Manipulation: Mechanisms, Grasping and Inverse Kinematics

RSS Lectures 14 & 15
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Mobility / Manipulation Duality

• Mobility:
  – Earth is fixed
  – Legs apply forces to earth
  – Reaction forces move body

• Manipulation:
  – Body is fixed to earth
  – Arms apply forces to manipuland
  – Forces move manipuland

• Goal of Field: Mobile Manipulation
  – Use of coordinated whole-body motion to effect desired manipulation of manipuland, environment
  – Examples: Lifting a sandbag, throwing a baseball, shoveling snow, replacing a ceiling smoke detector
Manipulation by Pushing

- Stable push:
  - Motions that keep object in *line* contact with manipulator
  - Motion planning, but with additional constraints

Fixturing

- Use of designed pegs, surfaces, prior knowledge of manipuland geometry to achieve desired pose

- Goldberg’s “part squeezer” (*Try it!*).
Soft-finger Manipulation

• Can exploit visual/tactile sensing & feedback

Mobile, Two-handed Manipulation

• Challenges: mass distribution; uncertainty
End Effectors

- The component that usually comes into intentional contact with the manipuland
- Often attached interchangeably to robot arm
  - … like a human hand picking up a specialized tool
- Many designs (here ordered roughly by time)

Manipulation Challenges

- How can the robot perceive the object’s type and pose?
- How can the robot reach for the object?
- How can the robot grasp the object?
- How can the robot move the object where desired?
- … Today we'll focus on grasping.

CMU robot “Herb” (Home Exploring Robot Butler, also after Herb Simon)
Mechanism Analysis

- Given some set of constraints, how can the motion of an object be characterized?
  - Rotating links
  - Sliding links
  - Point contacts

Rotation Center (RC)

- Consider finite planar displacement of rigid object
  - Some point in the plane is left fixed by displacement
  - This point is called the “rotation center” (RC)

- What if the displacement is a pure translation?
  - Where is the RC?
Instantaneous Center (IC):

- Consider a *differential* displacement (i.e. velocity)
  - Displacement still has a fixed point; where is it?
- What if the displacement is a pure translation?
  - Where can the IC lie?

Use of IC for Mechanism Analysis

- Example four-bar linkage:
  - Base link
  - Two sliding+rotating links A, B
  - Coupler link connecting AB

- Example four-bar linkage:
  - Base link
  - Four rotating links A, B, C, D
  - Coupler link connecting AB

- Constraints on A, B dictate coupler motion
- IC completely determined; characterizes linkage
IC for Mechanism Analysis (cont.)

- Consider this mechanism:
  - IC is

- Another possibility:
  - “False instantaneous center”

Unilateral constraints

- Point contact with boundary of manipuland
- Manipuland cannot violate constraint
  (but it can separate from it: thus “unilateral”)

- How does this point contact constrain the possible motions of the manipuland?
Reuleaux’s method (1876)

- Each unilateral constraint partitions space of ICs into regions left, right and on line of contact normal

Why is the “line of contact normal” key to analysis?
- Along it, differential rotation of either sign is possible (for now, we are assuming frictionless point contacts)

Reuleaux’s method (cont.)

1. Construct line of contact normal for each contact
2. Label plane regions as $\oplus$ or $\ominus$ w.r.t. this constraint

3. Each remaining region with consistent labels is a locus of possible instantaneous centers
→ Can the IC locus become empty? If so, how?