University of Notre Dame
Aerospace and Mechanical Engineering

ME 469: Introduction to Robotics
Final Exam

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NAME: ______________________________

- You have two hours to complete this exam.
- This is an open book exam. You may consult the course text, your class notes, your own homework sets and any documents provided on the course homepage such as homework solutions, tables, etc.
- There are 5 questions. Problem 1 is worth 30 points, Problem 2 is worth 25 points, Problem 3 is worth 15 points, Problem 4 is worth 10 points, Problem 5 is worth 5 points and Problem 6 is worth 15 points.
- Your grade on this exam will constitute 25% of your total grade for the course. *Show your work* if you want to receive partial credit for any problem.
- Answer each question in the space provided on each page. If you need more space, use the back of the pages or use additional sheets of paper as necessary.
- Do not start or turn the page until instructed to do so.

1. Consider the robotic manipulator illustrated in Figure 1.

   (a) Directly on the figure, draw the location and orientation of each link frame, attached to the manipulator in accordance with the Denavit–Hartenberg method outlined in class and in the course text. (10 points)

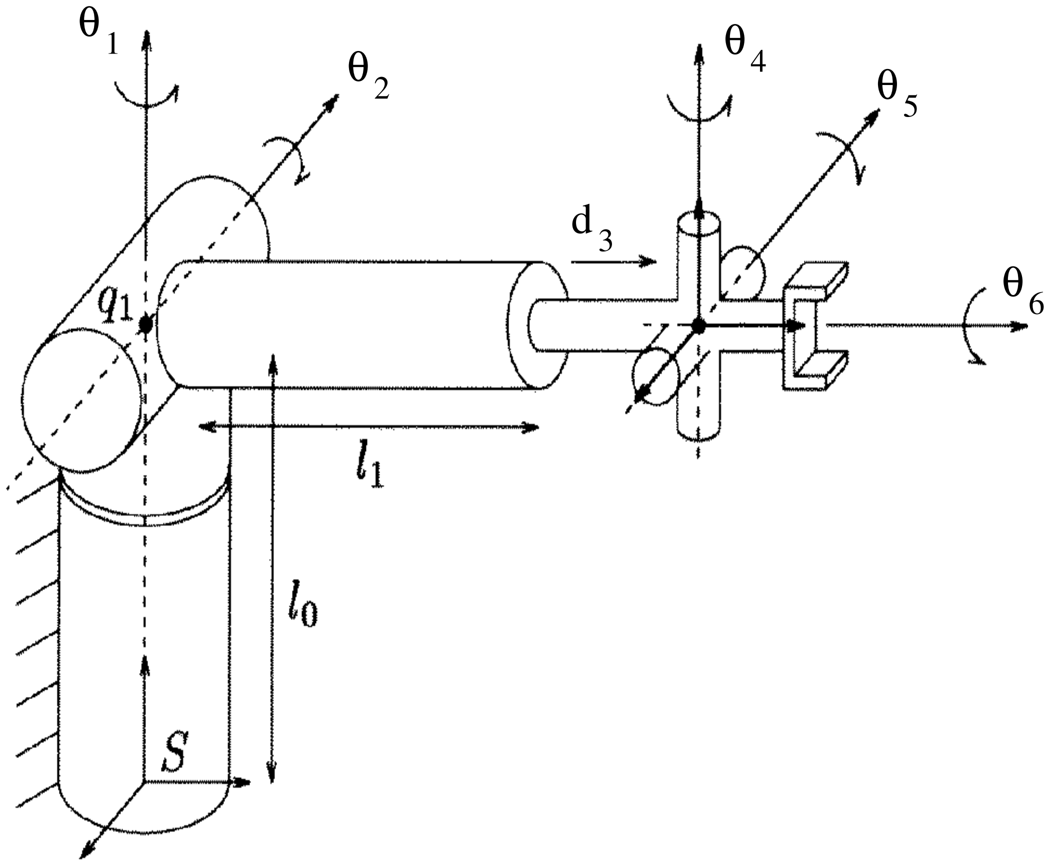

Figure 1. Robotic Manipulator for Problem 1.

(b) For each link, determine the link parameters,and complete the following chart. (10 points)

i	α_{i-1}	a_{i-1}	d_i	θ_i
1				
2				
3				
4				
5				
6				

(c) What is ${}^2_3T$? (10 points)

2. In the book, equations 3.16 and 3.17 on pages 97 and 98 give expressions for the forward kinematics of the Yasukawa Motoman L–3 robot.

   (a) Using these equations, determine the Jacobian that relates joint velocities to the *linear* velocity of the origin of frame 5, *i.e.*, find J such that

$$\begin{bmatrix} \dot{p}_x \\ \dot{p}_y \\ \dot{p}_z \end{bmatrix} = J \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \\ \dot{\theta}_4 \\ \dot{\theta}_5 \end{bmatrix}.$$

(10 points)

(b) Given a desired linear velocity of the origin of frame 5, how can one determine joint velocities that will achieve the desired motion? You do not have to compute anything, but you must give a mathematical expression in your answer. (10 points)

(c) Explain in terms that an Arts & Letters major could understand what a singular configuration of a robot is and what the good and bad effects are when a robot is near or at a singular configuration. (5 points)

3. Consider the digital image illustrated in Figure 2.

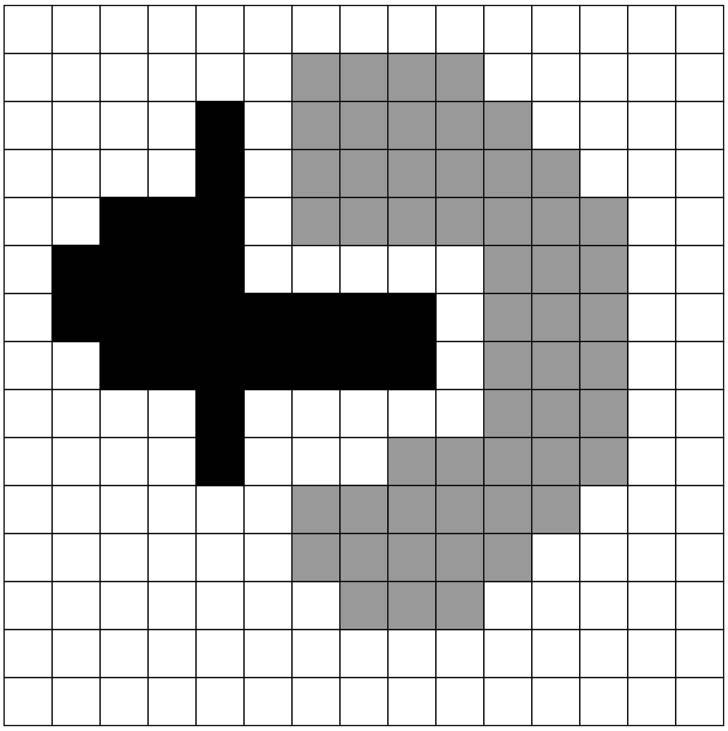

Figure 2. Image for Problem 3.

(a) In order to distinguish the grey object from the black object, is signature analysis or the connected components algorithm better? Explain your reasoning. (3 points)

(b) What is the area of the grey object? (3 points)

(c) Recall the definition of 4 and 8 perimeters:

$$\begin{aligned} P_4 &= \{(r,c) \in R \mid N_8(r,c) - R \neq \emptyset\} \\ P_8 &= \{(r,c) \in R \mid N_4(r,c) - R \neq \emptyset\}. \end{aligned}$$

i. What is the length of P_4? (3 points)

ii. What is the length of P_8? (3 points)

(d) Explain the relative advantages and disadvantages of the three vision–based robotic control methods outlined in class. (3 points)

4. The following questions concern feedforward neural networks (the type considered primarily in class).

   Answer each of the following with a one or two sentence answer:

   (a) Figure 3 is the example from class of the neural network trained to predict the `sin` function. Why does the neural network accurately model the `sin` function near the middle of the figure, but not at the higher and lower values for the angle? (5 points)

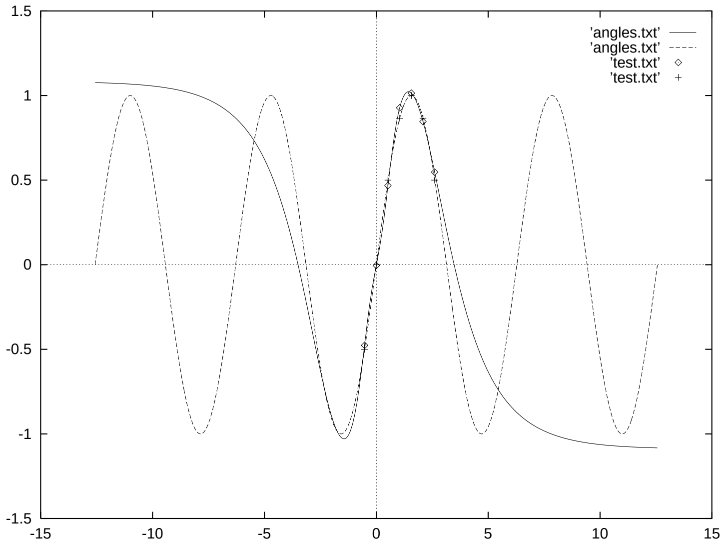

Figure 3. Neural Network Output for Problem 4a.

   (b) Explain in *words* the fundamentals of the backpropagation method of training a neural network and why it is advantageous relative to the "random perturbation" method presented in class. (5 points)

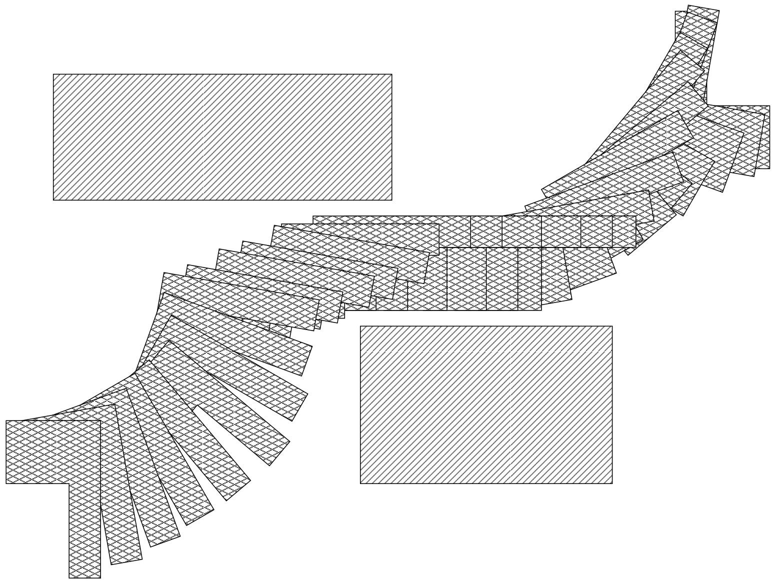

Figure 4. Workspace for Problem 5.

5. In the workspace illustrated in Figure 4, the robot is the "L" shaped polygon and the objects are the 2–dimensional rectangles. What is the dimensionality of the objects in the *configuration* space for this problem? (5 points)

6. The following questions concern the Improved Numerical Navigation Function Algorithm, which is reproduced on the following page.

   Answer each of the following with a one or two sentence answer:

   (a) At the end of the `for` loop labeled with 2, what does L_0 represent? (3 points)

   (b) In the `for` loop labeled 3, assuming none of L_0, L_1, L_2 or L_3 are empty, what does L_3 represent? (3 points)

   (c) In the `for` loop labeled 3, there is a line containing "$O(\mathbf{q}') \leftarrow O(\mathbf{q})$." Given a configuration, $\mathbf{q}$, what does $O(\mathbf{q})$ represent? (3 points)

   (d) As part of the overall precedure, what does the set of instructions labeled 4 (lines 1 – 12) do? (3 points)

   (e) As part of the overall precedure, what does the set of instructions labeled 5 (lines 18 – 29) do? (3 points)