Teaching Forward and Inverse Kinematics of Robotic Manipulators via MATLAB

Philip Dames, Denise Wong, Katherine J. Kuchenbecker

ICRA
5th June 2014
MEAM 520 Overview

- Graduate level course
- Diverse student body
  - Mechanical Engineering, Electrical and Systems Engineering, Computer and Information Science, Embedded Systems, and Robotics
  - Enrollment of around 100 students (~40 Undergraduate, ~60 Masters, ~3 Ph.D.)
- Textbook: “Robotic Modeling and Control” by Spong, Hutchinson, and Vidyasagar
MEAM 520 Topics

- Focus is on robotic manipulators
  - Rigid motions and homogeneous transformations
  - Forward and inverse kinematics
  - Dynamics and control
- MATLAB use in the course
  - Regular programming assignments, e.g.,
    - Graphing 2D workspace of a robot arm
    - Animating a flying box using recorded magnetic tracker data
    - Implementing Denavit-Hartenberg parameters
    - Graphing manipulability ellipsoids of a 6-DoF manipulator
  - Three projects
MEAM 520 Projects

**Goal:** Give students hands-on experience with real robotic hardware (under the constraint that we have 1 robot for 100 students)

1. PUMA Dance
2. PUMA Light Painting
3. Phantom Premium Virtual Haptic Environment
PUMA 260 Manipulator

- 6-DoF serial manipulator
  - RRR with offsets
  - Spherical wrist
- Connected to a Linux computer
  - Servo2Go ISA card
  - Optical encoders and DC brushed motors
- Controlled from MATLAB
  - Custom mex API in C++
  - Tightly integrated with simulation environment
PUMA 260 Simulator

- Uses Peter Corke’s Robotics Toolbox
- Kinematic simulator
  - Specify joint angles as a function of time
  - Joint angles/angular velocities limited
  - Allows for real-time execution of trajectories
- Allows students to test code *before* using the real robot
  - `pumaStart('Hardware','on')`
Forward and Inverse Kinematics

Joint coordinates
PUMA 260: \( \theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6 \)

Forward Kinematics

Pose of end-effector
PUMA 260: \( x, y, z, \phi, \theta, \psi \)

Inverse Kinematics
PUMA Dance

- Teams of 2 students solve the forward kinematics of PUMA
  - Specify waypoints in joint space with a time stamp
  - Implemented multiple interpolation methods
- Dances were played in time with music and lights
PUMA Dance Video
PUMA Light Painting

- Teams of 3 students solve the inverse kinematics of PUMA
  - All 8 solutions
- PUMA arm fitted with tri-color LED
  - Students control the 3D position, orientation, and RGB color of the end-effector
- Take long exposure image using webcam or DSLR camera

[Shomin & Fiene, ASME IDETC, 2011]
Simulation to Hardware

Simulation

Hardware
Light Painting Results
Virtual Haptic Environment

Phantom Premium 1.0

Legacy SensAble ISA card
Conclusion

- MATLAB provides an easy-to-use environment for students to explore robotics
- Simple transition between simulation and hardware
- Student testimonials:
  - "The mapping between theory and application through the problems and projects is very helpful in learning."
  - "Simulations obviously take a lot of time but it is great to have videos and graphics to go along with the concepts. Makes everything way more clear."
  - "The assignments are a lot of fun especially the coding assignments. I seriously look forward to working on them."
Questions?

Katherine J. Kuchenbecker
Associate Professor
kuchenbe@seas.upenn.edu