Particle Filtering for Localization in a Beacon-Based Environment

INFORMATION PROCESSING IN AUTONOMOUS SYSTEMS

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# Abstract

Particle filtering is a powerful probabilistic method for state estimation in dynamic systems. In this report, we investigate the application of particle filtering for localization of an agent in a beacon-based environment. The agent, equipped with a proximity sensor and an odometer, aims to estimate its location based on known beacon coordinates and limited sensor information. We present a perception algorithm, specifically, an adaptive particle filter, that effectively estimates the agent's whereabouts in the field.

**Table Of Contents**

[Abstract 1](#_Toc141604671)

[Introduction 3](#_Toc141604672)

[Real-World and Simulation Setup 3](#_Toc141604673)

[The Perception Algorithm 3](#_Toc141604674)

[Adaptive Particle Filtering (Optional) 3](#_Toc141604675)

[Simulation and Analysis 3](#_Toc141604676)

[Results 4](#_Toc141604677)

[Effect of Particle Number 4](#_Toc141604678)

[Conclusion 4](#_Toc141604679)

[References 4](#_Toc141604680)

# Introduction

The goal of this study is to design a perception algorithm that enables an agent to estimate its location in a field containing beacons with known coordinates. The agent's perception is limited to a proximity sensor and an odometer, and it lacks knowledge of its true location. We propose to implement a particle filtering algorithm to estimate the agent's state, known as adaptive particle filtering, which adjusts the number of particles based on the effective sample size. The effectiveness of the algorithm is assessed through simulation and analysis.

# Real-World and Simulation Setup

We generate a real-world environment with randomly placed beacons, whose coordinates are drawn from a uniform density over a rectangular region within (0, 0) to (EndX, EndY). The agent's trajectory is generated as a straight line from an initial point A to a final point B. The trajectory passes near at least 50% of the beacons, offering a challenging environment for localization.

# The Perception Algorithm

The agent perceives the world through its proximity sensor and odometer. The proximity sensor provides noisy distance measurements to the nearby beacons within a radius of 2 units from the agent's location. The measurements follow a Gaussian noise model. The odometer gives noisy velocity readings. Based on these sensor inputs, the particle filtering algorithm estimates the agent's state (position) using a set of particles, which are randomly initialized within the real-world.

# Adaptive Particle Filtering (Optional)

The adaptive particle filtering is a modification of the standard particle filtering algorithm. At each time step, the algorithm calculates the Effective Sample Size (ESS) to assess the diversity of particles. If the ESS falls below a threshold, the algorithm resamples particles to increase their number, enhancing the representation of possible states. On the other hand, if the ESS exceeds another threshold, the resampling step is skipped to reduce the number of particles, optimizing computational resources.

# Simulation and Analysis

We evaluate the performance of the adaptive particle filter through single-run simulations and Monte Carlo runs. The single-run simulation visualizes the estimated trajectory against the true trajectory, while plotting the mean squared estimation error over time. The Monte Carlo runs involve repeating the simulation 100 times to observe the variance in the mean squared estimation error.

# Results

The simulation results demonstrate that the adaptive particle filtering algorithm effectively estimates the agent's trajectory. The estimated trajectory follows the true trajectory closely, while the estimated position adapts to the changing environment. The mean squared estimation error over time shows the accuracy of the algorithm, with fluctuations due to random noise.

# Effect of Particle Number

We investigate the effect of the number of particles on the estimation performance by plotting the mean squared estimation error over time for variants of the particle filter with different particle numbers. As expected, increasing the number of particles generally leads to lower estimation error and smoother trajectories (an anomaly was found in 2N particles).

# Conclusion

The adaptive particle filtering algorithm presents a reliable and efficient approach for localization in a beacon-based environment. By dynamically adjusting the number of particles based on the effective sample size, the algorithm optimizes computational resources while maintaining estimation accuracy. The proposed algorithm successfully estimates the agent's state, effectively tracking its trajectory in the challenging field. Future research may explore the integration of additional sensor modalities and real-world implementations to further enhance the algorithm's performance.

In conclusion, the presented adaptive particle filtering algorithm proves to be a robust and practical solution for localization tasks in a beacon-based environment, demonstrating the efficacy of particle filtering in dynamic state estimation problems.

# References

[1] [*Notebook - Information Processing In Autonomous Systems(Dr. Avishai Carmi)*](https://github.com/yarin4444/INFORMATION-PROCESSING-IN-AUTONOMOUS-SYSTEMS/blob/main/Notebook%20-%20Information%20Processing%20In%20Autonomous%20Systems.pdf)

[2] [*Particle Filter and Monte Carlo Localization(Cyrill Stachniss)*](https://www.youtube.com/watch?v=MsYlueVDLI0)

[3] [*MathWorks - Help Center(Particle Filter: Projects)*](https://www.mathworks.com/support/search.html?q=particle%20filter&page=1)