Technical University of Crete
School of Electrical and Computer Engineering

COMP 614 – Graduate Course on Probabilistic Robotics – Fall 2016

Instructor: M. G. Lagoudakis **Final Examination** Dates: April 3-4, 2017

Instructions

⋆ This is a take-home exam; you must work on your own, without sharing ideas and/or solutions.
⋆ You may use any printed or electronic material during the exam, but no assistance from others.
⋆ Type up or write down your solutions and upload a single PDF file (plus code) before the deadline.
⋆ You may write your solutions in either English or Greek; ensure that your document is legible.
⋆ Make sure your name and student ID number are clearly shown on your deliverable.

Problem 1 [50%] - Robot Localization

Consider a point robot moving on the continuous two-dimensional $x - y$ plane. The robot is initially located at the origin $(0, 0)$.

At each discrete time step, the robot can choose any of the four available locomotion actions: $A = \{L, R, U, D\}$ standing for Left, Right, Up, and Down respectively. All four actions are noisy; they move the robot by one unit in the corresponding direction with additive two-dimensional zero-mean isotropic Gaussian noise described by $\sigma_L = 0.1$, $\sigma_R = 0.2$, $\sigma_U = 0.2$, and $\sigma_D = 0.3$ respectively.

There are two beacons (point landmarks) in this domain located at $B = (5, 5)$ and $C = (3, -3)$. The robot is equipped with distance sensors able to measure its (Euclidean) distance from each of these two beacons at each time step. The measurements are noisy; the true distance d is corrupted by one-dimensional zero-mean Gaussian noise described by $\sigma_B = 0.1 \times d$ and $\sigma_C = 0.3 \times d$ respectively.

Consider a scenario where the robot takes the following sequence of actions:

$$R \quad R \quad R \quad U \quad L \quad D \quad D \quad R \quad R \quad U$$

and records the following sequence of measurements from the two beacons (B and C):

```
6.49292   3.25706
5.00952   2.86673
5.37475   4.20433
4.65812   2.41266
4.64956   3.73500
4.79809   5.25568
7.99718   1.55293
7.04209   2.14931
5.88203   1.28366
6.03326   1.76163
```

(a) Write down the motion and sensor models of the robot.

(b) Use your favorite state estimation method to localize the robot, i.e. estimate its location on the $x - y$ plane at each time step.

(c) Generate a plot showing the initial location of the robot, the locations of the two beacons, and the estimated trajectory of the robot.

Hint: Lookup the function `normrnd` in Matlab/Octave for sampling a Gaussian with given μ and σ.

Problem 2 [50%] - Decision Making under Uncertainty

Consider a simple robot able to move inside the following 5×5 grid world (21 states), where `#` are walls, `o` indicates the initial location of the robot, `G` is a goal state, and `T` indicates a trap:

```
# # # # # # #
#           #
#   # #   # #
#         G #
#   # T   T #
# o       T #
# # # # # # #
```

At each discrete time step, the robot can choose any of the four available locomotion actions: $A = \{L, R, U, D\}$ standing for Left, Right, Up, and Down respectively. All four actions are noisy; they move the robot in the intended direction with a probability of 0.8, but there is a probability of 0.1 for moving sideways on each side. When the motion leads to bumping into a wall, the robot stays in place. States `G` and `T` are absorbing (terminal) and yield a final reward of $+1$ and -1 respectively, when entering such a state; at all other transitions a reward of $r = -0.04$ is given. Rewards are not discounted over time.

(a) Write down the full MDP model of the problem.

(b) Use the value iteration algorithm to obtain an optimal policy for this problem.

(c) Generate a plot with arrows showing the optimal policy you derived.

(d) Show the values of the resulting value function in each state.

Bonus: Bonus points up to 20% will be given for deriving and plotting optimal policies for four qualitatively different values of r.

Good Luck!