Title
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Adaptive Sampling Using Mobile Robots and a Sensor Network

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Introduction: Scalar Field Estimation

Static sensor nodes and mobile robots

- Advantages of static sensor nodes
  - Longer battery life
  - Higher temporal resolution

- Advantages of mobile robots
  - Higher spatial resolution
  - Ability to change the distribution of the readings

Main idea: Exploit advantages of both

- Static sensors
  - Uniformly deployed across the sensing field
  - Initial estimate generated from the sensor readings

- Mobile robots
  - Additional readings taken in critical locations
  - Estimate refined by using both initial and additional readings

Problem Description: Coordination between static sensor nodes and mobile robots

Problem Statement

- Given
  - A set of static sensor nodes uniformly distributed
  - A set of mobile robots

- Goal
  - Coordinate the motion of the mobile robots so that error associated with the reconstruction of the underlying scalar field is minimized

Assumptions

- Same sensors on mobile robots and static sensors
- Limited energy available to mobile robots
- No change in the scalar field during the data collecting tour
- Local Linear Regression used for estimation
- Centralized processing
- Accurate localization

Proposed Solution: Combining optimal experimental design and path planning

Definition of gain

- The Integrated Mean Square Error (IMSE) associated with Local Linear Regression can be estimated as follows:

\[
\text{IMSE}(X) \propto \int \frac{\tr{H(x)}}{n^2 f^2(x)} \, dx
\]

- \( H(x) \) is the Hessian matrix, \( f(x) \) is the estimated local reading density and \( X = \{x_1, x_2, \ldots, x_n\} \)

- The gain associated with each location \( x \) is defined as the decrease of the IMSE if more sensor readings taken at \( x \)

\[
G(x) = \text{IMSE}(X_0) - \text{IMSE}(X_0 \cup \{x\})
\]

Energy consumption model

- Based on a NAMOS boat
- The boat is assumed to have minimum turning radius
- Energy consumption is proportional to the distance traveled

Path planning for single mobile robot

- Approximate Breadth First Search: Maximizing gain collected with limited initial energy
- K-path: Minimizing the energy consumption while collecting given amount of gain
  - Based on the primal-dual schema
  - Approximation factor 2+\( \delta \) for certain gain

Path planning for multiple mobile robots

- Assumptions: All robots have the same initial energy and share the same energy consumption model
- Generate graph representing state transition for single robot
- Partition graph into sub graphs with equal gain
- Assign one mobile robot to each sub graph and apply the path planning for single mobile robots