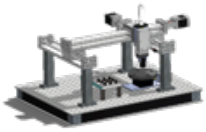
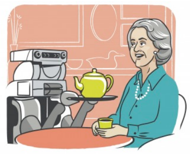
Manipulation

Overview, Concepts, Types





Many slides adapted from:
en.wikipedia.org
S. N. Kale, Assistant Professor, PVPIT, Budhgaon
www.amci.com/tutorials/tutorials-stepper-vs-servo.asp
www.modmypi.com/blog/whats-the-difference-between-dc-servo-stepper-motors

1

Bookkeeping

- Homework 2 out
- Project milestone 1 due right after spring break
- Make sure you make arrangements with your group for spring break
- A little tiny bit of stern stuff:
  - Do not let 1-2 people do all the building.
  - Do not do anything to mess up your group.

2

2

Project plans

1. Build!
   - No soldering, plenty of instructions
   - Everyone should participate!
2. Get working under ROS
3. Wall following
4. Soccer (this is the fun part)
   - Localization, data tracking, planning, sensors, …
5. Tournament/demos
6. Unbuild ☹

3

3

What is Manipulation?

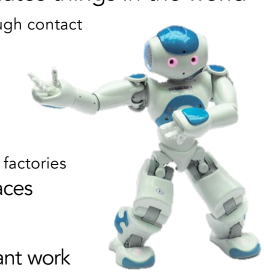
- How a robot:
  - Makes physical changes to the world around it
  - Physically interacts with the world and other agents
- Moving/joining/reshaping/painting/etc. objects
- Grasping, pushing, carrying, dropping, throwing, lifting, …
- **Using a manipulator** (usually an arm) **with some sort of end-effector**

slide adapted from www.cs.columbia.edu/~allen/F15/NOTES/graspingClass2_2.ppt 4

4

Manipulation

- So a manipulator manipulates things in the world
  - Physically alter the world through contact
  - As a primary goal
  - But not its own position
- When is this desirable?
  - Dangerous workspaces
    - Space; foundries; underwater; factories
  - Human-intractable workspaces
    - Too small; too big; too much precision needed
  - Boring, repetitive, unpleasant work



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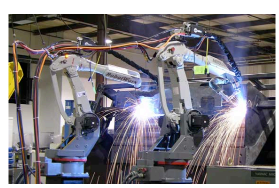
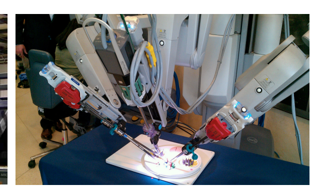
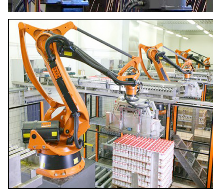
5

Manipulators







6

Manipulators

8

Manipulators

9

9

Uses

- Current
  - Industrial
    - Welding
    - Drilling
    - Attaching (screws, rivets)
    - Painting
    - Loading/unloading
  - Surgery
  - Space exploration
  - Chores
  - Patient care
  - Delivery
- Future
  - Elder care
  - Entertainment
  - Environment sampling
  - Compliant-material interactions (sewing)
  - Police work
- Plus: more chores, more patient care, more surgery, more space, &c. (but better)

10

10

Pick-and-Place

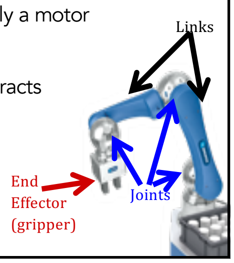
www.youtube.com/watch?v=wg8YYuLLoM0

11

11

Terminology

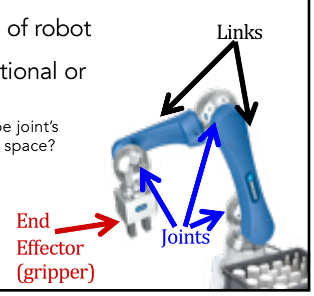
- Kinematic model: modeled as a chain of *rigid links* connected by *joints*
- Actuator
  - Generates motion or force; usually a motor
- End Effector
  - Device at the end of an arm; interacts with environment
  - Grippers, tools
- Actuation
  - How are parts made to move?



12

Kinematic Models

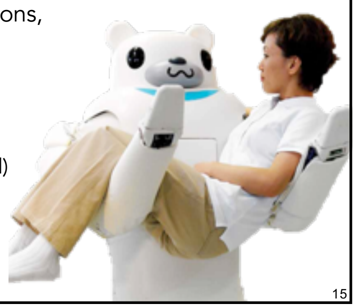
- Kinematic model: modeled as a chain of *rigid links* connected by *joints*
- **Links**: unjointed length of robot
- **Joints**: produce translational or rotational movement
  - Dofs: how many to describe joint's position and orientation in space?
  - Sliding or jointed
- Manipulator
  - Gripper, tool, sensor…
  - Also "end effector"



14

Manipulator Characterization

- By drive type
- By actuation: Tendons, direct servoing, underactuation
- By motion type
  - Prismatic (linear)
  - Revolute (rotational)
- By Characteristics
  - Payload, radius, Working area



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Joints

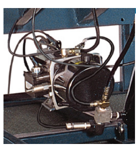
- Prismatic: sliding / translational

- Revolute: rotational

16

16

Actuators



Hydraulic Motor

Pneumatic Cylinder

Stepper Motor

Pneumatic Motor

DC Motor

Servo Motor

17

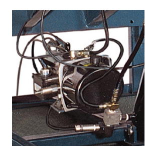
17

When Do We Use…

- Hydraulic/pneumatic
  - Heavy loads, high speeds
  - Sometimes hard to control (esp. pneumatic)
  - Doesn't produce sparks

Pneumatic Motor

Pneumatic Cylinder



Hydraulic Motor

18

18

When Do We Use…

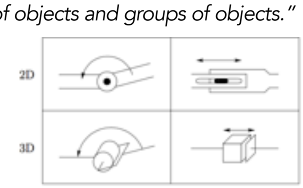
- Most common robotic actuators use combinations of electro-mechanical devices
  - Stepper motor
    - Subdivides a rotation into 4-10 increments
    - Open Loop
  - Servo Motor
    - Closed loop
    - Subdivides a rotation arbitrarily
    - AC servo motor
    - Brushless DC servo motor
    - Brushed DC servo motor
- But usually *motors.*

19

19

Kinematics: P[rismatic] & R[evolute]

- A kinematic chain of rigid links connected by joints
  - *"**Kinematics** is the branch of classical mechanics which describes the motion of objects and groups of objects."*
- Prismatic (denoted P)
  - Sliding / translational / linear; allows a linear relative motion between 2 links
- Revolute (denoted R)
  - Rotational; allows relative rotation between two links



Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006

21

21

Joints: Denotation

- A joint represents a connection between two links
- Denotation of **relative displacement** between links
  - θ for revolute joint
  - d for prismatic joint
- Denotation of axis of motion
  - z_i between link i and link i+1:
    - Axis of rotation of a revolute joint
    - Axis of translation of a prismatic joint

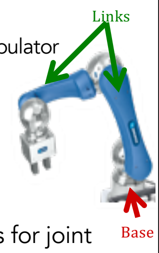
Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006

22

22

Configuration Space

- **Configuration**
  - Specifies location of every point on manipulator
- How?
  - Links are rigid
  - Base is (assumed to be) fixed
  - So just need values for the joint variables
    - Angle for R joints (θ), offset for P joints (d)
- Manip. configuration ≡ a set of values for joint variables
- Set of all possible configurations is the ***configuration space.***



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23

23

Sanity check

- What's a link?
- What's a joint?
- What's a base?
- What kinds of joint are there?
- What's a configuration?
- How is it specified?
- What's an end effector?

- A rigid, connecting piece
- Where two links move relative to each other
- The robot's "starting point" – furthest from end effector
- Revolute and prismatic
- Current orientation and position of manipulator
- Per joint, using θ or d
- The interactive bit on the end

26

26

DoFs for Manipulation

- A system has n DoFs if exactly n parameters are required to completely specify the configuration.
- For a manipulator:
  - Configuration can be specified by n joint parameters
  - # of DoFs = dimension of the configuration space
  - So, # number of joints determines DoFs
- Rigid object in 3D space has six parameters
  - 3 positioning (x, y, z), 3 orientation (*roll*, *pitch* and *yaw*)
- DoFs < 6 ⇒ arm cannot reach every point in workspace **with arbitrary orientation**

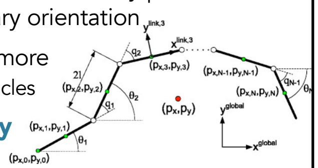
Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006

27

27

Notes on DoFs

- DoFs < 6 ⇒ arm cannot reach every point in workspace with arbitrary orientation
- Sometimes you need more
  - E.g., dealing with obstacles
- DoFs > 6: **kinematically redundant**
- Difficulty of control problem as # DoFs grows?
  - Increases *rapidly* with the number of links
    - Every 2 links need a joint
  - Control ∝ 1/Maneuverability

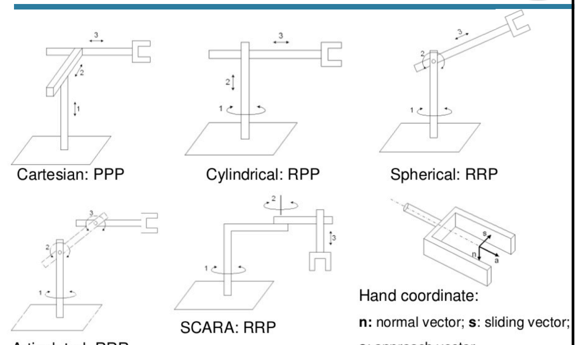


Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006.
Ehsan Rezapour, Pettersen, Gravdahl, Liljebäck, Kelasidi. Robotics and Biomimetics. 2014.

28

28

Common Configurations



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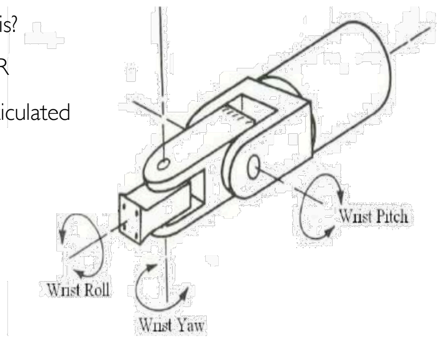
29

Configuration Example

- So this is?

  RRR

  Articulated



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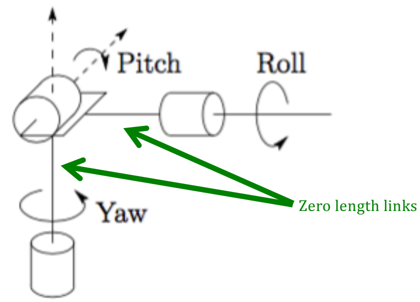
30

RPY: Spherical Joint



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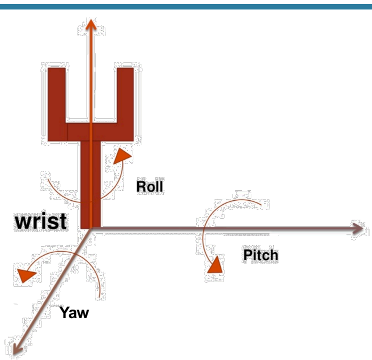
31

RPY: Whole joint



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32

Kinematic Model

- Link specification + joint specification
  - Configuration space can be **derived from** kinematic model
- How joint movement relates to link motion
- Assumptions:
  - Desired state of the robot can be specified by changes to joints
  - Any set of joint states can be specified
  - When specified, the links will execute as instructed

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33

Configuration Spaces

- **Configuration:** location of all points on a manipulator *at a point in time*
  - Specified by state of every joint (θ or d)
  - Can treat these as a **vector**, q
  - Example: if θ_1=60°, d_1=3cm, and θ_2=12.2° (← RPR)!
  - $q = <q_1, q_2, q_3> = <60, 3, 12.2>$
- **Configuration space**: set of all possible configurations — *This is also called joint space*
- Doesn't say anything about dynamics.
  - How is it moving? How CAN it move?

34

34

State Spaces

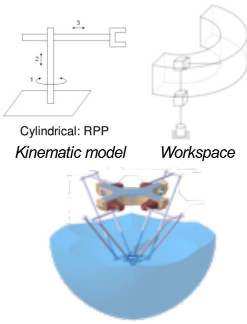
- **State:** manipulator's configuration *plus* dynamics (its movement) *plus* inputs (commands)
  - Sufficient to determine any future state of the manipulator
- **State space:** set of all possible states
- Specification: joint variables q, joint velocities $\dot{q}$
  - Acceleration is derived from joint velocities
- States represented as a vector $x = (q, \dot{q})$
- And that's it for dynamics for now!

35

35

Workspaces

- So where can a manipulator go (reach in space)?
- **Workspace:**
  - Set of all possible **positions** of end effector
  - In practice, these can be complex



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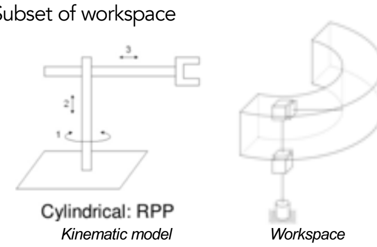
engineeriau.wordpress.com/2013/07/07/on-the-basis-of-workspaces-of-robotic-manipulators-part-1

36

36

Workspaces 2

- **Dexterous** workspace: end effector can be in any position **and orientation**
  - Subset of workspace



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37

37

Measuring Success

- **Accuracy:** how close is manipulator to specified configuration/is end effector to specified coordinate?
- **Repeatability:** how similar is behavior given an identical command?
- We only measure joint state (using encoders)
  - Everything else is inferred from rigid links
- Primary source of failure: **Rigidity of links**
  - And straightness, but that can be calibrated out
- Given gravity, load, angular velocity, …

38

38

Other Important Features

- Payload: How much can it lift?
  - Varies depending on location of end effector
- Speed: How fast can it go?
  - How does speed of a *joint* relate to speed of *arm*?
- Working radius: what's the boundary it can't reach past?
- Actuation type: How is it made to go?
  - Servo, tendon-driven, underactuated, …

39

39

Summary: Specifying Manipulators

- Kinematic model: Links, joints, and base
- Configuration space: arrangement of a manipulator
  - I.e., where are all its parts?
- State space: Configuration + motion
- Workspace: where it can reach, in what configuration
- Accuracy, repeatability/precision

40

40