E190Q - Autonomous Robot Navigation

Midterm Exam

March 12, 2015

Name:

Signature:

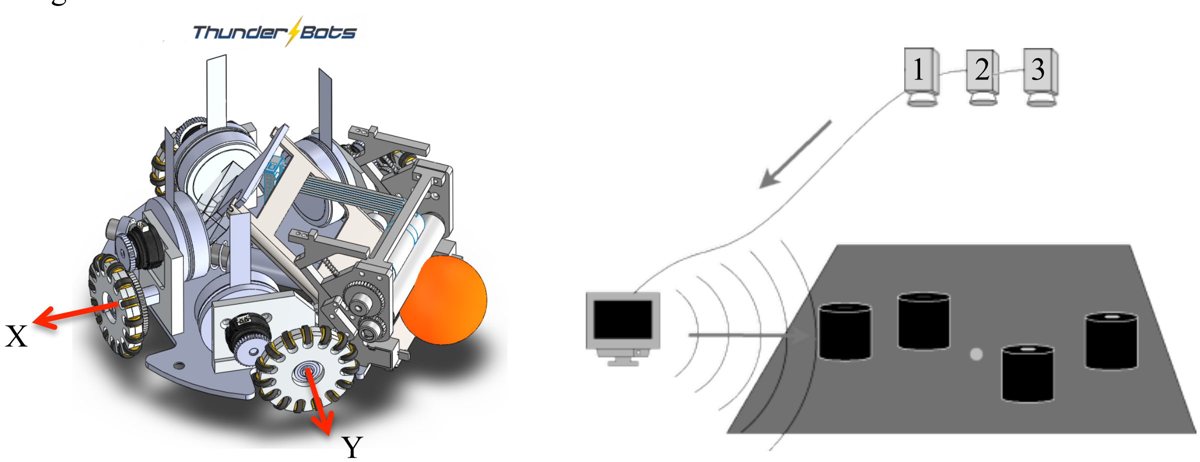
Time Limit: **1.25 hours**

Open Book
Open Notes
Open Computers – E190Q website only version of internet use

0. INTRODUCTION

Consider an omnidirectional robot used in RoboCup soccer league (see Fig. 1a). The robot has 4 *swedish* wheels, one placed on each side of the robot. Assume that each of the 4 swedish wheels can be actuated independently, and that they each have 16 mini wheels attached to them to allow sliding parallel to the swedish wheel's axis as shown in the figure below. Note the X and Y axis of the robot's local coordinate frame are shown.

Above the RoboCup field which has dimensions *l* by *w*, there are three video cameras, (Fig 1b), each of which can provide a measurement of a robot's position and orientation. The vision system broadcasts the robot positions and orientations to the robots as shown in the figure. One camera is directly above the center of the field. The other two cameras are centered along the long axis of the field with a distance *d* between them and the central camera.



(a) (b)

Figure 1: An omnidirectional robot for RoboCup. http://ubcthunderbots.ca/category/news/ is shown in (a). In (b), a field highlighting the overhead vision system is shown.

For this problem, let us assume there is only one robot and one ball on the field, each of which are unique to the vision system and hence can be distinguished. Assume that each camera has the whole field in view and provides its own measurement of the robot state [x_{ri} y_{ri} θ_{ri}] and ball position [x_{bi} y_{bi}], where $i=1..3$ corresponding to the i^{th} camera. Assume these measurements are all taken with respect to an individual camera's coordinate frame that is centered at the middle of the camera and aligned with its X axis parallel to the long side of the field. To note, due to optical lens distortion, each camera has an error associated with it, as depicted in Fig. 2.

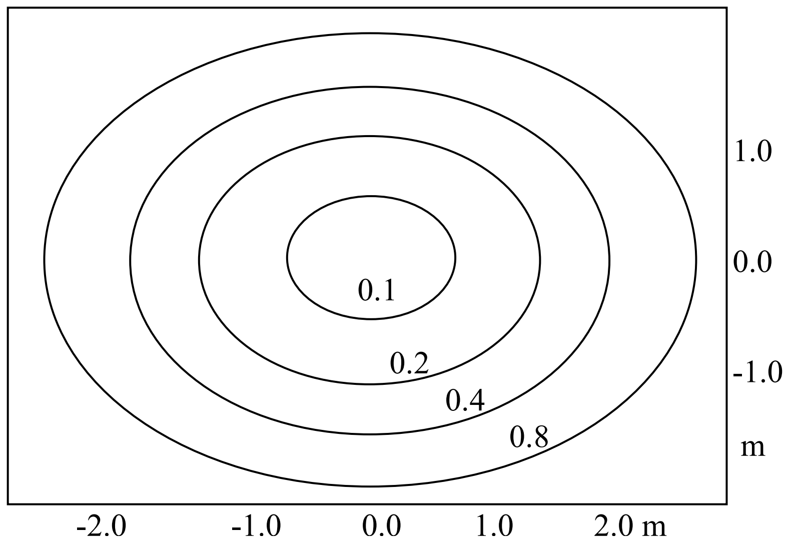


Figure 2: The mean position and orientation errors (in units of cm and radians respectively) as a function of where the position of the robot in the image. The outer rectangle indicates the image boundaries. Ellipses indicate contours of constant error, i.e. all robot positions measured when the robot is located somewhere on the inner ellipse have expected errors of 0.1 m in positioning and 0.1 radians in yaw angle.

The motion modeling of this robot is different than most differential drive systems. For example, the robot's velocity with respect to the local robot frame can be described as:

$$dx/dt = C(d\varphi_1/dt + d\varphi_3/dt)$$
$$dy/dt = C(d\varphi_2/dt + d\varphi_4/dt)$$
$$d\theta/dt = D(d\varphi_1/dt + d\varphi_2/dt - d\varphi_3/dt - d\varphi_4/dt)$$

In these equations, $d\varphi_i/dt$ is the wheel rotational velocity (in rad/s) for the i^{th} wheel. C and D are experimentally determined constants.

1. SENSING (10 points)

a) Provide an equation that describes the position of the robot with respect to the global coordinate frame in terms of measurements from camera 1. Assume the global coordinate frame is anchored to the field with its origin at the middle of the field and X axis parallel to the long side of the field. Draw a picture that includes the coordinate frames, a robot, and any variables.

b) Derive the same equations for camera 2 and camera 3.

c) If the robot also has an on-board camera facing forwards to track the ball, provide an equation that describes the ball's position in the global coordinate frame as a function of the robot's position and the on-board camera's measurement [ρ α], where ρ is the range to the ball and α is the relative bearing angle to the ball.

2: KF LOCALIZATION (15 points)

Design a Kalman Filter (KF) that will localize the robot.

a) What variables should be in the State Vector? In the Covariance Matrix?

b) Describe a prediction step of the KF algorithm that updates the state vector and associated covariance matrix. Assume there are no proprioceptive sensors except wheel encoders. State any other assumptions.

c) Describe a correction step for the KF. Be sure to define the innovation vector, the update equation for the innovation covariance, the state vector update and the covariance matrix update. State any assumptions.

d) If the overhead positioning system can not be used to track the ball, how can the KF localization algorithm you designed be extended to run SLAM and estimate the ball state?

3: PF LOCALIZATION (10 points)

Design a Particle Filter (PF) that will localize the robot.

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 state update equations). Assume there are no proprioceptive sensors except wheel encoders. State any other assumptions.

c) Describe a correction step for the PF. Be sure to define the weight calculation and the method of resampling. State any assumptions.

4: MOTION PLANNING (5 points)

A single query Probabilistic Road Map (PRM) will be used to plan paths for the robot. Propose a node expansion step. Specifically, given a node *n* in the roadmap defined by the configuration $[\ x_n\ \ y_n\ \ \theta_n]$ that has been selected for expansion, provide the equations that describe the position $[\ x_{n'}\ \ y_{n'}\ \ \theta_{n'}]$ of a newly generated node given the *n'*.

5: MULTIPLE CHOICE – 2 points awarded for each correct answer, 0 points if incorrect or 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 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 minimized.
   b) Only the previous 2 sensor measurements are required for accurate localization.
   c) The current state is only dependent on the previous state, and not the entire history of states.
   d) None of the above.

3. A Kalman Filter solution that fuses two measurements to calculate an estimate,
   a) can be derived from a weighted least squares solution.
   b) uses variances associated with each measurement to determine each measurements contribution to the estimate.
   c) assumes sensor measurements are modeled as Gaussian functions.
   d) All of the above.

4. The RANSAC algorithm used for line fitting,
   a) uses randomness.
   b) is iterative.
   c) calculates a new model for every iteration.
   d) All of the above.

5. The ZLOG method,
   a) detects zero crossings.
   b) approximates the Laplacian function.
   c) uses a Gaussian operator to deal with noise.
   d) All of the above.

BONDUS: The robot built by Kagome,
   a) uses wheeled locomotion.
   b) uses bipedal locomotion.
   c) is built as an autonomous mobile platform for perimeter security applications.
   d) All of the above.