E 190Q - Autonomous Robot Navigation

Midterm Exam - Practice

March 5, 2014

Name:

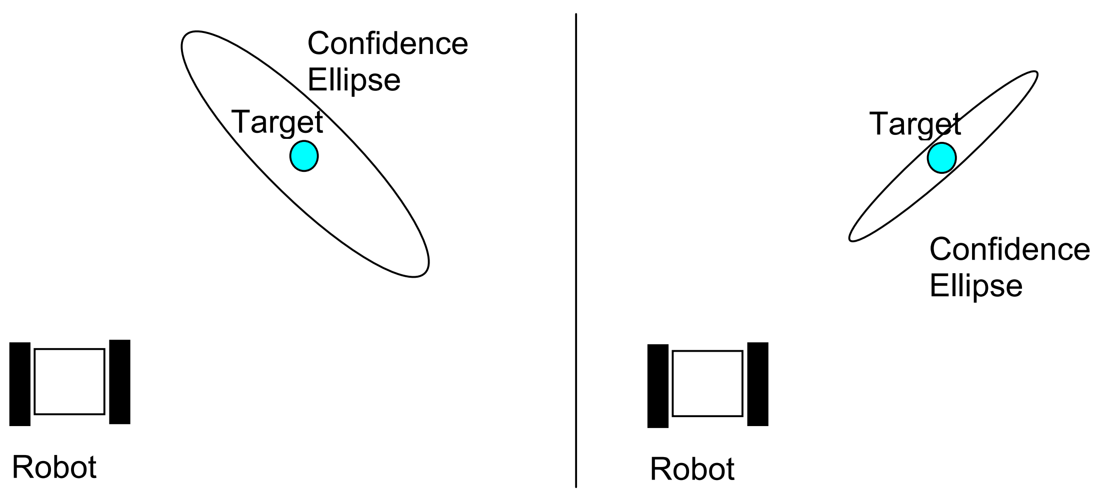
Signature:

Time Limit: **1 hour**

Open Book
Open Computers – E190Q website only for internet use

1. Confidence Ellipses
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)

2: State Estimation

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 $[\ x_2\ \ y_2\ \ z_1\ ]$ 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.

3: Range Sensors

The IR range sensors used on the X80 and other small robots are useful sensors but must be used with care. Answer the following questions regarding these sensors

a) Explain the basic principles on how the sensor works in 4 sentences or less. Be sure to use a diagram. Give the equation used to calculate range, labeling variables on the diagram.
b) Draw the response curve (sensor output as a function of distance). Be sure to give real distance values on the x-axis.
c) Provide 2 issues that limit the sensors performance. For each issue, explain why the issue arises in 2 sentences or less.

4: Control

Two robots are driving in a linear formation, as depicted in Fig. 2. Assuming there is no motion in the Y direction, and that yaw angles remain constant at 0, design a controller that tries to keep the distance between vehicles to be Δx_{des}. Assume that robot *r0* is travelling at a constant velocity $\dot{x}_0 = v_0$. Also assume that the robots can broadcast their positions and velocities to each other with no communication delay.

a) Start by writing an equation for error e that is a function of x_0, x_1, and Δx_{des}.
b) Using your answer from a), write the error dynamics equation. In other words, write an equation for $\dot{e}$.
c) Design a simple controller for robot *r1* so that it follows *r0* at the desired distance. That is, provide an equation for v_1. Hint, let v_1 be a function of two terms, one being v_0.
d) Show that your controller from c) is stable in that the distance between vehicles is driven to Δx_{des}, regardless of their start positions.

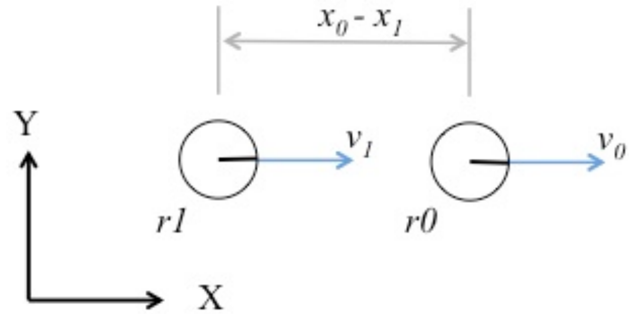


Figure 2: Two differential drive robots moving in formation.

5: Localization

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:

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

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.

6: Localization

Consider three differential-drive robots *r0*, *r1*, and *r2* sharing a 2D environment with no obstacles as shown in Figure 1. In the situation depicted, robots must determine their positions with respect to a *known map*.

Each robot *i* in the system has wheel encoders that measure right and left wheel distances travelled Δs_{Ri} and Δs_{Li}. Also, there are four range sensors placed around the workspace at locations (x_{s1}, y_{s1}), (x_{s2}, y_{s2}), (x_{s3}, y_{s3}), and (x_{s4}, y_{s4}) that measure distances z_1, z_2, z_3, and z_4, to anything directly in front of the sensor. These range measurements are continually broadcasted wirelessly to the robots at a very high frequency. The maximum range of these sensors is greater than the dimensions of the workspace.

Each sensor measurement is modeled as a random variable that follows a Gaussian distribution with zero mean and respective standard deviations $\sigma_{\Delta s}$, and σ_s. Each robot has diameter D.

Design a Particle Filter (PF) that will run on each robot, (i.e. it only localizes itself).

a) What variables should make up a particle?
b) Describe a prediction step of the PF algorithm that updates the position associated with a particle (i.e., provide position update equations).
c) Given have a function called $f(x, y, j)$ = GetDistanceToWall(x, y, j) that returns the distance from the position (x, y) to wall j, write a mathematical expression that calculates a particle's weight. Note that wall j refers to the wall with sensor *sj*, (e.g. wall *3* is the wall in the figure with sensor *s3*). Assume there is only one robot in the workspace when calculating the weight. State any other assumptions you feel necessary.
d) If more than one robot is operating in the workspace, does your weight calculation still work as well? In one sentence, explain why or why not.

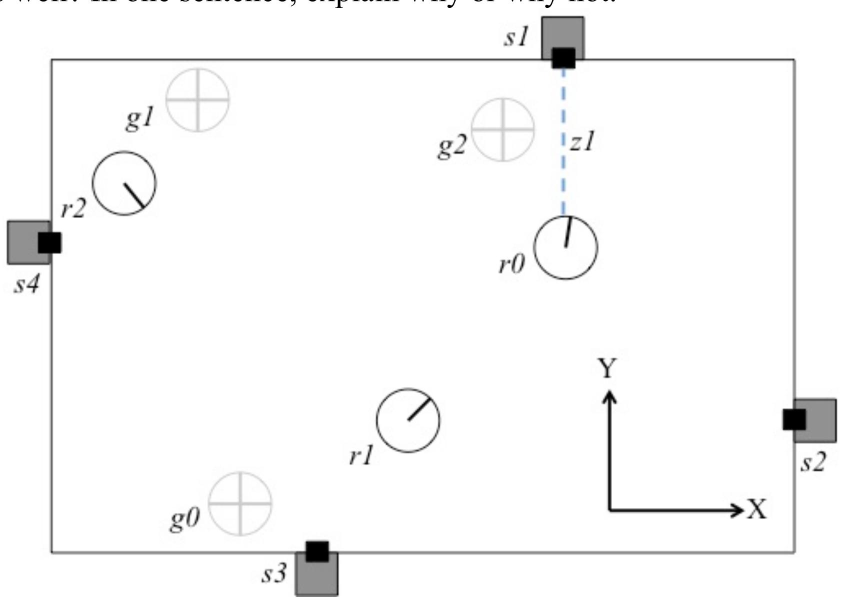


Figure 1: A top down view of three Differential drive robots sharing a rectangular workspace. Four range sensors are placed around the workspace, facing inwards.