CS401 – Intelligent Robots
Spring 2019 Midterm Test

Name:____

Student Number:____

Instructions:

1. <u>Print</u> your name and student number above.
2. Indicate your answers clearly in the spaces provided with each problem.
3. Problem I is 20 points. Problem II is 10 points. Problem III is 10 points. Problem IV is 10 points. Problem V is 15 points. Problem VI is 20 points. Problem VII is 15 points. Problem VIII provides extra credits.

Problem I Multiple Choice

1. (2 points) Different types of robot locomotion include _____.

A. sliding
B. rolling
C. flying
D. all of the above

2. (2 points) In motion 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. (2 points) 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

4. (2 points) 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 maximized
B. the current state is only dependent on the previous state, not the entire history of states
C. only current sensor measurement are required for current localization
D. None of the above

5. (2 points) 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

6. **(2 points)** Kalman filtering assumes that _____.

   A. system models are linear
   B. system uncertainties are Gaussian
   C. system states are Markovian
   D. all of the above

7. **(2 points)** The main differences between the occupancy map and the reflection map DOES NOT INCLUDE _____.

   A. that the former needs the inverse sensor model
   B. that the latter uses the maximum range reading
   C. that the former represents whether a cell is occupied by an object
   D. that the later counts the hit or miss probabilities

8. **(2 points)** Extended Kalman filtering should be used instead of Kalman filtering ________.

   A. the system is non-linear
   B. the system uncertainties are non-Gaussian
   C. the system is MIMO
   D. all of the above

9. **(2 points)** Particle Filtering DOES NOT includes ____ .

   A. importance sampling
   B. rejection sampling
   C. resampling
   D. normalization

10. **(2 points)** The probabilistic beam-based sensor model DOES NOT includes ____ .

   A. a mixture of multiple distributions
   B. a distribution for the maximum sensor reading
   C. a distribution for the measurement noise of the unexpected obstacle
   D. a distribution for the random measurement

Problem II Bayes Rule and Bayes Filter

1. **(5 points)** A robot is roaming within a room with two doors. The robot uses an ultrasound sensor to detect the binary status of two doors, x_1 and x_2, and obtain the binary measurement z. For door 1, the sensor has the detection error of 30% when the door is open and the detection error of 20% when the door is closed; for door 2, the detection errors are both 20%; then
(1) what is the probability of $p(x\text{=open} \mid z\text{=open})$ for each door? (Assuming $p(x\text{=open}) = 0.5$).
(2) what is the probability of $p(x_1\text{=close}, x_2\text{=close} \mid z_1\text{=open}, z_2\text{=open})$? (Assuming a fair prior).

2. **(5 points)** Given the observation model, $p(z_t \mid x_t, m)$, the action model, $p(x_{t+1} \mid x_t, u_t)$, and the prior model, $p(x_t)$, please derive the posterior $p(x_t \mid u_1, z_1, u_2, z_2, \ldots, u_t, z_t, m)$ under the Markovian assumptions.

Problem III Probabilistic Motion Models

1. **(5 points)** How to compute the posterior probability $p(x_{t+1} \mid x_t, u_t)$ based on the odometry and velocity models, respectively? What are the similarity and difference between these two methods?

2. **(5 points)** How to generate samples of x_{t+1} based on the odometry-based and velocity-based motion models, respectively? What are the similarity and difference between these two methods?

Problem IV Probabilistic Sensor Models

1. **(5 points)** What is the probability density mixture model for beam-based sensors, $p(z \mid x, m)$? What is the probability density mixture model for scan-based sensors, $p(z \mid x, m)$? What is the relationship between those two models?

2. **(5 points)** How to generate samples of x_n and compute the detection probability, $p(z \mid x_n, m)$, based on the landmark-based model with distance measurements, respectively?

Problem V Kalman Filters

1. **(5 points)** For a linear dynamic system, $x_{t+1} = \mathrm{A}x_t + u_t + w$, where u_t is the current odometry reading; x_t is the current Gaussian system state, $x_t \sim \mathcal{G}(\mu_t, \Sigma_t)$; w is the Gaussian noise, $w \sim \mathcal{G}(0, \mathrm{R})$, please derive the probability distribution of the predicted state, $\bar{x}_{t+1}$.

2. **(5 points)** For a linear sensor system, $z = Cx - m + v$, where m is the landmark; z is the sensor reading; v is the Gaussian noise, $v \sim \mathcal{G}(0, \mathrm{Q})$, please derive the probability distribution of the estimated state, $\hat{x}$.

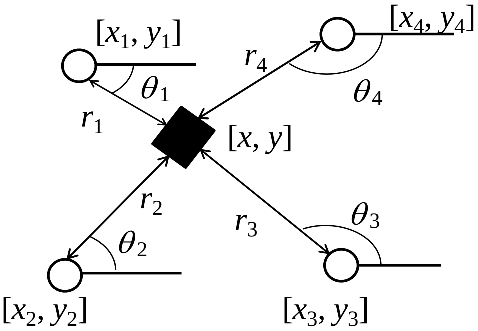
3. **(5 points)** For the above linear dynamic and sensor systems, please derive the probability distribution of the estimated state, $\hat{x}$.

Problem VI Mapping

1. **(5 points)** Please derive the belief (posterior) of the i^{th} occupancy grid map cell, $\mathrm{Bel}\left(m_t^{[i]}\right)$, given measurements, $z_{1:t}$, robot positions, $x_{1:t}$, in terms of the inverse sensor model, $p\left(m_t^{[i]} | z_t, x_t\right)$, prior, $p\left(m_t^{[i]}\right)$, and the previous belief, $\mathrm{Bel}\left(m_{t-1}^{[i]}\right)$. (use the log-odds representation)

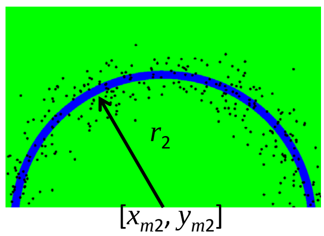
2. **(5 points)** For one cell, its reflection rate is 40% and interception rate is 60%; the probability of occupancy is 0.55, when the beam ends in it; the probability of occupancy is 0.4, when the beam intercepts it without ending in it, then what is the value of the reflection map of this cell and what is the value of the occupancy map of this cell if the number of beams is 1000?

3. **(10 points)** Please estimate the Gaussian probabilistic distributions of the four landmarks given the robot position, [x, y], and the range measurements of [r_1, r_2, r_3, r_4] and bearing measurements [θ_1, θ_2, θ_3, θ_4] ?
(list the major steps with equations and variables, assuming zero-mean Gaussian uncertainties)



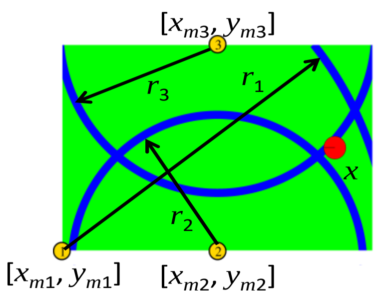
Problem VII Particle Filters

1. **(5 points)** Please list major steps to generate samples of the target position, x, from the distribution of $p(x \,|r_2)$, given a range measurement, r_2, with respect to the landmark at [x_{m2}, y_{m2}] (using the rejection sampling technique).



2. **(5 points)** Please list major steps to generate sample weights of the target position, x, from the distributions of $p(r_1| \, x)$ and $p(r_3| \, x)$, given range measurements, r_1 and r_3, with respect to the landmarks at [x_{m1}, y_{m1}] and [x_{m3}, y_{m3}].

3. **(5 points)** Please list major steps to re-sample the target position, x, from the above sample weights.



Problem VIII (Extra Credits)

Please give your reflections on why probabilistic models and reasoning techniques are preferred in the study of intelligent robots.