Kinematic Redundancy

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Quiz (10 points)

- Derive the forward kinematics
  - \( x_e = ? \)
  - \( y_e = ? \)
- Derive the 4x4 Jacobian Matrix for this two link manipulator

\[
J(q) = \begin{bmatrix}
\frac{\partial x(q)}{\partial q_1} & \frac{\partial x(q)}{\partial q_2} & \cdots & \frac{\partial x(q)}{\partial q_n} \\
\xi_1 z_0(q) & \xi_2 z_1(q) & \cdots & \xi_n z_{n-1}(q)
\end{bmatrix}
\]
Quiz (10 points)

\[
\begin{align*}
X_e &= l_1 c_1 + l_2 c_{12} \Rightarrow \sqrt{6} p t \\
Y_e &= l_1 s_1 + l_2 s_{12}
\end{align*}
\]

\[
\dot{x} = J \ddot{\theta} \Rightarrow \frac{dx}{dt} = J \frac{d\theta}{dt}
\]

\[
J = \begin{bmatrix}
\frac{2x_e}{\theta_1} & \frac{2x_e}{\theta_2} \\
\frac{2y_e}{\theta_1} & \frac{2y_e}{\theta_2}
\end{bmatrix}
\]
Quiz (10 points)

\[ T(\theta_1, \theta_2) = \begin{pmatrix} c_{12} & -s_{12} & L_1 c_1 + L_2 c_{12} \\ s_{12} & c_{12} & L_1 s_1 + L_2 s_{12} \\ 0 & 0 & 1 \end{pmatrix} \]

\[ J_{2 \times 2} = \begin{bmatrix} -L_1 s_1 - L_2 s_{12} & -L_2 s_{12} \\ L_1 s_1 + L_2 c_{12} & L_2 c_{12} \end{bmatrix} \]
Project objectives
Project Team Assignment

• Active Projects
  • Teleoperating a Humanoid Nursing Robot from Motion Capture System
  • Building a haptic devices for home-based stroke rehab
  • Arm-hand-finger Coordination
  • Vision-based reactive motion control for human-robot handing-over
  • Human driver motion study
Project Team Assignment

- Teleoperating a Humanoid Nursing Robot from Motion Capture System
  - Yudong YU <yyu6@wpi.edu>
  - Arjun Jagdish <ajram@wpi.edu>
  - Sanjuksha Nirgude <snirgude@wpi.edu>
  - Tianyu Cheng <tcheng@wpi.edu>
  - Sihui Li <sli16@wpi.edu>
Project Objectives

- Establish mocap teleoperation for the humanoid robot
  - Reaching and grasping
- Investigate algorithms on
  - Demo data processing (e.g., segmentation, labeling, autonomous processing)
  - Low-level learning (e.g., task trajectories)
  - High-level learning (e.g., task plan, objectives, relevant features)
  - Motor skill refinement (e.g., RL based on the demonstrated skills)
Project Team Assignment

- Vision-based reactive motion control for human-robot handing-over
  - Gunnar Horve <gchorve@wpi.edu>
  - Heramb Nemlekar <hsnemlekar@wpi.edu>
  - Himanshu Raghuvanshi <hraghuvanshi@wpi.edu>
  - Onkar Trivedi <otrivedi@wpi.edu>
  - Dharini Dutia <dkdutia@wpi.edu>
  - Rohit Voleti <rnvoleti@wpi.edu>
Project Objectives

• Setup 3D camera for capturing human partner’s feature
  • Frequency, accuracy, handling imperfect data (jitter, occlusion)
  • Hand position, gaze, body gesture, ...

• Reactive motion control
  • Based on the best judgement of human partner’s motion and intent

• Investigate physical human-robot interaction
  • Can the human partner train the robot to be a good partner for handing over? → a lot of things you can learn...
Project Team Assignment

• Building a haptic devices for home-based stroke rehab
  • Nathaniel Goldfarb <nagoldfarb@wpi.edu>
  • Rishi Khajuriwala <rdkhajuriwala@wpi.edu>
  • Aishwary Jagetia <adjagetia@wpi.edu>
  • Nishant Shah <nshah3@wpi.edu>
  • Brandon Lam <bllam@wpi.edu>
  • Akshay Kumar <akumar5@wpi.edu>
  • Matthew Bowers <mpbowers@wpi.edu>
Project Objectives

• Build a pair of haptic devices
  • Stroke patient holding the end-effector for exercise
  • DOFs = 3 active + 3 Passive

• Create software interface
  • Similar to Novint Falcon

• Prototype an dual-arm exoskeleton
  • Can be mounted on the chair back or arm
  • DOFs = 4 active + 3 passive
Project Team Assignment

- Arm-hand-finger Coordination
  - Haowei Zhao <hzhao6@wpi.edu>
  - Aniketh Reddy Seelam <aseelam@wpi.edu>
  - Gaurav Vikhe <gsvikhe@wpi.edu>
  - Aayush Shah <asshah@wpi.edu>
Project Objectives

• Big picture
  • Intelligent prosthetics that can infer operator’s motion intent based on partial motion knowledge

• Framework of prosthetic arm control
  • Motion knowledge module + motion template module + adaptive learning module

• What to achieve in this course project
  • Study motion correlation of arm/hand joints in daily activity dexterous manipulation
Project Team Assignment

- Human driver motion study
  - Kenechukwu Mbanisi <kcmbanisi@wpi.edu>
  - Tess Meier <tbmeier@wpi.edu>
Project Objectives

- Collect pilot data from 3-4 subjects

- Refine experiment protocol
  - What to measure
  - How to measure

- Establish hypotheses
  - Data segmentation, classification
  - How to build models for high-level task reasoning, decision making, and low-level motion execution? \( \rightarrow \) supervised learning, LFD ...
  - Establish hypotheses based on preliminary data analysis result
What is Preliminary work report?
- The first two chapters of your project proposal and report

Chapter 1 – Introduction
- Motivation, background, significance of the project
- Show me you have understood the project objectives

Chapter 2 – Related work
- Closely related to your project, what has been done in previous research?
- Read many papers
How to find your related work?

• Start with the relevant chapters in the Handbook of Robotics

• Narrow your topic down to several keywords

• Search Google scholar
  • More recent, more citations

• Off-campus access to WPI library
  • https://www.wpi.edu/library/research/off-campus-access
How to read so many papers?

- Your relevant chapter in the *Handbook of Robotics*
  - Read the highly relevant section very carefully
  - Skim less relevant sections, read title and figure captions

- The piles of papers you find out google scholar
  - Read the abstract, introduction and related work
  - Briefly review the methodology and results – get the big idea
  - Jump to conclusion/discussion
Team work

- Divide your topics
- Each one searches for one thing
- Sit together and sort things in your basket
- Evaluate their relevance and importance, and come up a list
- Each takes something home to read, and write a paragraph
- Put it together and revise
Don’t …

• Don’t copy and paste the sentences from the original papers
  • You need to digest and express the idea in your own word
  • To many sentences copied = cheating
  • Ruin your team if anyone cheats

• Don’t miss your citation
  • Everything you refer comes from somewhere
  • Don’t make up things
Do ...

• Team leader, show your leadership
  • You need to be one step ahead your team
  • You need to keep tracking the project focus
  • You need to check your team’s performance, help and adjust
  • You need to respect, listen and judge

• Teammates
  • Be clear about each other’s responsibility
  • Deliver what you have promised, in time
  • Be active and supportive
Human-inspired Kinematic redundancy resolutions
Initial motivation

• How to design and control **exoskeleton robots**?
Admittance control

- How to predict the arm posture correctly
Research Question

• How to improve the **human-compatibility** of exoskeletons?

  • Understanding human motion control

  • From this understanding, develop human-compatible robot control strategies
How to human motor system control the arm posture?

How to human motor system control coordination of arm, hand and fingers?
Robot Motion Control

- Can the exoskeleton render natural arm postures?

- Can we coordinate the manipulator arm and the tool tip of a robot to maximize the end-effector’s benefit?

- Can we facilitate human-robot interaction, based on accurate prediction of human motion and intent?
Direct and general applications
What we already know ...

Regularity in human arm motions + Robot manipulator redundancy resolutions
Robot manipulator redundancy resolution

- **Resolutions at Different Levels**
  Position, velocity, acceleration

- **General Resolution to Inverse Kinematics**
  Pseudo-inverse, general IK solver, ...

- **Task-based Resolutions**
  Jacobian matrix augmentation

- **Performance-based Resolutions**
  Various performance indices, global vs local optimization, ...
Human arm motion control

- **Motion Regularity and Variability**
  - Donders’ law [Donders:1848], Fitts’ law [Fitts:54], 2/3-power law [Terzuoloa,Viviana:80], motion variability [Bernstein:67], uncontrolled manifold [Scholz,Schoner:99]

- **Arm Motion Control Criteria**

- **Criterion Synthesis**
  - Spatial+temporal [Biess,Flash:07]