Robotics 550 Fall 2022
Robotics Systems Laboratory

Quiz # 2 (50 points)

Printed name: ____

Signature: ____

Question:	1	2	3	4	5	6	Total
Points:	10	10	10	5	10	5	50
Score:							

1. Examine the following matrices. Mark **True** or **False** for the properties listed. You will not lose points for wrong answers – it is better to guess than to leave blank!

   (a) (2 points) The matrix $\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ is a :

   ◯ **True** ◯ **False** valid rotation matrix in SO(3)
   ◯ **True** ◯ **False** valid homogeneous transformation in SO(2)
   ◯ **True** ◯ **False** valid rigid-body transformation in SE(2)

   (b) (2 points) After re-projecting known points into an image, you notice they are all shifted to one side from the location they are supposed to, but appear in the correct location relative to each other and having the correct scale. What part of which calibrations could be wrong?

   ◯ the intrinsic matrix focal length component
   ◯ the intrinsic matrix optical axis offset component
   ◯ the intrinsic matrix skew component
   ◯ the extrinsic matrix rotation matrix component

   (c) (2 points) A transformation composed in the following order:
   Rotate by ψ around the world z-axis,
   Rotate by θ around the current x-axis,
   Rotate by γ around the world y-axis,
   Rotate by ϕ around the current z-axis

   Which among the following represents the correct order of matrix multiplication for the given homogeneous transformations? Mark the correct answer by filling in the circle.

   ◯ $R_{\psi,z}R_{\theta,x}R_{\gamma,y}R_{\phi,z}$
   ◯ $R_{\phi,z}R_{\gamma,y}R_{\theta,x}R_{\psi,z}$
   ◯ $R_{\phi,z}R_{\theta,x}R_{\psi,z}R_{\gamma,y}$
   ◯ $R_{\gamma,y}R_{\psi,z}R_{\theta,x}R_{\phi,z}$

   (d) (2 points) A 4×4 matrix in SE(3) has how many degrees of freedom?

   ◯ 3
   ◯ 6
   ◯ 12
   ◯ 16

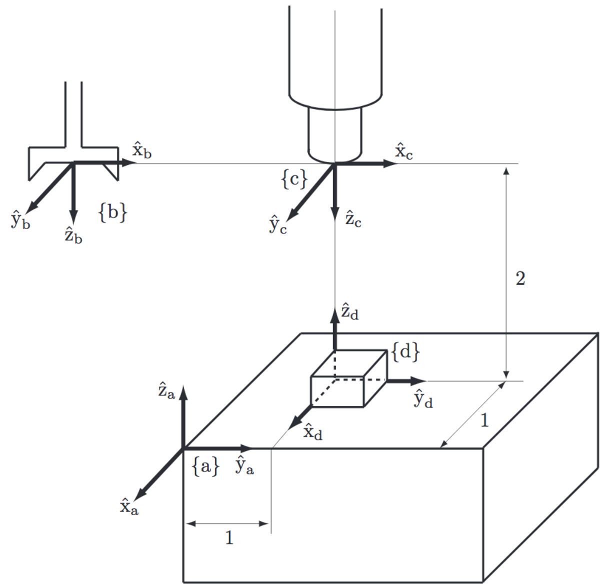
   (e) (2 points) How many parameters are measured when finding a camera intrinsic matrix

   ◯ 3
   ◯ 4
   ◯ 5
   ◯ 6

2. These short answer questions test your engagement in the lab work.
   (a) (3 points) What are the advantages and drawbacks of using closed form inverse kinematics over numerical inverse kinematics?

   (b) (4 points) Describe the camera to workspace calibration procedure needed to locate blocks in the world frame. What pieces of information need to be solved for?

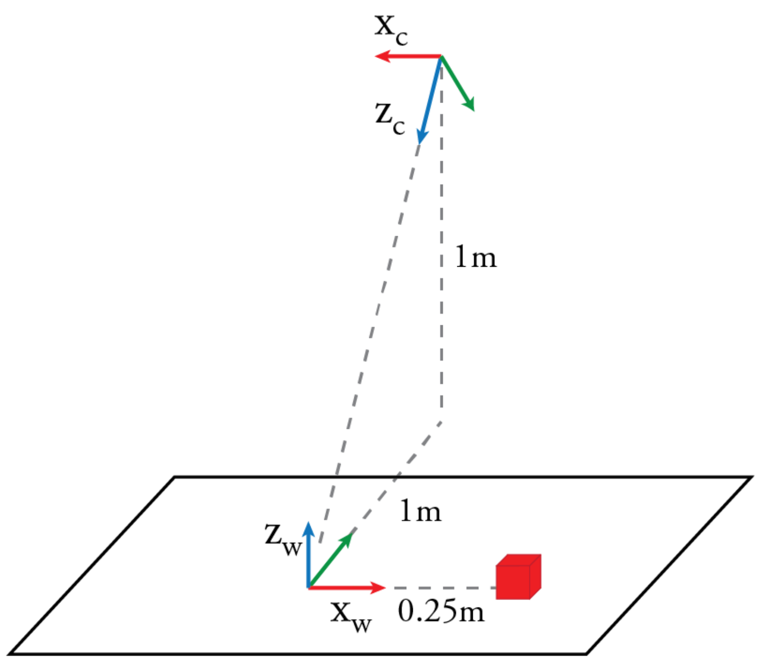
   (c) (3 points) What are the largest sources of uncertainty when performing automated grasping tasks? List at least two, as well as ways these sources of uncertainty can be accounted for.



3. Four reference frames are shown in the robot workspace of the figure above: the fixed frame $\{a\}$, the end effector frame $\{b\}$, the camera frame $\{c\}$, and the work piece frame $\{d\}$

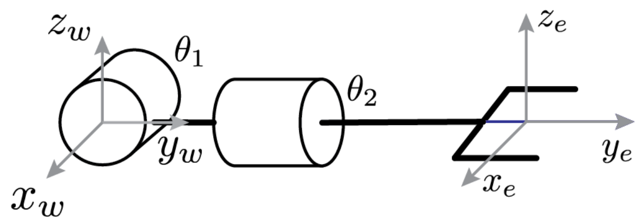
   (a) (5 points) Find T_d^a, T_c^a, and T_d^c in terms of the dimensions given in the figure.

   (b) (5 points) The camera has a focal length of 500 pixels. The image sensor is 640 pixels wide and 480 pixels tall, is perfectly centered on the optical axis ($\hat{z}$ axis of the camera frame), and $\hat{u}$ and $\hat{v}$ are aligned with $\hat{x}$ and $\hat{y}$ respectively. Write down the matrix equation for the pixel location (u, v) of a point on the $\hat{x}$,$\hat{y}$ plane in the fixed frame (x_a, y_a, z_a). Use Homogeneous coordinates. You should write out the matrices but do not have to multiply them.



4. (5 points) You decide to place the camera so it is looking at the origin of the world frame at a 45° angle. What is the extrinsic matrix for the camera assuming it is precisely placed according to the diagram above?

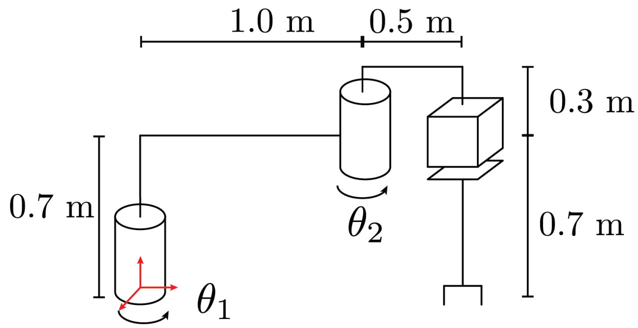
5. We have a 2-DOF wrist shown below in the configuration $q = [\theta_1, \theta_2] = [0, 0]$ The wrist frame $\{w\}$ is shown and in this configuration has the orientation aligned with the end effector frame $\{e\}$.



(a) (5 points) Write down the FK solution for the *orientation* of the $\{e\}$ frame with respect to the $\{w\}$ frame as a rotation matrix R_e^w that is a function of joint angles θ_1 and θ_2.

(b) (5 points) Write the inverse trigonometric equations for finding the IK solution for the joint angle θ_1 and θ_2 as functions of the rotation matrix R_e^w elements $r11,\ r12,\ r13$ etc.

6. We are given a SCARA arm used for placing parts on a flat work-surface. This is an RRP arm, with all axes vertical; the tool is on the work-surface at the zero configuration, with the tool frame oriented parallel to the world frame, and with the arm fully extended. The prismatic joint can retract to 0.5m above the work-surface.



   (a) (3 points) write the DH parameter table for this arm, you are allowed to chose the base frame where convenient.

#	d	θ	r	α
1	____	____	____	____
2	____	____	____	____
3	____	____	____	____

   (b) (2 points) Describe the reachable workspace of this arm.