Motion Planning (RBE550)
Programming Assignment 3: PRM Algorithm Implementation

Assignment By:
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Question asked in Assignment:
For PRM, what are the advantages and disadvantages of the four sampling methods in comparison to each other?

Answer:

1. Uniform Sampling:
   Advantages:
   a. Simple, efficient and easy to implement
   b. It covers the whole graph uniformly with uniform weights connections
   c. Generates a diverse set of configurations
   Disadvantages:
   a. Can lead to an inefficient roadmap with long paths
   b. Requires a large number of samples to achieve good coverage
   c. In case of less sample points, can result in incomplete solution

2. Random Sampling:
   Advantages:
   a. Can produce a diverse set of samples across the configuration space
   b. Can be used with any type of robot model or environment, as it does not rely on any specific characteristics of the system
   c. Simple and easy to implement
   Disadvantages:
   a. Requires large number of samples to achieve good coverage
   b. The randomness of the samples can lead to inefficient paths in some areas of the configuration space

3. Gaussian Sampling:
   Advantages:
   a. More efficient than uniform random sampling for narrow passages
   b. Can reduce the number of samples needed to achieve good coverage
   c. Tackles the obstacle boundary condition
   Disadvantages:
   a. Can produce samples that are not diverse enough for some environments
   b. Can lead to long paths due to the clustering of samples around narrow passages
   c. Requires tuning of the covariance matrix of the Gaussian distribution to achieve good results
   d. May not be efficient for concave obstacles

4. Bridge Sampling:
   Advantages:
   a. Can be more efficient than other sampling methods in narrow passages
   b. By sampling more densely in narrow passages, bridge sampling can produce higher quality paths
   c. Tackles the obstacle boundary condition
   Disadvantages:
   a. More complex sampling method than other methods
   b. Additional computations required for bridge sampling can increase the computation time
   c. More number of sample points required for better results

Algorithm Results and Explanation:

PRM Algorithm:
In this assignment, PRM algorithm is implemented with 4 different sampling methods:

1. Uniform Sampling
2. Random Sampling
3. Gaussian Sampling
4. Bridge Sampling

Based on the sampling methods, the results from these 4 sampling approaches differ greatly. The parameters given while implementing these algorithms also have a great impact on the output. This randomness results in sometimes not generating the path. **(Run the main.py file multiple times to get all the paths from all sampling methods.)**

1. **Uniform Sampling:**

When samples are distributed uniformly throughout a map, a grid-like structure is created, as can be seen in the output image. The path determined for the majority of the solution is also along a straight line since the nodes are uniformly spaced and dispersed. This is so because the diagonals of the resulting grid are where the shortest path may be discovered. But as we can observe in the resultant graph, many unnecessary nodes also gets created in the graph which may cause higher computational power.

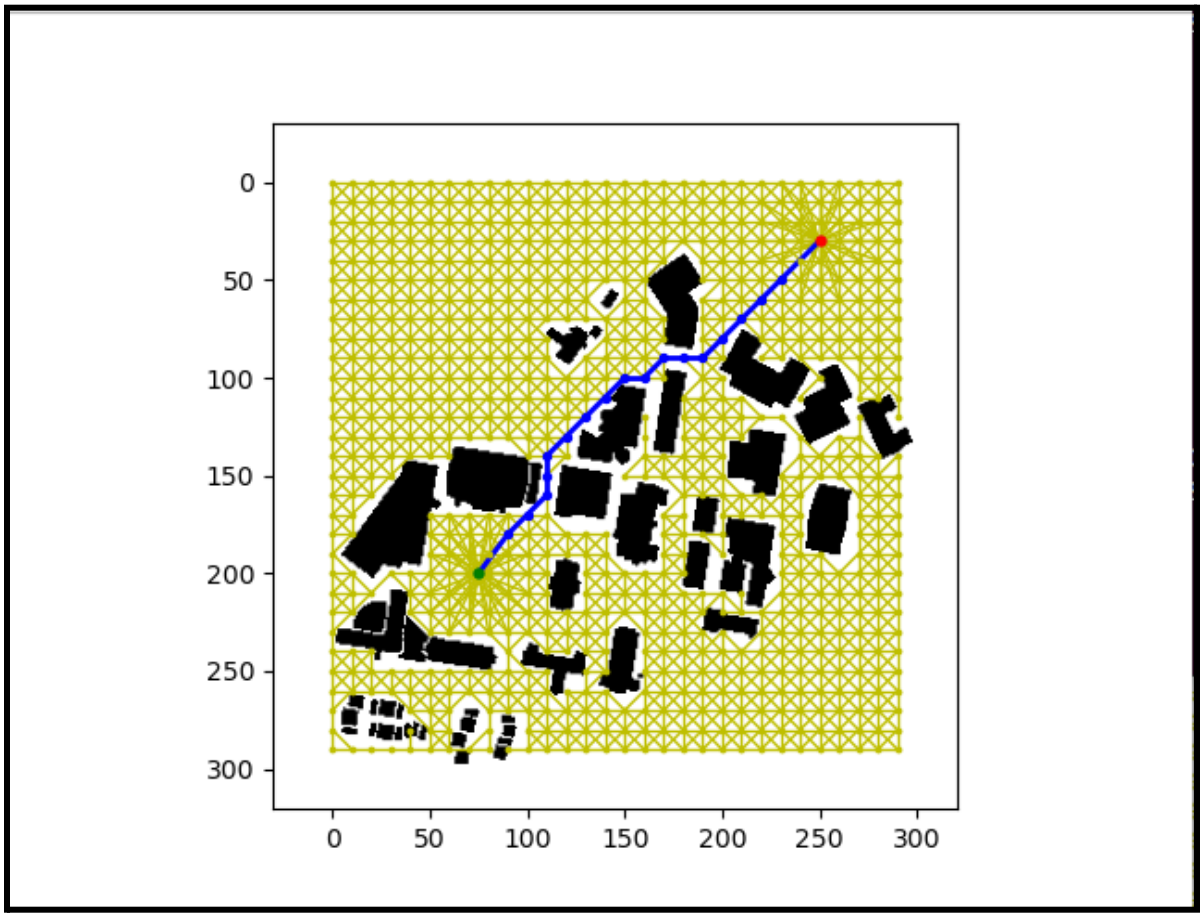

Fig 1: Uniform Sampling

2. **Random Sampling:**

This method involves randomly selecting points in the configuration space of the robot, which are then used to construct the roadmap. Then, the availability of a path between two nodes is checked. The random sample graph is different for each run, as would be anticipated. Therefore, in this sampling method, the shortest path is not guaranteed. We can get any type of path or no path.

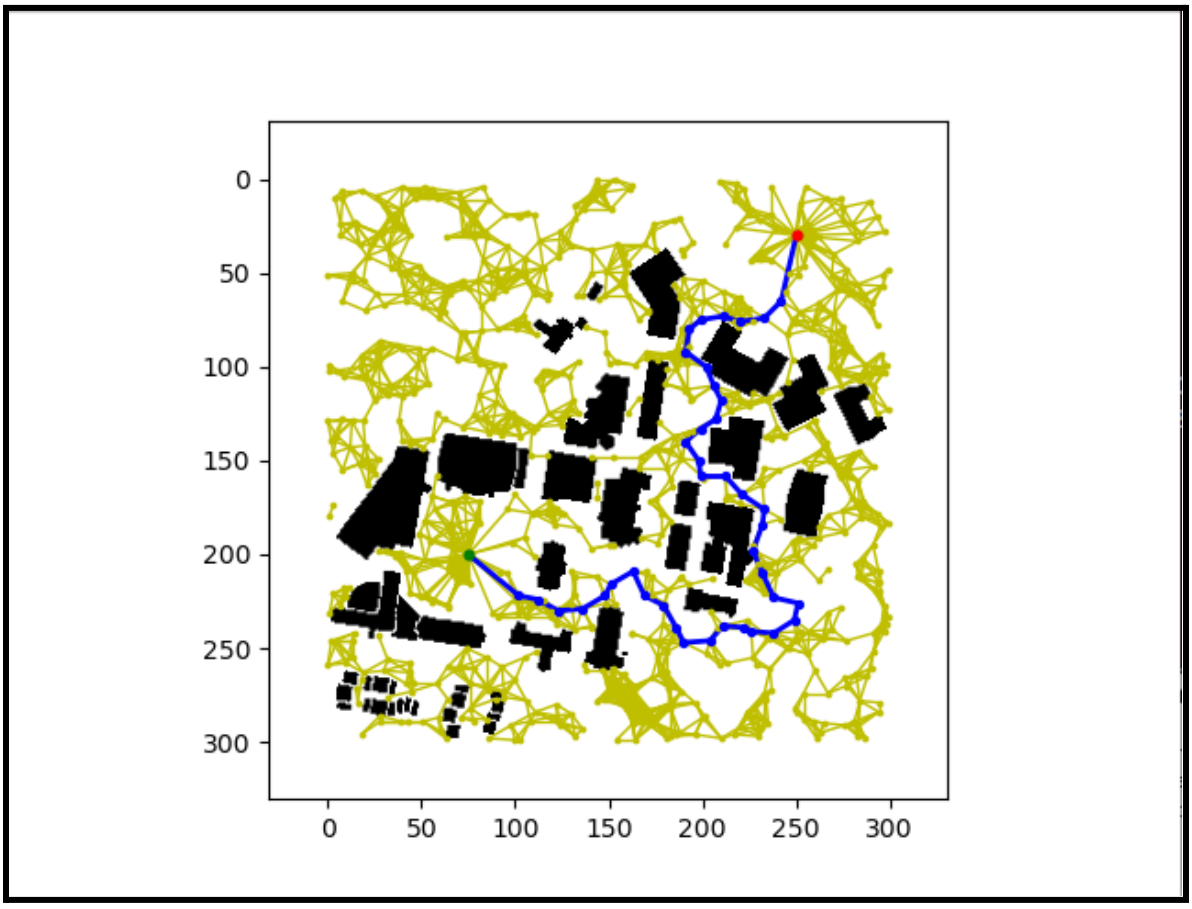

Fig 2: Random Sampling

3. **Gaussian Sampling:**

This method involves sampling points from a Gaussian distribution centered around a set of predefined milestone points. The standard deviation of the Gaussian distribution determines the spread of the samples around the milestone points. Gaussian sampling can produce a more concentrated set of samples around milestone points, which can improve the coverage of the configuration space and the quality of the roadmap. However, the use of Gaussian sampling requires careful tuning of the standard deviation parameter to balance the trade-off between coverage and path quality. We first select q1 point randomly and then select q2 point by using the gaussian normal distribution of q1 point. To sample the points in this, we have one condition that one of the points from these two needs to be on the obstacle and the other should be free. We sample the free one.

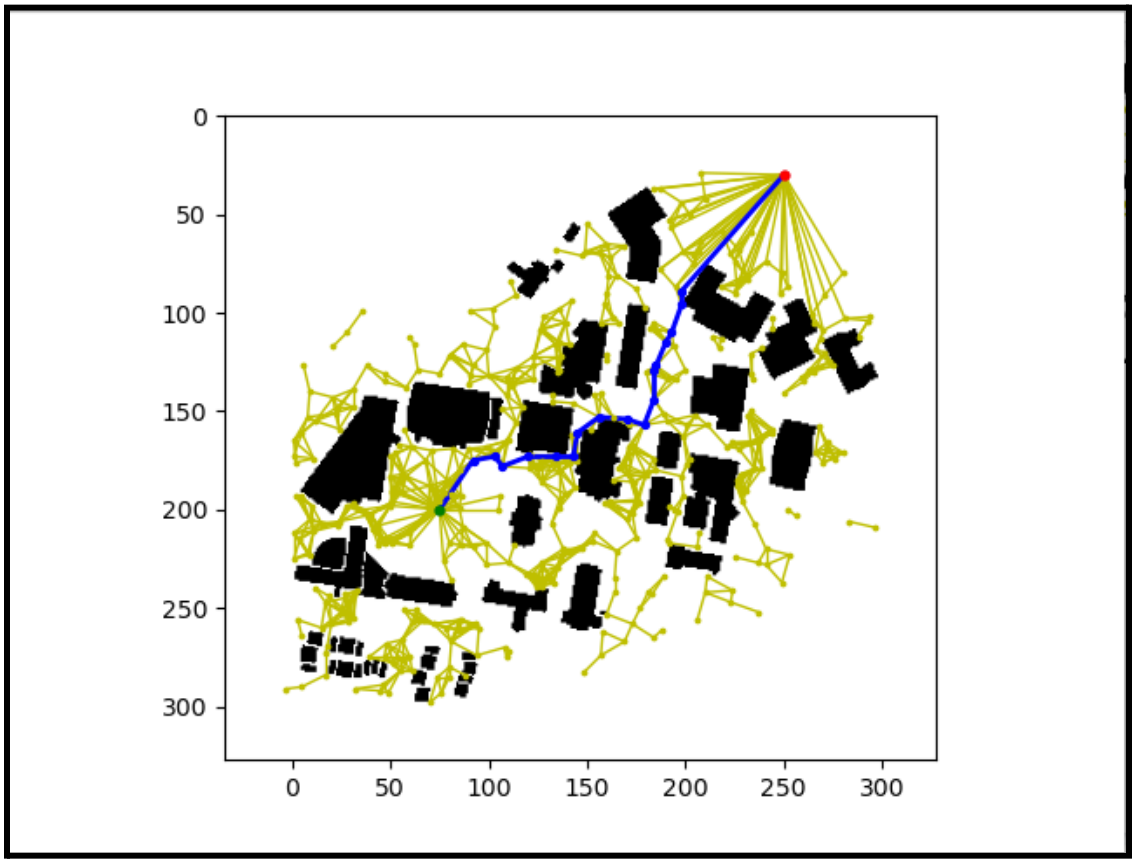

Fig 3: Gaussian Sampling

4. **Bridge Sampling:**
   It involves sampling points in the narrow passages of the environment. In this algorithm, the nodes are placed between two obstacles as a midpoint. Using a probability distribution, a random node is sampled, then a second node is sampled (Gaussian in this case). Then, if a sample is present in the empty space, we drop it in the middle of these and append it to the list. The nodes are situated between these two obstacles, as can be seen. As a result, the goal and start points, which are in open space, must each be linked to an adjacent node independently.

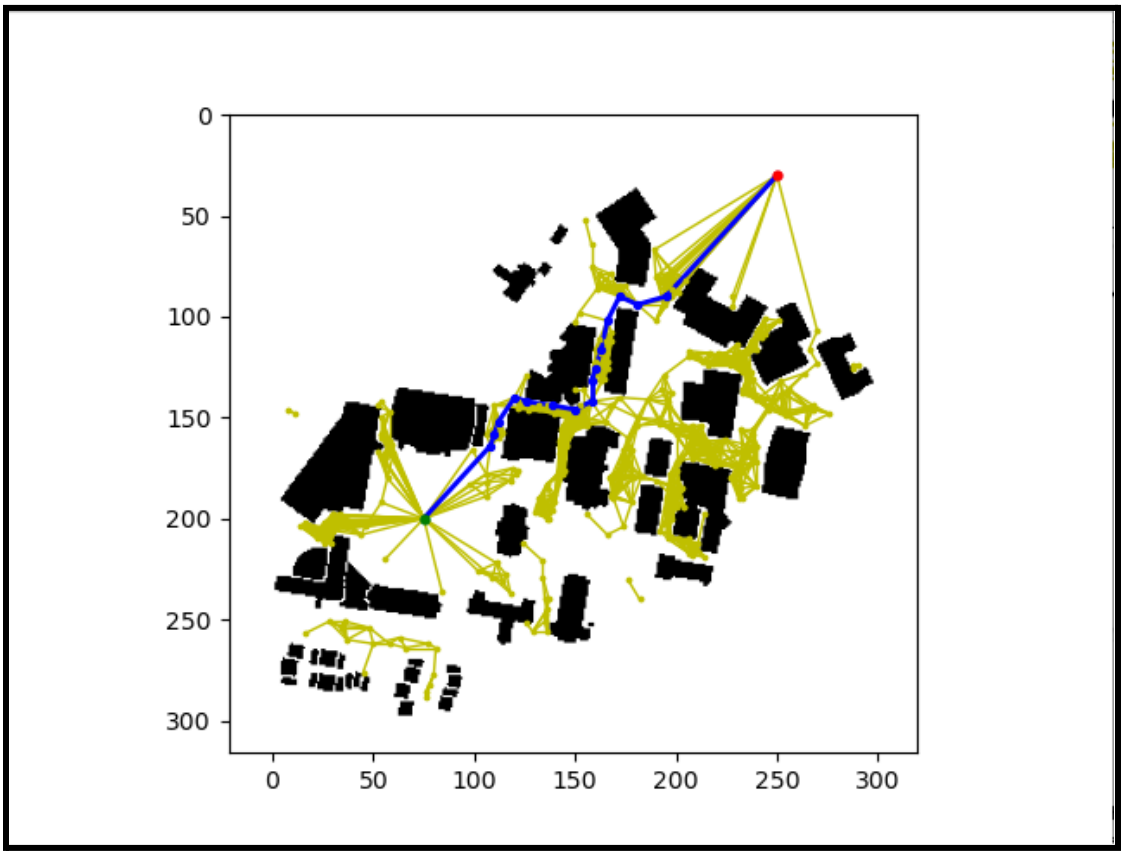

Fig 4: Bridge Sampling

Note: These Results are also stored as .png files in Outputs Folder.

References:

1. https://medium.com/acm-juit/probabilistic-roadmap-prm-for-path-planning-in-robotics-d4f4b69475ea
2. https://www.w3schools.com/python/ref_math_dist.asp
3. https://numpy.org/doc/stable/reference/random/generated/numpy.random.multivariate_normal.html
4. https://numpy.org/doc/stable/reference/random/generated/numpy.random.multivariate_normal.html