CPE 485 - Autonomous Mobile Robots

Final Exam

March 18, 2010

Name:

Signature:

Total Marks: **70**
Closed Book

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. Different types of robot locomotion include
   a) Sliding.
   b) Rolling.
   c) Flying.
   d) All of the above.

2. In Proportional feedback control, adjusting the gain K
   a) Will always reduce the error.
   b) Can lead to unstable behavior in the system being controlled.
   c) By decreasing it will always decrease the error more quickly.
   d) All of the above.

3. Markov localization, the Markovian assumption is made which assumes that
   a) The probability that a robot's state estimate equals the actual robot state is maximized.
   b) The current state is only dependent on the previous state, and not the entire history of states.
   c) Only current sensor measurements are required for accurate localization.
   d) None of the above.

4. Particle Filtering should be used instead of Kalman Filtering
   a) When 100000 particles minimum are needed.
   b) When the initial robot position is unknown.
   c) When the robot is operating in an environment without any locations that produce identical sensor measurements.
   d) None of the above

5. A motion planning algorithm will be good for many applications if
   a) The algorithm is slow and a sub-optimal.
   b) It is not complete.
   c) It might not create a feasible trajectory.
   d) None 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:
   a) Encoders have no errors.
   b) Encoders always model slipping perfectly.
   c) The model that calculates wheel motion from the control inputs is not perfect.
   d) All of the above

7. Markov Localization can be used instead of Particle Filter localization when:
   a) The environment is large enough.
   b) There are only 10 possible values for each of the 3 degrees of freedom of the state vector.
   c) The sensor model is unknown.
   d) All of the above

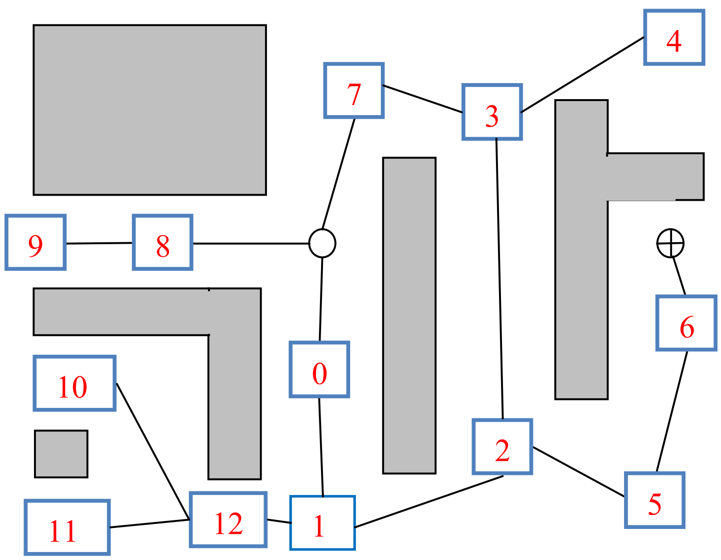
8. If a robot localized itself using a particle filter with 5 particles, but had no knowledge of its start location,
   a) The localization algorithm could run slowly because it uses so many particles.
   b) The localization algorithm would perform extremely well because it has 5 particles and therefore 5 estimates of the state instead of one.
   c) All 5 particles would go through a prediction step.
   d) None of the above.

9. The X80 is equipped with:
   a) No active sensors
   b) No passive sensors.
   c) All active sensors.
   d) None of the above.

10. If automobiles were build with 4 swedish wheels,
   a) The automobile would be able to move sideways.
   b) Parallel parking would be much easier.
   c) We would have trouble driving quickly on curved roads.
   d) All of the above

Question 11: (10 marks)
The A* algorithm is being used to plan a path through a building hallway system. Given the map below, show the first 5 iterations of the A* algorithm by numbering the cells in the order that they are explored. The start location is ○ and the goal location is ⊕ . Provide details of the iterations (including the first). Details should include the fringe set and their path cost breakdowns (*f(n), g(n), h(n)*). That is, fill in the first 5 rows of the table below. Finally, draw the final path on the figure.

You can assume that the admissible heuristic used to calculate *h(n)* is the Euclidean distance to the goal. The Euclidean distance is = $sqrt(\Delta x^2 + \Delta y^2)$, where $\Delta x = x(goal) - x(n)$ and $\Delta y = y(goal) - y(n)$. A ruler will help with this problem.



Node Selected	Fringe	f(n)	g(n)	h(n)
(◯)	Node(0) Node(8) Node(7)	f(0) = … f(8) = … f(7) = …	g(0) = … g(8) = … g(7) = …	h(0) = … h(8) = … h(7) = …

Question 12: (10 marks)
The range sensors used on the X80 must are useful sensors but must be used with care. Answer the following questions regarding these sensors

a) Explain the basic principles on how the ultrasonic range sensor works in 4 sentences or less. Be sure to use a diagram, labeling variables on the diagram. Give the equation used to calculate range.
b) Explain the basic principles on how the IR range sensor works in 4 sentences or less. Be sure to use a diagram, labeling variables on the diagram. Give the equation used to calculate range.

Question 13: (10 marks)
An Autonomous Underwater Vehicle can surface to receive GPS measurements x, y and z_{GPS} with measurement standard deviation (σ_x σ_y σ_z). The GPS sampling rate is 1 Hz. While underwater, the AUV uses a Doppler Velocimetry Log (DVL) that measure forward speed v, (with standard deviation σ_v) and a compass measurement z_θ (with standard deviation σ_θ) to estimate its state. A particle filter is used to fuse these two measurements to produce the state estimates of $[x\ y\ \theta]$. The depth of the AUV is considered known using a highly accurate pressure sensor.

a) What is a particle?
b) Provide an outline of the PF algorithm
c) Explain using mathematical equations how the prediction step in the algorithm could use the compass and speed measurements. Assume the DVL and compass have a sampling rate of 30 Hz.
d) Explain which step in the algorithm would use the GPS measurements. How would they be used? Assume the AUV will surface every 5 minutes.

Question 14: (10 marks)
A particle filter is used to localize a differential-drive robot within an indoor environment. The robot's state is defined by [x y θ].

a) Consider the 3 particles below, determine the robot's position [x y].

x (m)	*y (m)*	*θ (rad)*	*W*
5.4	7.5	0.31	0.399
5.2	7.7	0.28	0.399
1.1	4.4	0.99	0.002

b) Consider the 3 particles below, determine the robot's orientation [θ]. You can assume that π = 3.14.

x (m)	*y (m)*	*θ (rad)*	*w*
5.4	7.7	3.13	0.333
5.2	7.7	-3.10	0.333
5.5	7.6	3.11	0.333

c) While conducting localization with the X80 in lab, comparing an actual measurement of 40cm with a particle's expected measurement of 41cm, could produce the same weight as when comparing an actual measurement of 70cm with a particle's expected measurement of 69cm.

Explain why this is a problem in 2 or fewer sentences.

d) Why might it be a good idea to only resample particles when moving? Explain in 2 or fewer sentences.

Question 15: (10 marks)
In the file storage floor of a law firm, an autonomous robot is used to move boxes of files. For correct operation, the robot must be able to know within which of 4 rooms it is located.

To accomplish this, the robot is equipped with wheel encoders which measure the right and left wheel rotations ($\varphi_r \ \varphi_l$), and a laser scanner that outputs a set of range measurements (z_t).

From experiments, the probability of being in a particular room has been determined, given it is known which room it was previously in, as well as the robot's odometry. More specifically, we know the probability functions:

$$
\begin{aligned}
p(\, l_t=1 \mid \varphi_r, \varphi_l, l_{t-1}=1) &= f_{11} \\
p(\, l_t=1 \mid \varphi_r, \varphi_l, l_{t-1}=2) &= f_{21} \\
p(\, l_t=1 \mid \varphi_r, \varphi_l,, l_{t-1}=3) &= f_{31} \\
p(\, l_t=1 \mid \varphi_r, \varphi_l,, l_{t-1}=4) &= f_{41} \\
p(\, l_t=2 \mid \varphi_r, \varphi_l,, l_{t-1}=1) &= f_{12} \\
p(\, l_t=2 \mid \varphi_r, \varphi_l,, l_{t-1}=2) &= f_{22} \\
p(\, l_t=2 \mid \varphi_r, \varphi_l,, l_{t-1}=3) &= f_{32} \\
&\dots \\
p(\, l_t=4 \mid \varphi_r, \varphi_l,, l_{t-1}=4) &= f_{44}
\end{aligned}
$$

Markov localization will be used determine which room the robot is residing in.

a. Design a prediction step that determines the probability of being in each room. That is, give the equations for $p(\, l_t' = 1\,)$, $p(\, l_t' = 2\,)$, $p(\, l_t' = 3\,)$, and $p(\, l_t' = 4\,)$.

b. Design a correction step for the algorithm. That is, give the equations for $p(\, l_t = 1\,)$, $p(\, l_t = 2\,)$, $p(\, l_t = 3\,)$, and $p(\, l_t = 4\,)$. State any assumptions necessary.

Some Equations that might be useful:

$$d = c\, t / 2$$

$$\lambda = c/f$$

$$D = f\, l / x$$

$$p(A \wedge B) = p(A \mid B)\, p(B)$$

$$E[X_1 X_2] = E[X_1]\, E[X_2]$$

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

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

$$p(x_t \mid o_t) = \Sigma_{x'}\; p(x_t \mid x'_{t-1}, o_t)\, p(x'_{t-1})$$

$$p(x_t \mid z_t) = \frac{p(z_t \mid x_t)\, p(x_t)}{p(z_t)}$$

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

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

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