

PROBLEM SET 3

COM SCI 188: Intro to Robotics

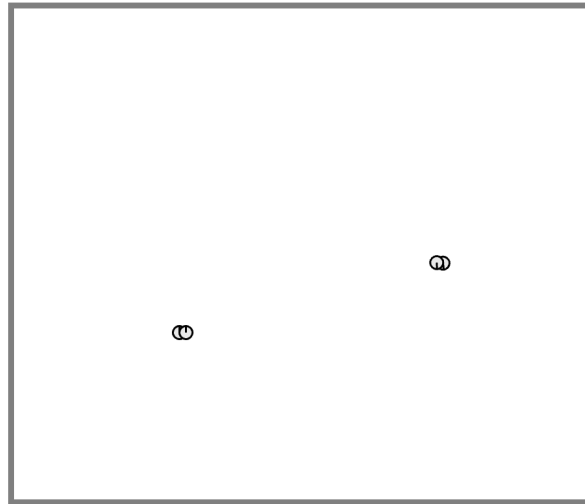
Spring 2025

Question:	1	2	3	4	5	Total
Points:	33	20	18	20	9	100

1. Particle Filter & Localization.

- (a) (3 points) What is the primary purpose of *Resampling* in a Particle Filter algorithm?
- A) To concentrate computational resources on high-probability particles by discarding low-weight particles and duplicating high-weight ones.
 - B) To increase the total number of particles in order to improve computational accuracy as uncertainty grows.
 - C) To inject additional Gaussian noise to increase computational diversity in the particle set.
 - D) To reduce computational complexity by converting the belief distribution from Gaussian to uniform.
- (b) (4 points) When calculating the *Posterior Probability* of a particle after a sensor reading, which formula is used?
- A) $P(\text{location} \mid \text{reading}) = P(\text{reading} \mid \text{location}) + P(\text{location})$
 - B) $P(\text{location} \mid \text{reading}) = \mu \pm \sigma^2$
 - C) $P(\text{location} \mid \text{reading}) = \frac{P(\text{reading} \mid \text{location})P(\text{location})}{P(\text{reading})}$
 - D) $P(\text{location} \mid \text{reading}) = \frac{P(\text{reading} \mid \text{location})}{P(\text{reading})P(\text{location})}$
- (c) (4 points) In robot localization, what does the measurement model represent?
- A) The probability of the robot moving to a new location given a control input.
 - B) The probability of receiving a sensor measurement given the robot's current location.
 - C) The probability of the robot's initial position.
 - D) The probability of a landmark being detected at any point on the map.

- (d) (4 points) Which of the following is a specific advantage of a Particle Filter over a standard Kalman Filter for robotics applications?
- A) It can naturally handle non-linear systems and non-Gaussian noise.
 - B) It is significantly more computationally efficient for high-dimensional state vectors.
 - C) It provides a single mean and covariance matrix as the final output.
 - D) It does not require any sensor noise model to function.
- (e) (4 points) Recall the robot that navigates the 2D square room with just 2 range sensors (left and right). The figure below shows 4 particles of the robot at time step $t - 1$. At timestep t , the robot receives a movement command ($\theta = -\pi/2, d = 1$). Draw a possible configuration of the particles after the prediction step. The robot turns (counterclockwise is positive) before it moves.



- (f) (4 points) After executing the movement, the robot receives sensor reading ($Left = 1.7m, Right = 1.8m$). Circle the particle(s) with highest posterior probability.

(g) (10 points) **Particle Filter vs Kalman Filter.**

Both Particle Filters and Kalman Filters are built around Bayesian filtering:

- Prediction: predict where you might be after motion.
- Update: correct the prediction using sensor measurements.
- Belief representation: (particles for PF, mean/covariance for KF).

For each concept below, choose whether it applies to Particle filter, Kalman filter, or both.

Concept	PF	KF
Represents belief with multiple samples (particles)	<input type="radio"/>	<input type="radio"/>
Assumes Gaussian noise and linear system	<input type="radio"/>	<input type="radio"/>
Uses motion models and measurement models	<input type="radio"/>	<input type="radio"/>
Handles non-linear and non-Gaussian models naturally	<input type="radio"/>	<input type="radio"/>
Uses a single mean and covariance matrix	<input type="radio"/>	<input type="radio"/>
Performs prediction-update (Bayes filtering cycle)	<input type="radio"/>	<input type="radio"/>
May require resampling to focus on high-probability particles	<input type="radio"/>	<input type="radio"/>
Uses an optimal gain to balance prediction and measurement	<input type="radio"/>	<input type="radio"/>
Requires an initial estimate (initial belief)	<input type="radio"/>	<input type="radio"/>
Can be used for robot localization and SLAM	<input type="radio"/>	<input type="radio"/>

2. Simultaneous Localization and Mapping.

- (a) (4 points) What is the primary purpose of SLAM in robotics?
- A) To control robot movements and avoid obstacles
 - B) To detect and track moving objects in the environment
 - C) To map an unknown environment while tracking the robot's position
 - D) To optimize battery usage during navigation
- (b) (4 points) Why can't a basic Kalman Filter be used directly for SLAM?
- A) SLAM systems have no noise.
 - B) SLAM motion and measurement models are nonlinear.
 - C) Landmark motions are not Gaussian.
 - D) Kalman Filters require extensive compute.
- (c) (4 points) Which of the following is true about the Extended Kalman Filter?
- A) It requires the system dynamics and measurement models to be linear.
 - B) It uses Jacobians to locally linearize motion and measurement models.
 - C) It represents uncertainty using a set of weighted particles.
 - D) It produces exact state estimates regardless of noise or model error.
- (d) (4 points) In SLAM, *Loop Closure* is a critical concept. What happens when a robot successfully closes a loop?
- A) The robot terminates exploration after completing a full traversal of the environment.
 - B) Previously collected sensor measurements are ignored to avoid duplicating mapped features.
 - C) The robot recognizes a previously visited location, reducing uncertainty in both its pose and the map.
 - D) The SLAM algorithm becomes unstable and must be restarted.
- (e) (4 points) What is the computational complexity of the *motion update* (prediction) step in EKF-SLAM? Why? Use the $O(\)$ notation.

3. Motion Planning.

- (a) (3 points) What is the primary objective of motion planning?
 - A) To find a sequence of control inputs that maximizes the robot's speed.
 - B) To compute a collision-free path from a start to a goal position.
 - C) To minimize the robot's battery consumption during navigation.
 - D) To detect dynamic objects and reclassify the environment.

- (b) (3 points) What is the main idea behind PRM?
 - A) Grow a tree from the start to the goal position
 - B) Randomly sample free space and connect samples to build a graph
 - C) Search the entire configuration space exhaustively
 - D) Maximize the robot's velocity during planning

- (c) (3 points) In PRM, which of the following is true about the roadmap?
 - A) It only connects samples in collision
 - B) It connects nearby collision-free samples
 - C) It only connects samples after reaching the goal
 - D) It requires a full map before planning starts

- (d) (3 points) What is the main advantage of RRT over PRM?
 - A) RRT builds a global roadmap in advance
 - B) RRT grows a tree quickly toward unexplored areas
 - C) RRT guarantees finding the shortest path
 - D) RRT only works in static environments

- (e) (3 points) In RRT, what happens when a random sample is generated?
 - A) It is ignored unless it is at the goal
 - B) It is connected to the nearest node in the tree if collision-free
 - C) It replaces the previous nodes in the tree
 - D) It deletes earlier branches of the tree

- (f) (3 points) Which of the following statements about PRM and RRT is correct?
 - A) Both PRM and RRT guarantee an optimal path.
 - B) PRM builds a graph first; RRT grows a tree during search.
 - C) RRT is slower than PRM in open environments.
 - D) PRM is only used for real-time dynamic environments.

4. Markov Decision Processes.

- (a) (3 points) What is the Markov property?
 - A) The future depends only on the current state.
 - B) The future depends on all past states.
 - C) The current state depends on future observations.
 - D) Observations are independent of the state.

- (b) (3 points) What does a *policy* represent in an MDP?
 - A) A probability distribution over states.
 - B) A model of state transition dynamics.
 - C) A mapping from states to actions.
 - D) A function that assigns rewards to states.

- (c) (3 points) What is the goal when solving an MDP?
 - A) To minimize the number of states in the model.
 - B) To find a policy that maximizes expected cumulative reward.
 - C) To exactly predict all future state transitions.
 - D) To eliminate uncertainty in the environment.

- (d) (3 points) In MDPs, what is "discounting" used for?
 - A) Making immediate rewards more important than distant rewards.
 - B) Increasing the future rewards' value.
 - C) Ignoring all rewards beyond a fixed number of steps.
 - D) Penalizing the robot for collisions.

- (e) (4 points) Write the Bellman equation for the value of a state $V(s)$. What is the main idea behind the Bellman equation (1 sentence)?

- (f) (4 points) How does "policy iteration" differ from "value iteration"?

5. Imitation Learning.

- (a) (3 points) What is a major challenge in imitation learning related to *compounding errors*?
- A) Small mistakes early in execution can lead the agent into unseen states, causing errors to accumulate over time.
 - B) The agent cannot observe the expert's actions directly.
 - C) The reward function becomes non-stationary during training.
 - D) The state and action spaces must be fully observable and discrete.
- (b) (3 points) What is a key difference between *Behavior Cloning* and *Inverse Reinforcement Learning*?
- A) Behavior Cloning requires an explicit reward function, while Inverse Reinforcement Learning does not use rewards.
 - B) Behavior Cloning models environment dynamics, while Inverse Reinforcement Learning assumes known dynamics.
 - C) Behavior Cloning is model-based, while Inverse Reinforcement Learning is purely model-free.
 - D) Behavior Cloning learns a policy directly from expert actions, while Inverse Reinforcement Learning infers a reward function from expert behavior.
- (c) (3 points) What assumption is commonly made by Behavior Cloning but relaxed by Inverse Reinforcement Learning?
- A) That the reward function is unknown.
 - B) That the state space is continuous.
 - C) That expert actions are optimal in demonstrations.
 - D) That the policy must be deterministic.