Final Exam 16-311 Intro to Robotics

Name:_____ Team: _____

- You will have 1 hour and 30 minutes to complete this exam
- There are 4 questions on 12 pages. Make sure you have all of them.
- When making drawings - be precise. Rounded edges should look rounded, sharp edges should look sharp, sizes should be close to scale. Neatness counts.
- Show your work. Partial credit may apply $\rightarrow$ Likewise, justify algebraically your work to ensure full credit, where applicable.
- It should be *very* clear what your final answer is, circle it if necessary.
- You may need to make certain assumptions to answer a problem. State them (e.g. what is optimal).
- You are allowed one *handwritten* crib sheet for the exam. No cell phones, laptops, neighbors, etc. allowed.
- Good Luck!

1 Short Answer Questions - 20 pts

a) What are the pros and cons of increasing the number of particles for a particle filter when used for robot localization (provide 1 of each)? (2 pts)

b) If $\mathbf{R}$ is a pure rotation and $\mathbf{T}$ is a pure translation (and both are homogeneous transform matrices), prove that $\mathbf{RT} \neq \mathbf{TR}$. (4 pts)

c) When Nico (the rock/paper/scissors robot) cheats by purposely announcing the incorrect play by the human, why do people associate that more with "malfunctioning" rather than if it cheats by identifying the humans play in mid-motion then quickly changing its own play (which when noticed, gets called "cheating")? (2 pts)

d) Given:

$$\mathbf{H}_1 = \begin{bmatrix} \cos\theta & \sin\theta & 0 & a \\ -\sin\theta & \cos\theta & 0 & b \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \mathbf{H}_2 = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & c \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Describe what is happening to an object undergoing $\mathbf{H} = \mathbf{H}_1\mathbf{H}_2$. Be *very* specific and include any applicable reference frames. Draw the initial body frame, any intermediate frames and the final body frame. (5 pts)

e) Why does the phrase "optimal solution" have to be qualified? (2 pts)

f) What is the Derivative term used to correct in a PID controller? The Integral term? Provide a single drawback of each? (4 pts)

2 Eye-K - 35 pts

While building a planar robotic arm, you suddenly discover that someone has taken all of your joint encoders and left a few USAR cameras in their place. You think back to the beginning of the course and recall learning about stereo depth systems so you decide to continue with your project using the vision system to determine the end-effector position.

Givens:

The cameras are mounted parallel to each other.

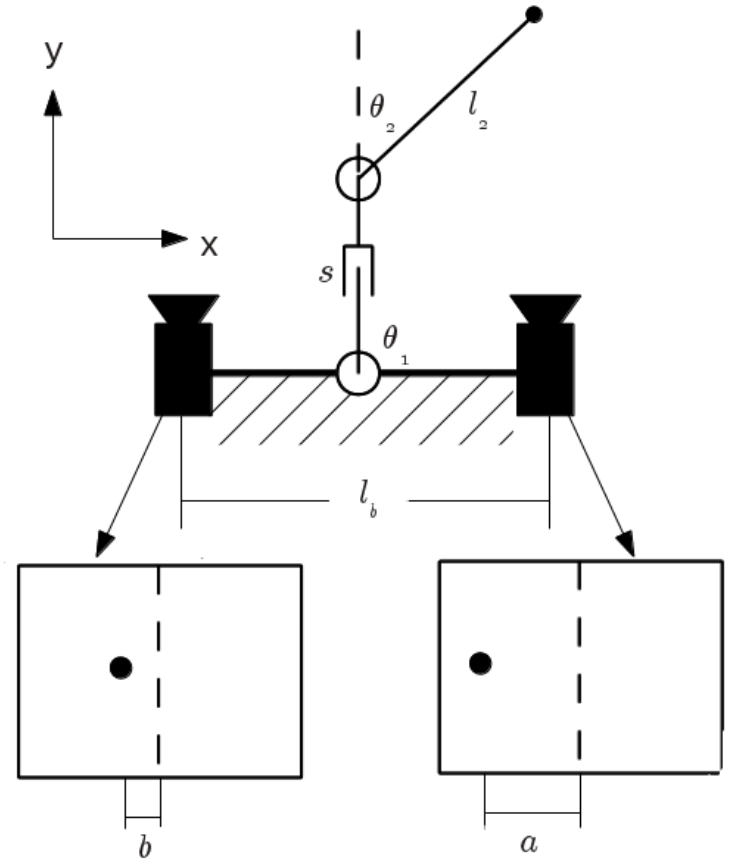
The arm is centered between them.

θ_1 and θ_2 measure the shoulder and elbow angles.

The forearm is l_2 long while the upper arm is variable length s.

l_b is the distance between cameras.

The cameras have focal length f (in meters) and the pixel size ρ (meters per pixel).



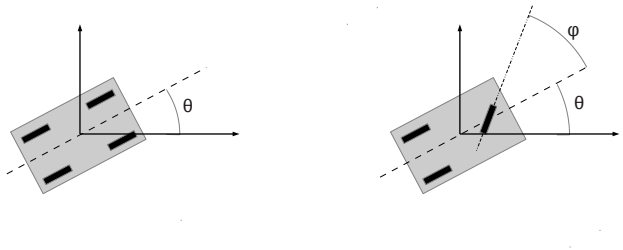
a) Given distances a and b (in pixels), what is the position (x, y) of the end-effector? (15 pts)

b) What is the robot configuration (θ_1, θ_2, s) for the position in a) if you are told that $\theta_1 + \theta_2 = \varphi$ (and the value of φ is given)? (15 pts)

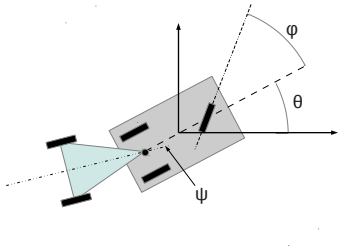
c) If $\varphi = 90^\circ$ for a given (x, y) location how many different configurations can the arm be in?(1 pts) draw them. (4 pts)

3 To Lie or not to Lie - 25 pts

Use the following vehicles for reference:



(a) Cart (b) Tricycle



(c) Tricycle with trailer

For all configurations, the axles center-points are d meters apart.

a) Given a cart with four fixed wheels, what are the constraints? (5 pts) What are the initial intrinsic motions, i.e. what are the g's? (5 pts)

b) Show that all of the constraints found in part a are Pfaffian constraints (i.e. show that the vectors $w_i(q)$ and $\dot{q}$ are perpendicular). (3 pts)

c) Given the intrinsic motions for a tricycle, describe what they physically represent? hint: $q = [x, y, \theta, \phi]^\intercal$ (2 pts)

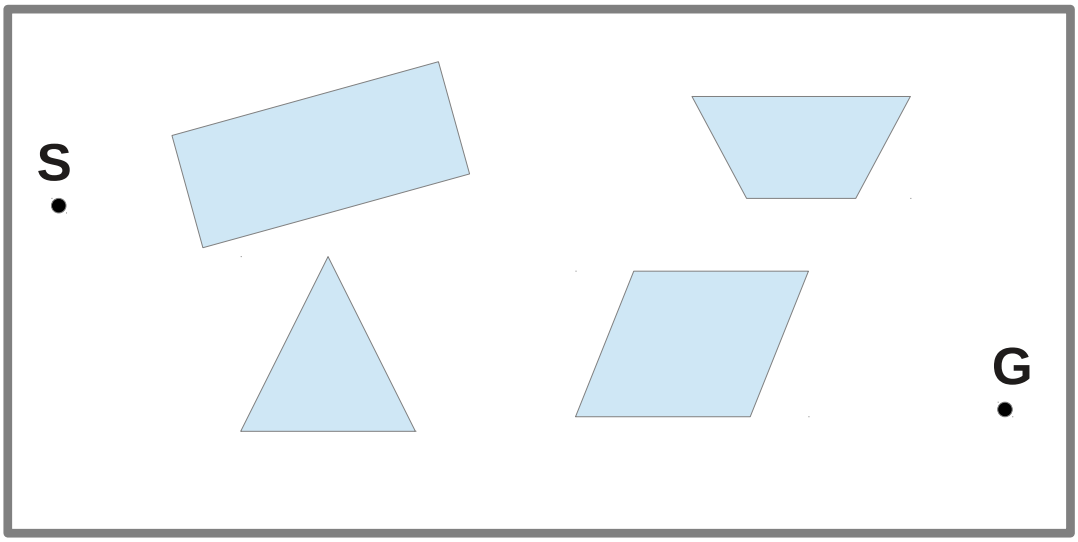
$$g_1 = \begin{bmatrix} \cos\theta \\ \sin\theta \\ \frac{1}{d}\tan\phi \\ 0 \end{bmatrix} \qquad g_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

d) Can a tricycle get to any configuration? prove it.(6 pts)

e) Describe what additional constraint the tricycle has when you attach a trailer (assume it pivots at the center of the tricycle drive wheels and forms an angle ψ with the tricycle centerline)? (2 pts) What is the state space (q)? (2 pts)

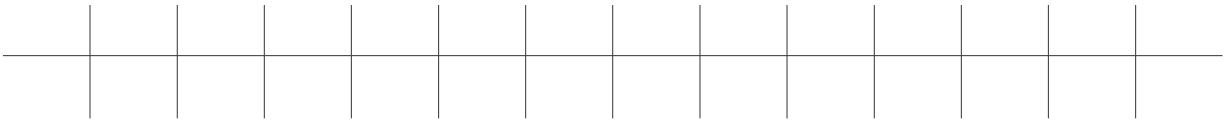
4 How do I get there? - 20 pts

a) Draw the trapezoidal decomposition of the following workspace. (5 pts)



b) Draw the adjacency graph for your decomposition found above. (5 pts)

c) Use the scale below to assign edge weights on your adjacency graph based on their length. Also, determine the distance from each node to the goal to use as a heuristic. (Use integers for all weights and heuristic values and clearly indicate what values correspond to which node and edge.)



Now perform A* on the adjacency graph, assume you start at the node for the region with the S and finish at the node in the region with the G. Show which nodes get expanded for each time step and what the final path is. (10 pts)