

# ME:4140 Modern Robotics & Automation

## Homework #5

Due: see ICON

Make sure to upload any supporting documents, e.g., hand work, codes, sketches, etc.

### Instructions (READ THESE FIRST!)

- To complete this homework, you can use an **Adobe** pdf reader or **Google Chrome** (after completing make sure to download with changes).
- Answer all questions by typing or selecting radio buttons in this document.
- Upload your completed document and any supporting documents, code, sketches, etc., to ICON.
- Round all values to 3 decimal places.

Example #1: what is the value of Pi? Answer: 3.142

Example #2: what is  $100/3$ ? Answer: 33.333

**Name:**

First

Last

Student ID

1. Frame  $\{b\}$  initially at  $T = I$ , rotates about a screw axis given by  $\mathcal{S}_b = \{q, \hat{s}, h\}$  by an amount  $\theta = \pi/3$ , where  $q = (2, 4, 1)$ ,  $s = (\frac{\pi}{4}, \frac{\pi}{6}, \frac{\pi}{6})$  and  $h = 4$ . (15)

Determine the following:

- (a) the screw axis  $\mathcal{S}_b$

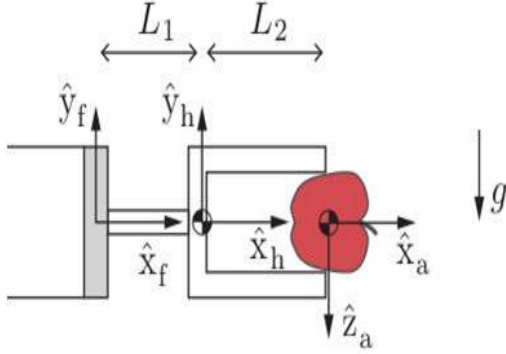
- (b) the new frame configuration  $T'$ , which is  $\{b'\}$  relative to  $\{b\}$

2. The new frame position  $\{a'\}$  has an orientation given by  $R = \text{Rot}(\hat{x}_a, \frac{\pi}{6})\text{Rot}(\hat{y}_a, \frac{\pi}{3})$  and its origin located at  $(0, 2, 3)$ , both with respect to the original frame position  $\{a\}$  given by  $\mathcal{I}$ . Using this information determine the following: (15)

- (a) rotation amount  $\theta$

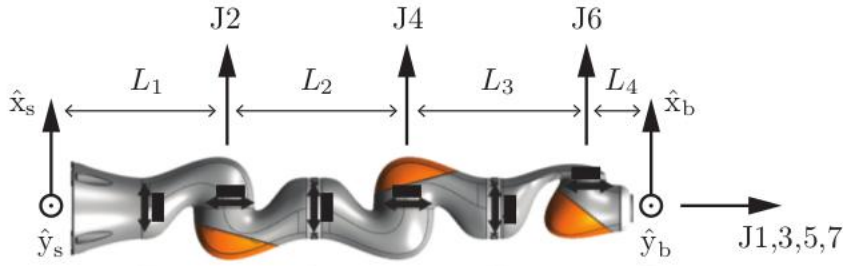
- (b) the screw axis  $\mathcal{S}_a$

3. The robot hand shown in the figure below is holding an apple. The robot is equipped with a force-torque sensor at its wrist that measures forces and torques in  $\{f\}$ . Frame  $\{h\}$  and  $\{a\}$  correspond to the center of mass of the hand and apple, respectively. The distances between the frames are  $L_1 = 10$  cm and  $L_2 = 15$  cm. (15)



Assuming gravity is  $10 \text{ m/s}^2$  and the mass of the apple and hand are  $0.1 \text{ kg}$  and  $0.5 \text{ kg}$ , respectively, what is the wrench  $\mathcal{F}_f$ , measured by the sensor?

4. Shown below is the the KUKA LBR iiwa 7R robot arm in its candlestick configuration. (15)  
 The  $\{s\}$  frame is at the base with the  $\hat{y}_s$ -axis pointing out of the page and the  $\{b\}$  frame is aligned with  $\{s\}$  at the end-effector. The screw axes for the seven joints are illustrated (positive rotation about these axes is by the right-hand rule). The axes for joints 1, 3, 5, and 7 are aligned and the axes for joints 2, 4, and 6 are aligned. The lengths are given by  $L_1 = 350$ ,  $L_2 = 410$ ,  $L_3 = 410$ , and  $L_4 = 136$  (all in mm).



- (a) If a force of  $f_b = (10, 5, 0)$  N is applied to frame  $\{b\}$  (joint 7), what is the wrench in  $\{b\}$ ?

- (b) What is the wrench in the base  $\{s\}$ ?