COS 495 - Autonomous Robot Navigation

Final Exam Practice

Fall Semester, 2012

Duration: **2 hours**
Total Marks: 70
Closed Book

Start Time:

End Time:

By signing this exam, I agree to the honor code

Name:

Signature:

Multiple-Choice – 2 marks awarded for each correct answer, 0.5 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)

Consider three differential-drive robots *r0*, *r1*, and *r2* sharing a 2D environment with obstacles as shown in Figure 1. In the situation depicted, robots must navigate towards their respective goal locations *g0*, *g1*, and *g2*.

A single query PRM will be used to construct collision free paths for all robots to get from their current configuration to their goal configuration. To ensure probabilistic completeness of the planner, a milestone in the roadmap consists of a multi-robot configuration with 10 variables, namely [$x_0, y_0, \theta_0, x_1, y_1, \theta_2, x_2, y_2, \theta_2, t$], that include the 2D position and orientation of each robot, as well as time.

a. Write the pseudo code for a single-query Probabilistic Road Map motion planning algorithm.
b. Describe how milestone generation might occur within the algorithm. Be sure to provide a mathematical equation that informs the reader on how robot configurations will be updated.
c. What is the most time-consuming part of the PRM algorithm?

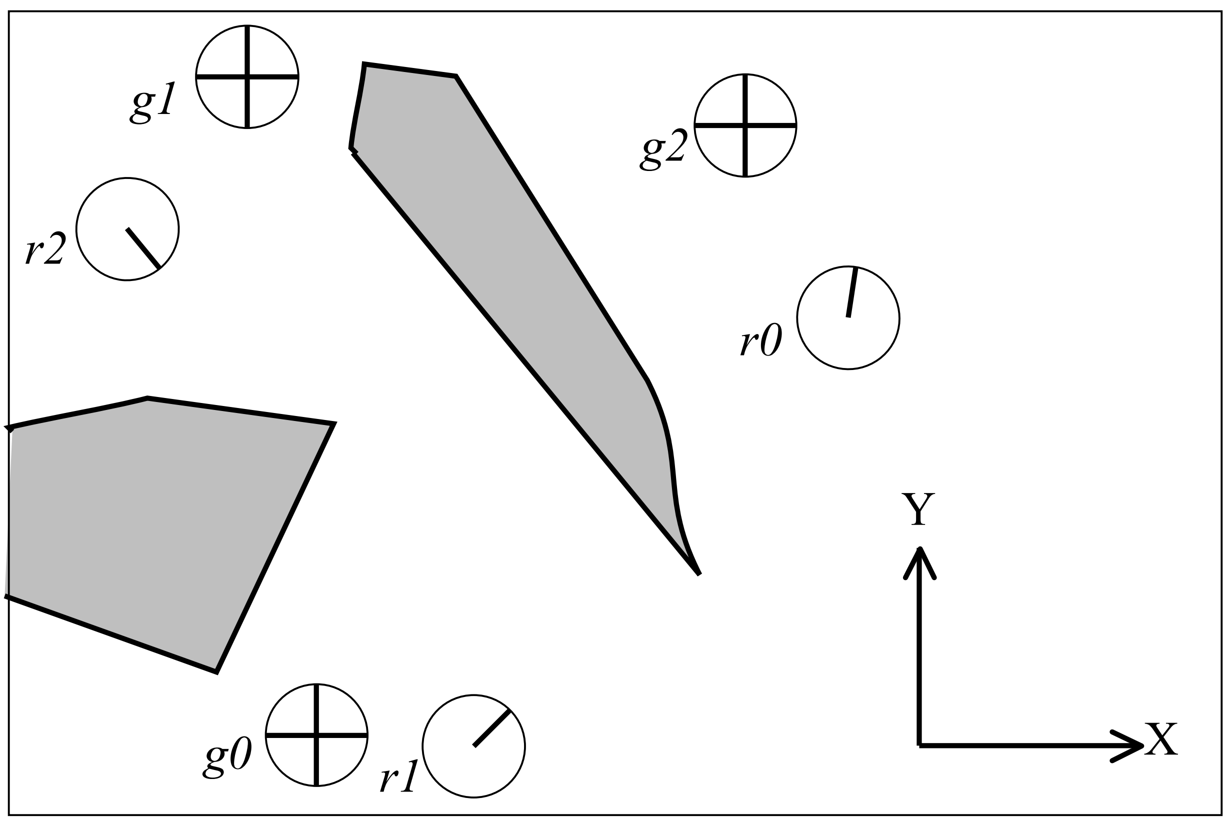

Figure 1: Three Differential drive robots sharing a workspace.

Question 12: (15 marks)

Assuming the robots in Figure 1 are Dr Robot X80's, design a multi-robot Particle Filter to localize robots. To simplify the problem assume each robot *i* only has a single forward facing IR range sensor that measures a distance z_i. However, each robot uses its camera to detect artificial features on the robots, and can use these features to measure the range and bearing to all other robots in the system. For example, robot *i* measures the range ρ_{ij} and relative angle α_{ij} to robot *j*. As well, robots can communicate their individual range measurements to each other. You can assume that each robot is only estimating the position of itself, and that particles only include the configuration of the individual robot and the weight.

a) Draw a diagram depicting the three robots and their range measurements. Be sure to label each robot's configuration and measurements.
b) Provide equations that describe the position of robot *j* in terms of the position of robot *i*, the range ρ_{ij}, relative angle α_{ij}, and yaw angle of robot *i*.
c) Assuming you have a function called f(x,y,theta) = GetClosestWallDistance(x,y,theta), write a mathematical expression that calculates a particle weights, that benefits from the additional inter-robot measurements. Assume there is no noise in the inter-robot measurements.
d) Describe a potential prediction step of the algorithm (use equations that are a function of individual wheel distance odometry measurements $\Delta s_{R,i}$, $\Delta s_{L,i}$ for robot *i*.)

Question 13: (10 marks)

With the same set of three robots, implement an Artificial Potential Field motion planning system.

a) For a single robot operating in a workspace with a single circular obstacle, draw a diagram depicting the robot, and the appropriate force vectors (attraction, repulsion, summation). Make sure all variables are labeled.
b) Write the equations for attraction and repulsion vectors
c) Provide a control law that will guide your robot in the direction of the resulting force vector.
d) Now, include forces that ensure no collision between robots.

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 (φ_r φ_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:

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

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:

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

$$\lambda = c/f$$

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

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

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

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

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

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

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

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

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

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