

# CPE 481 - Autonomous Mobile Robots

## Final Exam

March 21, 2007

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**Name:**

**Signature:**

**Time Limit: 2 hours**  
**Total Marks: 70**

**Closed Book**  
**No Calculators**

**Multiple-Choice – 2 marks awarded for each correct answer, 1 mark deducted for each incorrect answer, 0 marks if no answer. Circle the answer that BEST completes the sentence.**

1. Issues that affect robot locomotion include
  - a) The robot's stability.
  - b) The robot's work environment.
  - c) The robot's type of contact with the environment.
  - d) All of the above
  
2. Proportional feedback control
  - a) Produces very large control signals when the error is very small.
  - b) Requires some measurement of the state being controlled.
  - c) Always induces overshoot when tracking a step response.
  - d) All of the above
  
3. Markov localization
  - a) Is not scalable for all applications.
  - b) Requires many particles
  - c) Is a form of particle filter localization for indoor environments.
  - d) None of the above
  
4. Particle Filtering should be used instead of Kalman Filtering
  - a) When only 100 particles or less can be updated in real time.
  - b) When the initial robot position is unknown.
  - c) When the robot is equipped with perfect sensors.
  - d) None of the above

5. A good motion planning algorithm is
- Complete.
  - Optimal.
  - Fast.
  - All of the above
6. A robot will have better localization capabilities if it uses encoder measurements instead of control inputs in the prediction step because:
- Encoders have no errors.
  - Encoders do not model slipping.
  - The model that takes the control inputs and converts them to real wheel motion is not perfect.
  - All of the above
7. If the VideoRay ROV was in an empty square tank, its differential drive configuration will allow it to
- Follow any path through the workspace provided the path does not lead to collision with the walls.
  - Follow any trajectory through the workspace provided the trajectory does not lead to collision with the walls.
  - Follow any path and any trajectory through the workspace provided they don't lead to collision with the walls.
  - All of the above
8. If a robot localized itself using a particle filter with 5 particles,
- The localization algorithm could run slowly because it uses so many particles.
  - The localization algorithm would perform extremely well because it has 5 particles and therefore 5 estimates of the state instead of one.
  - All 5 particles would go through a prediction step.
  - None of the above.
9. The X80 is equipped with:
- Exteroceptive sensors
  - Proprioceptive sensors
  - Active sensors
  - All of the above.
10. For a differential drive robot operating in a 2 degree of freedom workspace, how many degrees of freedom can be used to define the configuration space in a motion planning problem.
- 2 degrees of freedom
  - 3 degrees of freedom
  - 4 degrees of freedom
  - Any of the above

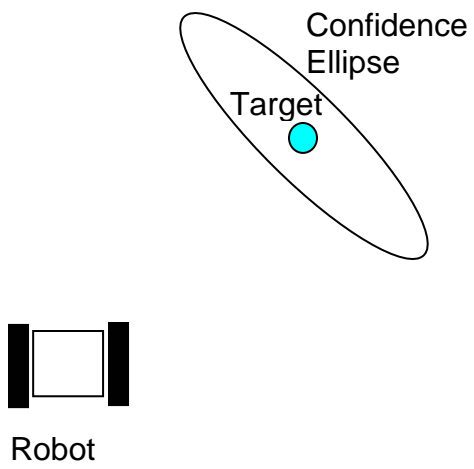
**Question 11:** 10 marks

- a. Using a table, compare three different range sensors. Use four different characteristics to compare them. List these characteristics in the left column. List the sensor types along the top row. Within each cell of the table, provide a number between 1 and 10. Let 1 indicate the sensor does not have that particular characteristic, while 10 indicates the sensor is strongly believed to have that characteristic. For example:

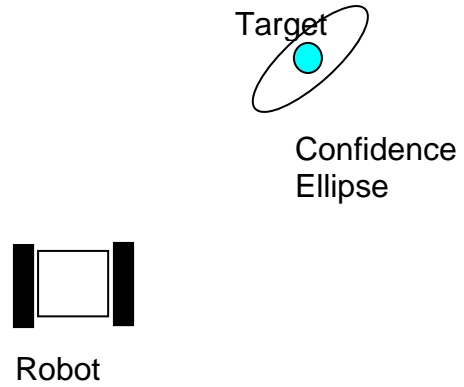
<b>Characteristic</b>	<b>Sensor type 1</b>	<b>Sensor Type 2</b>	<b>Sensor Type 3</b>
<b>1</b>	1	10	1
<b>2</b>	5	2	2
<b>3</b>	7	4	1
<b>4</b>	1	1	2

- b. The two figures below depict a robot, a target that is being sensed, and a confidence ellipse (aka error ellipse). The confidence ellipse provides an idea of how much confidence we have in the estimate of target position.

First, compare the two situations in terms of similarities and/or differences. Second, based on the confidence ellipse, guess what type of sensor is being used in each situation.



(a)



(b)

**Question 12:** 10 marks

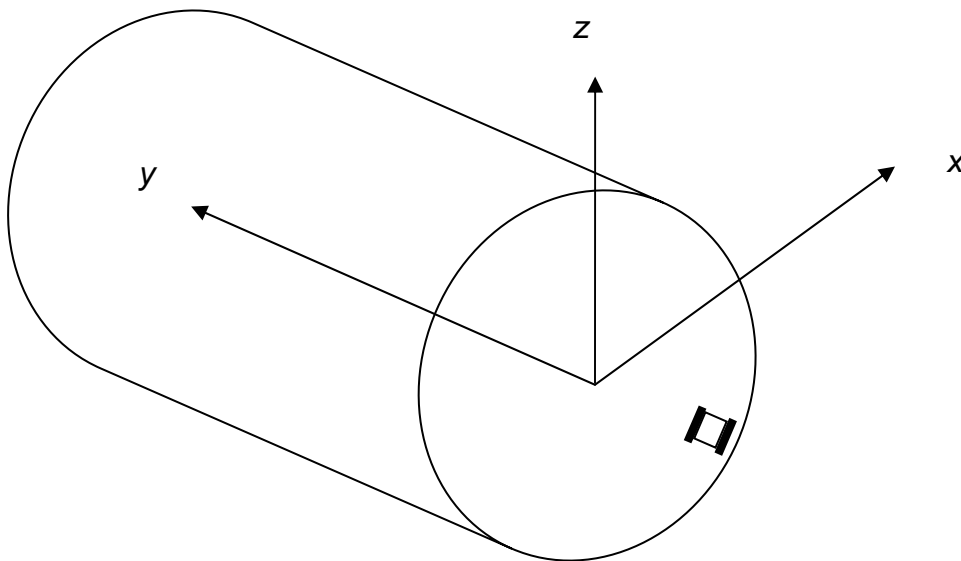
A free flying blimp robot that has fixed roll, pitch and yaw orientations (i.e. they all equal zero), is flying over a target. The robot has a special GPS system that gives it PERFECT knowledge of its location in 3D space (i.e.  $x y z$ ). The robot is also equipped with a downward facing camera of focal length  $f$  that it uses to track targets. At one instance in time, the robot is located at position  $[x_1 y_1 z_1]$  and detects the target at position  $[x_{f1} y_{f1}]$  on the camera's focal plane. At a later instance in time, the robot is located at position  $[x_2 y_2 z_2]$  and detects the target at position  $[x_{f2} y_{f2}]$  on the camera's focal plane. Given this set of measurements, determine the position of the target.

**Question 13:** 10 marks

For a security robot system, you will be using a particle filter for localization.

- a) What is a particle?
- b) What is the kidnapped robot problem?
- c) A new magnetic robot magBot is a differential drive robot of very small width  $w$ , that has magnetic wheels allowing it to stick to metal walls and ceilings. It will operate within a very large metal pipe of radius  $R$ . Note that  $R \gg w$ .

For our special case, the robot will only move up and down the wall, but never deeper into the tunnel. Let the particle  $p$  describe the state of a differential drive robot and be defined by  $[x\ z]$ .



Propagate the particle forward for the prediction step of the PF algorithm. Assume you have access to wheel distances  $s$  (in meters), as well as random numbers  $r = \text{rand}()/((\text{double}) \text{RAND\_MAX})$ . That is, give a new predicted estimate  $x_t, z_t$  in terms of  $x_{t-1}, z_{t-1}, s$  and  $r$ . State any assumptions.



**Question 14:** (10 marks)

- a. Write the pseudo code for a single-query Probabilistic Road Map motion planning algorithm.
- b. How can “clustering” occur when randomly selecting new nodes for expansion.
- c. Describe an algorithm to avoid clustering.
- d. Compare PRM motion planning with A\* planning. List at least 4 differences or similarities.
- e. What is probabilistic completeness?



**Question 15:** (10 marks)

In an autonomous racing competition, a car is driving down a straight two-lane highway. There are walls on both sides of the highway. The autonomous car has a side-mounted sonar on the right side of the vehicle. From experiments, the driver has determined the probability of being in a particular lane, given she knew which lane she was driving in, and she knew the steering wheel position  $\theta$  and throttle position  $\rho$ . More specifically, she knows the two probability functions:

$$\begin{aligned}p(l_t=1 \mid \theta_t, \rho_t, l_{t-1}=1) &= f_{11} \\p(l_t=1 \mid \theta_t, \rho_t, l_{t-1}=2) &= f_{21} \\p(l_t=2 \mid \theta_t, \rho_t, l_{t-1}=1) &= f_{12} \\p(l_t=2 \mid \theta_t, \rho_t, l_{t-1}=2) &= f_{22}\end{aligned}$$

The driver would like to construct an algorithm that can automatically determine which lane the car is residing in. To do this, she has decided to use Markov Localization.

- a. Design a prediction step that determines the probability of being in each lane. That is, give the equations for  $p(l_t' = 1)$  and  $p(l_t' = 2)$ .
- b. Design a correction step for the algorithm. That is, give the equations for  $p(l_t = 1)$  and  $p(l_t = 2)$ . State any assumptions necessary.



**Some Equations that might be useful:**

$$d = c t / 2$$

$$\lambda = c/f$$

$$D = fl/x$$

$$p(A \wedge B) = p(A | B) p(B)$$

$$E[X_1 X_2] = E[X_1] E[X_2]$$

$$\Delta\theta = (\Delta s_{right} - \Delta s_{left}) / b$$

$$\Delta s = (\Delta s_{right} + \Delta s_{left}) / 2$$

$$p(x_t | o_t) = \sum_{x'} p(x_t | x'_{t-1}, o_t) p(x'_{t-1})$$

$$p(x_t | z_t) = \frac{p(z_t | x_t) p(x_t)}{p(z_t)}$$

$$x = \frac{b(x_l + x_r)/2}{(x_l - x_r)}$$

$$y = \frac{b(y_l + y_r)/2}{(x_l - x_r)}$$

$$z = bf/(x_l - x_r)$$

$$p(x'_{i,t}) = \sum p(x_{i,t} | x_{j,t-1}, o_t) p(x_{j,t-1})$$