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Humanoid Robotics

Assignment 4

Due Tuesday, May 20th, before tutorial.

Active Perception:

1. Understanding and Applying View Planning Strategies
In the lecture on Active Perception, several view-planning strategies were introduced, including both greedy and global approaches. These strategies aim to optimize sensor viewpoints in various robotic applications.

a. **Provide concise definitions (1–2 sentences each) for the following planning strategies: (2 points)**
- Single-step Next-Best-View (NBV)
- One-Shot Global Planning (Set Covering Optimization)
- N-Step Greedy Planning
- Receding Horizon Planning

b. **Match each of the following application scenarios to the most suitable planning strategy. Justify your choice in one sentence: (1 point)**
- A warehouse inspection drone must quickly scan a small set of known critical points in a fixed layout exactly once with minimal computation.
- An autonomous car navigating a dynamic urban environment replans its sensor viewpoints continuously as new obstacles appear.

2. Next-Best-View Selection with Volumetric Information (VI) Gain Metrics
In this task, you will implement a simple next-best-view (NBV) strategy for exploration in a partially known 2D occupancy grid, as introduced in the lecture. The environment will be generated randomly, and your NBV algorithm should be able to operate on any such generated map. A function to generate these randomized grid worlds is provided as well.

a. **Single Next-Best-View Selection (2 points)**
Write a function that selects the next-best-view on a given grid.
The NBV should be selected based on the number of unknown (white or grey) cells observable from a candidate position, within a variable field of view [4, 8 cell neighborhood] and length [1,2,3].
Visualize the grid:
- Display black, grey, and white cells.
- Mark the selected NBV in red.
- Highlight the cells visible from this viewpoint in yellow.

b. **Multiple View Planning (2 points)**
Extend your implementation to simulate a short planning sequence.
Assume that all visible cells from an NBV are revealed as free after visiting.

- Write a function that selects and executes the next n NBVs sequentially, where n = 3.
- After each NBV:
  - Update the grid to reflect the newly revealed cells.

- Recalculate the next NBV based on the updated information.
- Visualize the full sequence, marking all visited NBVs and the cells they revealed.

c. Cost-Aware NBV Selection **(2 points)**

Now include a simple motion cost in your NBV selection.

- Use Euclidean distance from the current position to the candidate NBV as the motion cost.
- Adjust the NBV score using a weighted sum of:
  - Information gain (number of unknown cells visible), and
  - Motion cost.
- Use a weight factor α = 0.3 for the motion cost (MC): $score = IG - \alpha \cdot MC$
- Discuss how different values of α influence the balance between exploration gain and travel effort.

3. Information Gain Calculation for Continuous Occupancy Maps

In this task, instead of binary occupancy map, you are provided a partially observed continuous occupancy map with occupancy probability p_{occ} such that $0 \leq p_{occ} \leq 1$. The occupancy map is provided as NumPy array (occupancy_map.npy). The coordinate system is located at the bottom left with x-axis to the east and y-axis to the north.

Along with it, we provide 4 images of the sensor pose with its 2.5D pose (x, y, θ). The sensor can view along the direction show in the image upto 5 cells or till it hits an occupied cell, whichever is earlier. We consider a cell to be occupied if $p_{occ} \geq 0.7$ and do not use it for IG or visibility calculation. For the 4 sensor poses, calculate the following:

a. Information Gain using Shanon Entropy formula for continuous occupancy probability: **(2 points)**

For each of the 4 sensor poses, the raycasting can be done along the direction θ shown in the visualized map. A single ray emits from the sensor and traverses a maximum of 5 cells along horizontal, vertical or diagonal axis. Scale the step size accordingly as in the diagonal heading the ray needs to travel more to traverse one cell. Calculate the expected information gain using the Shanon entropy formulation.

b. Occlusion-aware Information Gain: **(2 points)**

For the same 4 sensor poses, calculate the occlusion-aware information gain by weighing the Shanon information gain with the visibility probability taught in the lecture.

c. Tabulation and Discussion: **(2 points)**

Record the results in the table below and compare the effect of adding the occlusion-awareness in part b to part a. Also, based on the cells observed by the ray for each sensor pose, determine if the viewpose can be used for free space exploration or for obstacle mapping. Mention if a particular viewpose is suited for neither of them. Justify your answers.