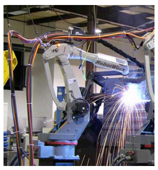
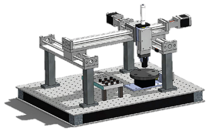
Manipulation
Configurations





Many slides adapted from:
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
en.wikipedia.org

Questions…

2

- What's a link?
  - A rigid, connecting piece
- What's a joint?
  - Where two links move relative to each other
- What's a base?
  - The robot's "starting point" – furthest from end effector
- What kinds of joint are there?
  - Revolute and prismatic
- What's a configuration?
  - Current orientation and position of manipulator
- How is it specified?
  - Per joint, using angle and distance
- What's an end effector?
  - The interactive bit on the end

DoFs for Manipulation

3

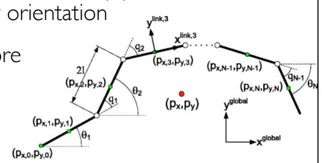
- A system has n DoFs if exactly n parameters are required to completely specify the configuration.
- For a manipulator:
  - Configuration can be specified by n joint parameters, so
  - # of DoFs = dimension of the configuration space
  - So, # number of joints determines DoFs
- Rigid object in 3D space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

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

Notes on DoFs

4

- DoFs < 6 ⇒ arm cannot reach every point in workspace with arbitrary orientation
- Sometimes you need more
  - E.g., dealing with obstacles
- DoFs > 6 is kinematically redundant

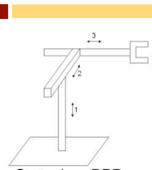


- Difficulty of control problem as # DoFs grows?
  - Increases *rapidly* with the number of links
    - Every 2 links need a joint
  - Control ≈ 1/Maneuverability

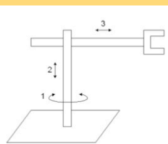
Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006.
Ehsan Rezapour, Pettersen, Gravdahl, Liljebäck, Kelasidi. Robotics and Biomimetics. 2014.

Configurations

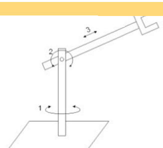
5



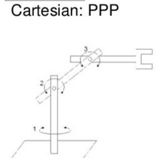
Cartesian: PPP



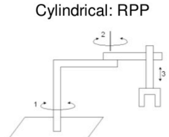
Cylindrical: RPP



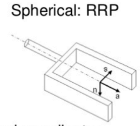
Spherical: RRP



Articulated: RRR



SCARA: RRP



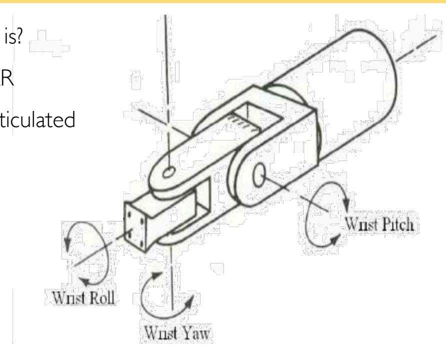
Hand coordinate:
n: normal vector; **s**: sliding vector; **a**: approach vector

S. N. Kale, Assistant Professor, PVPIT, Budhgaon

Configuration Example

6

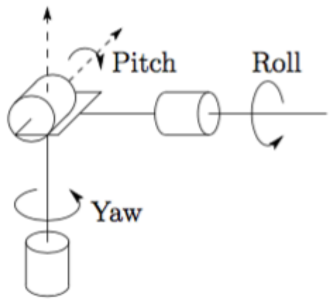
- So this is?
  - RRR
  - Articulated



S. N. Kale, Assistant Professor, PVPIT, Budhgaon

RPY Again: Spherical Joint

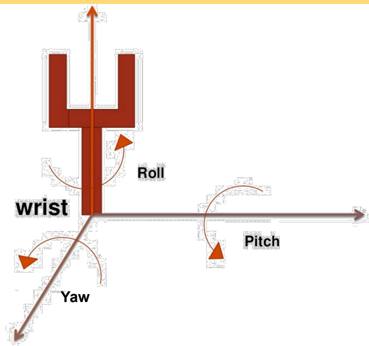
7



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

RPY Again: Whole Gripper

8

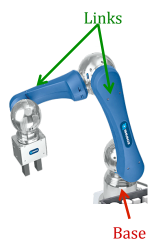


S. N. Kale, Assistant Professor, PVPIT, Budhgaon

Configuration Space

9

- **Configuration:** location of every point on system (manipulator)
- Configuration can be inferred from a set of values for joint variables
- How can we specify?
  - Links are rigid, base is (assumed to be) fixed
  - So if we know values for the joint variables
    - Angle for **R** joints (θ), offset for **P** joints (d)
  - Can infer location of any point
- Set of all possible configurations: ***configuration space***



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

Kinematic Model

10

- 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

S. N. Kale, Assistant Professor, PVPIT, Budhgaon
Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006.

Configuration Spaces, cont'd

11

- **Configuration:** location of all points 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?

State Spaces

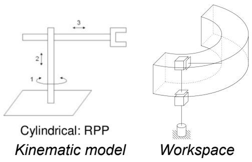
12

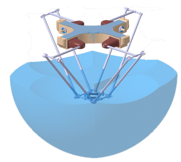
- **State:** manipulator's configuration *plus* dynamics (its movement) *plus* inputs (commands)
  - Sufficient to determine any future state of the manipulator
- **State space:** set of all possible states
- Specification: joint variables q, joint velocities $\dot{q}$
  - Acceleration is derived from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

Workspaces

13

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



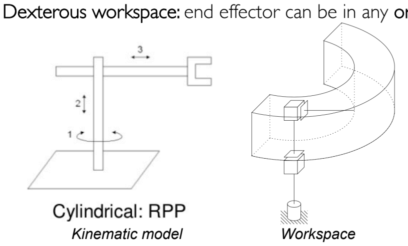


Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006.
engineerjau.wordpress.com/2013/07/07/on-the-basis-of-workspaces-of-robotic-manipulators-part-1

Workspaces 2

14

- So where can a manipulator go (reach in space)?
- Workspace: possible **positions** (x,y,z) of end effector
  - Dexterous workspace: end effector can be in any **orientation**



Spong, Hutchinson, Vidyasagar. Robot Modeling and Control. 2006.
engineerjau.wordpress.com/2013/07/07/on-the-basis-of-workspaces-of-robotic-manipulators-part-1

Measuring Success

15

- 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, …

Other Important Features

16

- 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, …

Summary: Specifying Manipulators

17

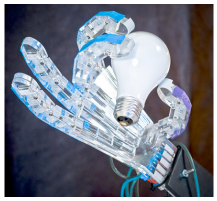
- Kinematic model: Links, joints, and base
- Configuration space: arrangement of a manipulator
  - I.e., where are all its parts?
- State space: Configuration + motion
- Workspace: where it can reach, in what configuration
- Accuracy, repeatability/precision

Grippers, Actuating Grippers, Grasping

Grippers

19

- Five categories of robot grippers:
  - Impactive
    - Jaws or claws which physically grasp (grasping) by direct impact upon the object
  - Ingressive
    - Pins, needles or hackles penetrate surface
      - Textile, carbon and fiberglass handling
  - Astrictive
    - Suction forces applied to surface
    - Vacuum, magneto- or electroadhesion
  - Kontugutive / Contigutive
    - Requiring direct contact for adhesion
    - Glue, surface tension or freezing

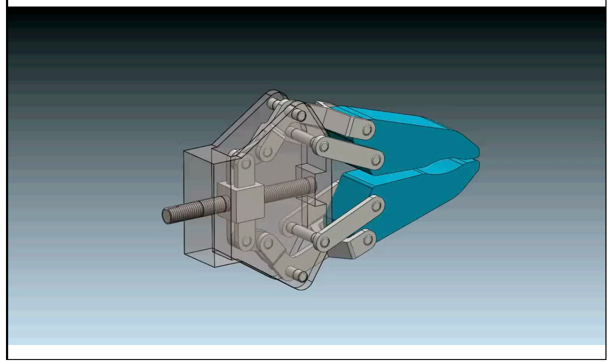


Monkman, Hesse, Steinmann, Schunk. Robot Grippers. 2007.
news.nationalgeographic.com/news/2009/05/090505-robot-hand-picture.html

Prismatic Impactive Gripping

https://www.youtube.com/watch?v=qKZLx1wtFCk

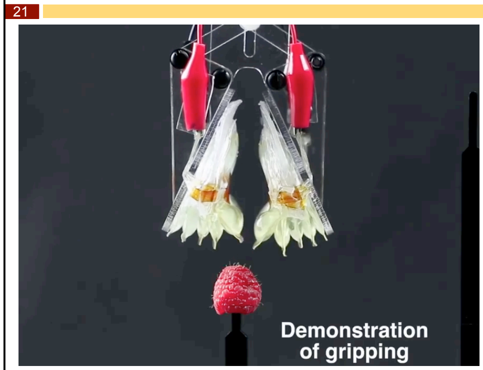
20



Soft Impactive Gripping

https://www.youtube.com/watch?v=qPVt0bZtNAM

21



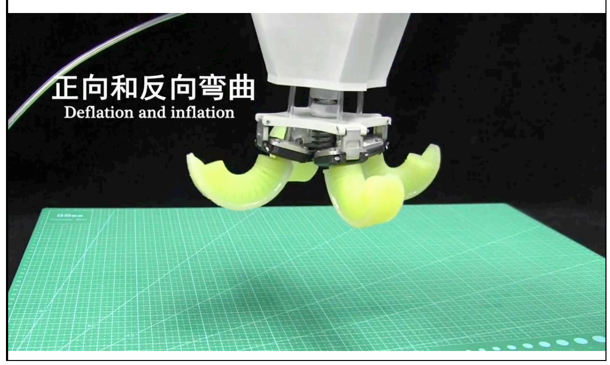
"…relies on two kinds of soft robot technology: pneumatics and dielectric elastomer actuators."

[Science Magazine, Jan. 2018]

Soft Pneumatic Impactive Gripping

https://www.youtube.com/watch?v=gI0tzsO8xwc

22



And Then There's This.

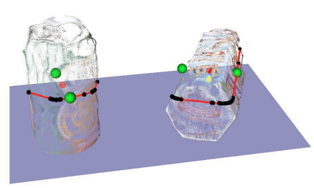
https://www.youtube.com/watch?v=0d4f8fEysf8

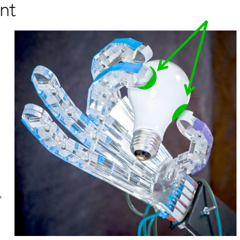
23

Grasps

24

- Grasp:
  - A set of contact points on an object's surface
  - Goal: constrain object's movement



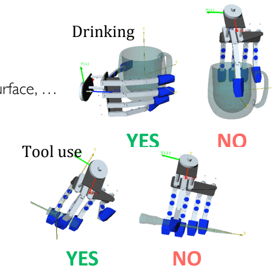


www.intechopen.com/books/robot-arms/robotic-grasping-of-unknown-objects1
news.nationalgeographic.com/news/2009/05/090505-robot-hand-picture.html

Grasps

25

- Grasps vary by:
  - Hand (gripper)
  - Object being grasped
    - Topology, topography, mass, surface, …
  - Type of motion desired
- For each hand or hand/object pair:
  - Where to grasp it?
  - How hard?
  - Then what?



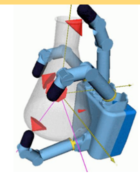
- Additional constraints (e.g., don't spill)

www.madry.pro
León, Morales, Sancho-Bru. Robot Grasping Foundations. 2013

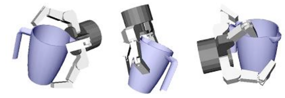
The Grasping Problem

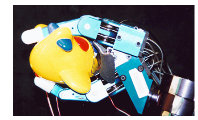
26

- Grasps are not obvious (easy to calculate)
  - Any given object has arbitrary contact points
  - Hand has geometry constraints, etc.



- Synthesized trial-and-error
  - For a hand/object pair:
  - Different grasp types planned and analyzed





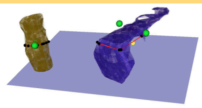
- Real trial and error

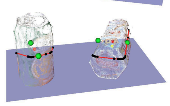
www.cs.columbia.edu/~cmatei/graspit/
www.programmingvision.com/research.html
www.cc.gatech.edu/gvu/people/faculty/nancy.pollard/grasp.html

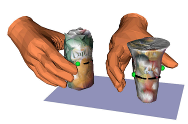
Grasp Planning

27

- **Grasp synthesis:** Find suitable set of contacts, given
  - Object model
  - Constraints on allowable contacts
- **Grasp points** are determined
  - Mostly assume point **contacts**
  - Larger areas usually discretized
  - **Contact model** defines the force the manipulator exerts on contact areas
- **Grasp analysis**
  - Is that grasp stable?





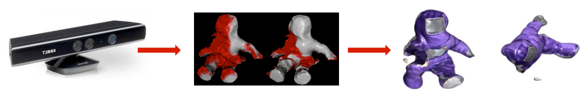


León, Morales, Sancho-Bru. Robot Grasping Foundations. 2013.
www.intechopen.com/books/robot-arms/robotic-grasping-of-unknown-objects1

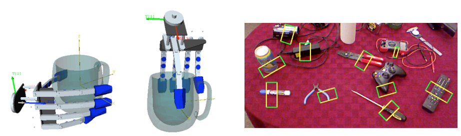
Current Research Questions

28

- How do you get the object model?



- What are the constraints?

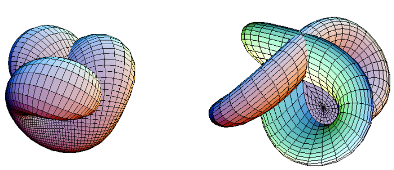


www.madry.pro
www.cs.washington.edu/robotics/3d-in-hand

Types of Motion

29

- Point to point
- Path-following
  - Manifold: the surface an end effector can trace out



- So how do we actuate grasping?

Actuation: Characteristics

30

- **Continuous rotation**: revolute joint that spins 360°
  - Most joints have a smaller range of motion
- **Underactuated system** (vs. fully actuated): has fewer actuators than DoFs
  - Some joints can't be controlled directly
  - Most common example: fingertips
- **Back-driveable:** can be moved by an external force without damage
  - Some kinds of actuation will break if you move them around in space

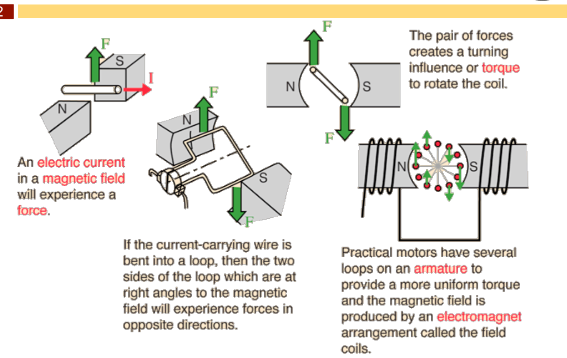
Actuators: Motors

31

- Motor (usually a simple DC motor)
  - You put in power and it spins; increase and it goes faster
- Servo: usually, motor + encoder + plus controller
  - Sometimes:
    - Geared
    - Limited to 180°
    - Non-backdriveable
  - This is somewhat fuzzy!
- Stepper motor: Spins to specific rotations
  - As a product of how it is designed

Motors writ (very) broad

32

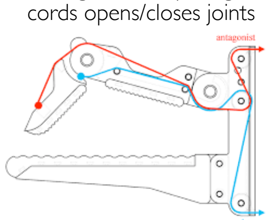


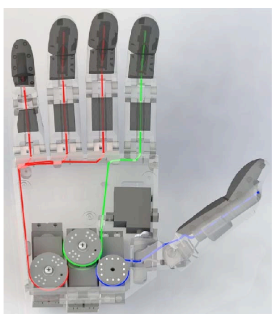
http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html

Actuators: Tendons

33

- String/cords across joints through holder; pulling cords opens/closes joints



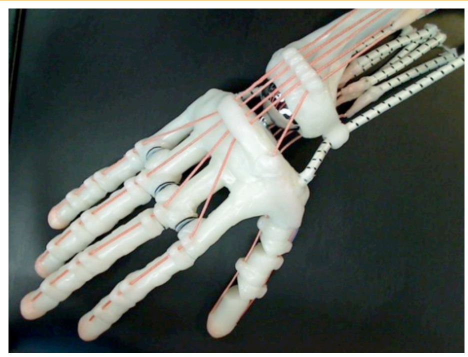


- Note underactuation!

Kappassov, Zhanat et al, ICMA 2013
Ma, Raymond et al, Advances in reconfigurable mechanisms and robots II, 2016

Actuators: Tendon-Driven

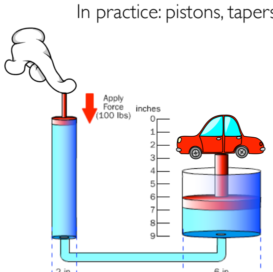
34

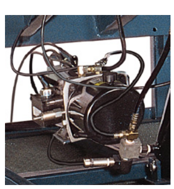


Hydraulics

35

- Hydraulics: Force multiplication using incompressible liquid
  In practice: pistons, tapers, …





Hydraulic Motor

http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/mothow.html

Pneumatics

36

- Use compressed air to generate energy.
  - Quick to respond
  - Not ideal under high pressures
- Piston style
  - Generate linear force by acting on a piston
  - Convert linear force to torque (if needed)
- Diaphragm style
  - Rubber diaphragm and stem in circular housing
  - Good for valves requiring shorter travel