METR4202/7202: Advanced Control & Robotics

Take Home Final Exam **2013**

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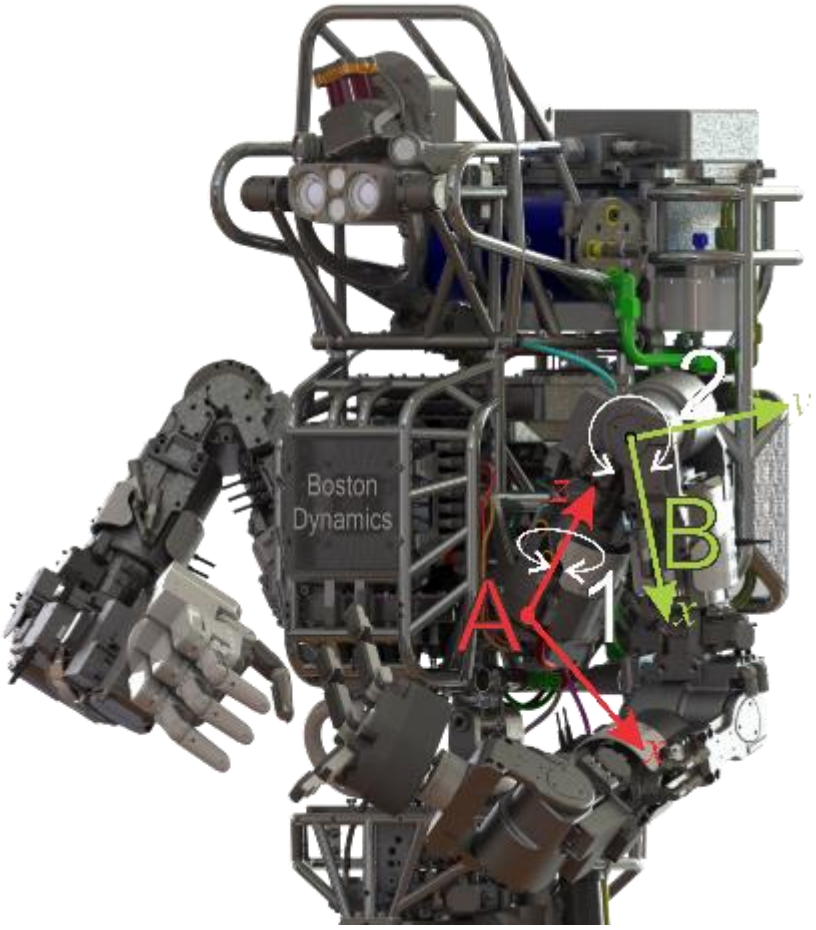
(1) Atlas's Atlas:

The Boston Dynamics Atlas robot has an oblique shoulder joint (see picture below), describe the Kinematics across this joint.

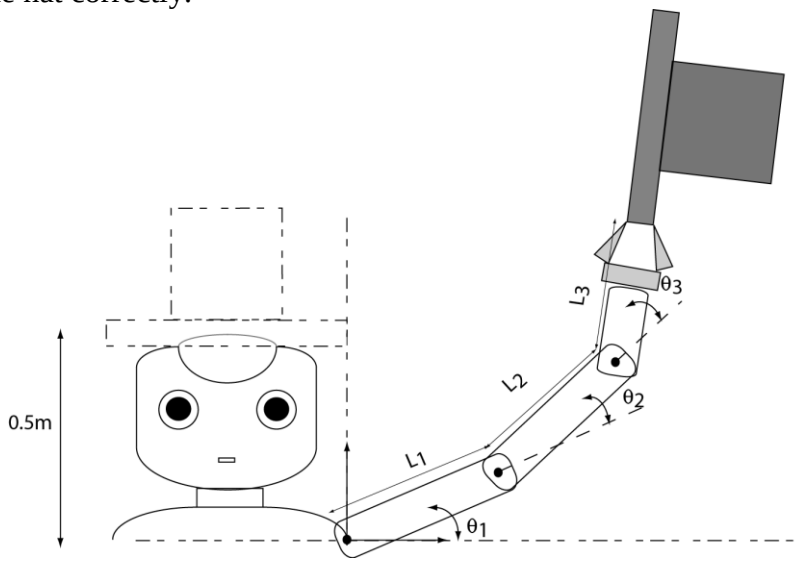
- Can Denavit–Hartenberg be used to efficiently encode the frame transformations across the joint?
- Describe the kinematics across the shoulder joint for the **two** motors (highlighted **1** and **2**) between from Frame {A} to Frame {B}. For link lengths and other parameters that use generic variables such as L_1, L_2, etc..



(2) Hats-Off to Robotics

A small humanoid robot is being programmed to place a hat on its head. The objective is to place the hat in the position shown by the dashed outline in the figure below. Assume that the arm is composed of 3 revolute joints and is constrained to move in the plane of the page. The arm consists of 3 links with dimensions: L_1=0.4, L_2=0.3, L_3=0.1.

In order to place the hat on its head, assume that we must place the edge of the hat brim at a location 0.5m above its shoulder joint. The hat brim should be in a horizontal position and is gripped at its edge by the hand and is aligned with the last link of the arm. Please calculate/plot valid workspace (e.g., from the frame located at the right-most end of the brim where the robot is grasping it) and joint trajectories to place the hat correctly.



(3) Camera Calibration

Consider the calibration of a camera with a **planar, non-arbitrary, calibration pattern**. (such as the checkboard pattern of the Matlab Camera Calibration toolbox). Assume: (1) the camera distortion is initially negligible, (2) a feature finding code can extract **N** features per picture and (3) that **P** pictures (or images) are taken at arbitrary poses.

- For the intrinsics: how many parameters are there? Of these, what can be determined explicitly (*hint:* is this upto scale?)?
- For the extrinsics: how many unknown parameters are there for each picture $\mathbf{P}_i$?
  (*hint:* is the first object frame arbitrary? If so, what might this let us do?)
- What is the total number of parameters that have to be determined?
- How many constraints are provided by each image **P**?
- Thus, what is the lower bound on the number of features per image **N** (i.e., **N**≥ ?? regardless of the number of images **P**)?
- Bonus: Briefly explain how might this change if the planar pattern is arbitrary (i.e., not arranged in a checkerboard)?

(4) SIFT Features

You are working on a vision project that uses SIFT features.
Please design (and explain your design) for a 2D Fiducial Marker / Target for robust recognition / tracking by SIFT?

(5) Camera Placement & Steroposis

It is proposed to add two (stereo) compact cameras to a small model aircraft/UAV (e.g., 3DR ARF APM:Plane) to track cars from the air.
Please discuss:

- Should one or both cameras be included? Where should the one (or two) cameras be placed on the plane?
- Please delineate the issues (and/or specifications) in selecting the camera. Please suggest a class of camera to use (i.e., *DSLR* (e.g., Canon 70D), *single-board camera* (e.g., IDS uEye UI-1221LE), *web-camera* (e.g., Microsoft LifeCam Studio), *mobile-phone* (e.g., Google Nexus 4), etc.). From this, please research and suggest a specific model of camera to use.
- Discuss the merits of this idea

(6) Controllability & Observability (Kalman Filters):

- Controllability:
  i. Does a system have to be fully observable to be fully controllable?
  ii. Does a system have to be fully actuated to be fully controllable? (i.e., for a system with N states, what is the minimum number of actuators needed?)
- Kalman Filters:
  i. What is the computational complexity of a linear Kalman filter?
  ii. For what systems / conditions is the estimate from a linear Kalman filter optimal?

(7) Cart & Pole

Consider the cart-pole (inverted pendulum) problem. Please describe the dynamics for a double pendulum (i.e., a "2-pendulum").

- Using a linearization of the model you find, then design a pole placement controller.
- From this, comment on whether this controller can perform a swing-up?
- Comment on if this be generalized to an N-pendulum system? (i.e., what happens to the dynamics of this as $N \rightarrow \infty$?)

(8) Autonomous Systems

Borrowing from recent advances in smart highways, you are engineering a pedestrian collision warning system for motorcylces. The system should operate day/night, in Brisbane weather conditions (good and bad), and may be assumed to be for (sealed) road conditions.

Using a sound and principled approach, outline the design of a system for achieving this including the type of sensors needed, the expected results, and the limitations of the system