- Applications
 - » spray painting
 - » arc welding
 - » gluing

Robot Specifications

- **Number of Axes**
 - Axes 1-3 : “Arm” -Positions the wrist
 - Axes 4-6 : “Wrist” -Orient the tool (or end-effector)
 - Axes 7-n : “Redundant Joints”
 - » obstacle avoidance, joint lockup prevention (singularities), stiffness realization, etc.
- **Work Envelope Geometries**
 - Cartesian, Cylindrical, Spherical, Articulated, SCARA
- **Load Carrying Capacity**
 - varies from 2.2 Kg (Minimover 5 Microbot) to 4,928 Kg (GCA-XR6)

Robot Specifications

- **Maximum Speed**

tool tip speed

92 mm/sec

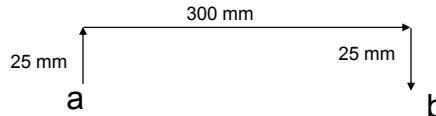
Westinghouse Series 4000



9,000 mm/sec

AdeptOne

Cycle Time :
Adept “Stroke”

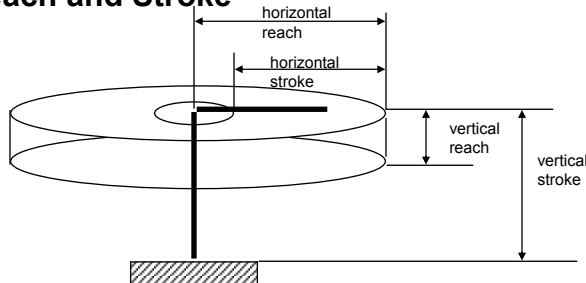


For AdeptOne

<i>Payload</i>	<i>Cycle Time</i>
1 lb	0.9 sec
13 lbs	1.3 sec
20 lbs	1.7 sec

Robot Specifications

- **Reach and Stroke**



Dextrous Workspace

“locus of tool positions for which the tool can be oriented in all possible ways”

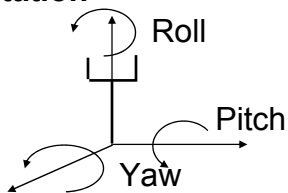
dextrous workspace is usually much smaller than work envelope position workspace

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Robot Specifications

- **tool orientation**



spherical wrist: all three axes intersect at a common point

- **For maximum orientation capability**
 - » no joint limits
 - » adjacent wrist axes must be orthogonal
- **For Kinematic simplicity**
 - » wrist must be “spherical”

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Robot Specifications

- **Repeatability**
 - measure of the ability of the robot to position the tool tip in the same place repeatedly
 - important for repetitive tasks
 - radius of smallest sphere to enclose points
 - ± 2 mm to ± 0.005 mm
- **Precision / Resolution**
 - measure of the spatial resolution with which the tool can be positioned in the work envelope
 - may vary!

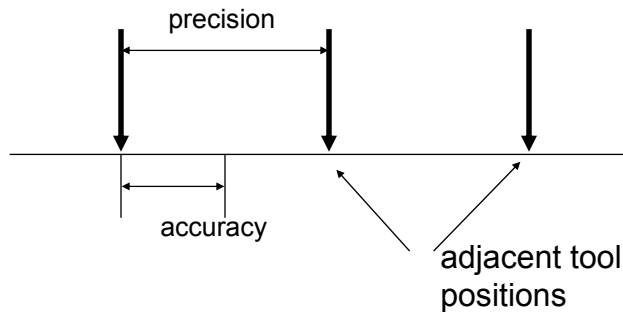
	<i>Horizontal Precision</i>	<i>Vertical Precision</i>
Cartesian	Uniform	Uniform
Cylindrical	Decreases Rapidly	Uniform
Spherical	Decreases Rapidly	Decreases Rapidly
SCARA	Varies	Uniform
Articulated	Varies	Varies

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Robot Specifications

- **Accuracy**
 - measure of the ability to place the tool tip at an arbitrarily prescribed location in the work envelope



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Robot Specifications

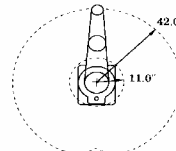
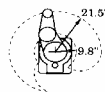
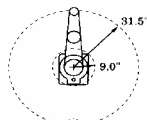
• Operating Environment

- clean room robots
 - » some clean room robots are evacuated internally with suction in order to scavenge particles generated by friction surfaces
 - » others use special non-shedding materials and employ magnetic washers to hold ferromagnetic lubricants in place
- harsh environments
 - » in spray painting, a robotic arm may be clothed in a shroud in order to minimize the contamination of its joints by the airborne paint particles

Robots

	AdeptOne	AdeptTwo	AdeptThree
Reach	31.5" (800 mm)	21.5" (546 mm)	42.0" (1067 mm)
Vertical Stroke	7.7" (196 mm) or 11.6" (295 mm)	8.0" (203 mm)	12.0" (305 mm)
Maximum Payload	20 lbs (9 kg)	20 lbs (9 kg)	55 lbs (25 kg)
Repeatability	0.001" (0.025 mm)	0.001" (0.025 mm)	0.001" (0.025 mm)
12" cycle time (1 lb)	0.9 sec	0.9 sec	1.1 sec
12" cycle time (20 lbs)	1.7 sec	1.7 sec	1.4 sec
Option Compatibility			
High-accuracy Positioning System (HPS)	Yes	Yes	No
Fifth Axis (servo pitch)	Yes	No	Yes
Robot Mounted Camera	Yes	Yes	Yes
Cleanroom Package	Yes	No	No

Work Envelope



Robot Controllers

	Adept MC	Adept CC
Operating System	V	V
System Processor	1 Mb 68000 (10 MHz)	1 Mb 68000 (10 MHz)
Robot Motion Processors	Two 68000 (10 MHz)	Two 68000 (10 MHz)
Serial Ports	Five RS-232C	Five RS-232C
Maximum Digital I/O	36 internal/512 total	32 internal/512 total
Option Compatibility		
Robot Control	Any Adept robot	Any Adept robot
AdeptVision	Any AdeptVision system	AdeptVision II/AdeptVision XGS-II
Adept V+	Yes	Yes
68020 System Processor	Yes	Yes
AdeptMotion I	Yes	Yes
NEMA 12	Yes	No

Task Planning

- **Robotic task is broken down into**
 - motion commands
 - force/torque commands
 - strategies to react to forces/torques
- **Trajectory Generation**
 - joint trajectories
 - » position of each joint as a function of time
 - » coordinated motion of joints to provide desired end-effector motion

Manipulator Design

- **Dexterity Considerations (Geometry, Workspace)**
- **Control Considerations**
- **Rigid Vs Flexible**
- **End-Effector Toolings**
- **Actuators and power transmission**
- **Sensors**
- **Depending on task (e.g., number of DOF?)**

Robot Control

- **Motion Control**
 - design of a stable and robust algorithm to coordinate joint motion and enable the robot to follow a specified trajectory, described in a Cartesian coordinate frame
 - Point-to-Point
 - Trajectory Following
 - Independent Joint Control
 - Inverse Dynamics Control (Computed Torque)
- **Force Control**
- **Compliance Control**
- **Hybrid Position/Force Control**
- **Impedance Control**

Robot Programming

- **Robot Operating System and Robot Programming Language**
 - VALII, Karel, Robot-Basic, etc
- **User Interface**
 - AdeptMotionWare
- **Walk-Through Programming**
- **Telerobotics**