Adaptive Sampling in Environmental Robotics

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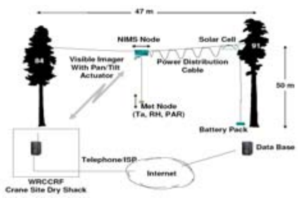
Exploiting Mobility for Environmental Science

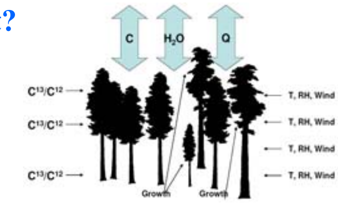
Motivation

- *Networked Infomechanical Systems (NIMS)*
- Enables mobility for application science by
  - Extended visibility using motion
  - Sensing close to the phenomena
  - Interaction of mobile and static sensors
- We need mechanisms
  - Make NIMS an efficient tool for observing phenomena.
  - Enable scientists to create and verify a model of their observations.



Why is it Important?

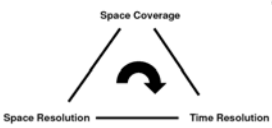
- Environmental Science
- Habitat monitoring
- Example
  - Aging in forests
  - CO_2 Respiration
  - Global warming at microclimate level
  - Comparison of different forests (ex. Oxygen generation)

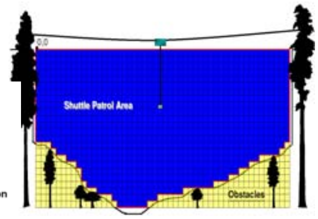


Creating Dynamic Map of the Environment based on some sensing attribute

Goal

- There are constraints associated with locomotion and sampling.
- Maximize information about underlying phenomena within constraints of the system.
- Optimize the trade-off of Spatial resolution, temporal resolution and spatial coverage.
- Create a Map of the phenomena



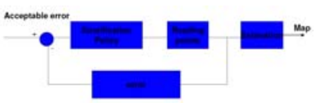


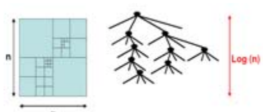
Sampling Policy

- Robot as a *Geostatistical* Agent
- Sampling has a cost
  - Time , Energy
- Limited sampling budget
  - Limited time to follow a dynamic phenomena
  - Limited energy
- Divide the environment into pixels.
  - Sample pixels to create a map (image) of the phenomena
- Sampling techniques
  - Uniform, random, stratified and nested stratified

Experimental Deployment and Initial simulation results

Spatial Error and Adaptive Sampling

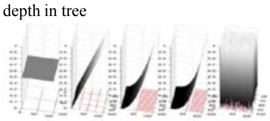


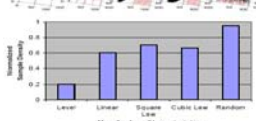


•Step-size randomly proportional to depth in tree

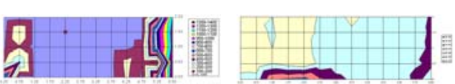
Divide and Conquer

- Stratify the current cell into four
- μ = α * cell size   (μ is mean of step size)
- Collect data in current cells (Gaussian)
- Calculate the variance
- Iterate until variance is below threshold





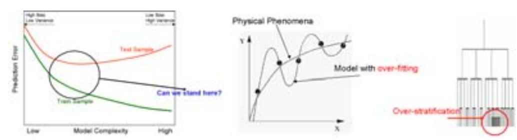
Experimental Deployment



- At left is the map of Photosynthetic Active Radiation (PAR) and at right is the map of Relative Humidity at Boelter Hall, UCLA.

- Experimental Deployment at Wind River Canopy Crane Research Facility at Washington State. Compare the deployment scale with the canopy crane which is 87m tall in this panoramic view.

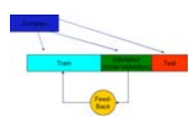
Bayesian Information Criterion



Adding model complexity may lead to over-fitting or over-stratification

A Regulatory Scheme

- Enabled by a cross validation
- **Information Criterion** techniques
  - Relying on **in-sample** data
  - Penalty for complexity



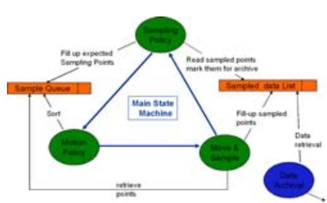
$$BIC(I) = \frac{n}{2}Log(RSS) + \frac{K_I}{2}Log(n)$$

credit for how good it fit   **penalizing increasing model dimension**

$$BIC_{parent} = \frac{n_{samples}}{2}Log(\hat{\delta}^2) + \frac{1}{2}Log(n_{samples})$$

$$BIC_{child} = \frac{n_{samples}}{2}Log(\hat{\delta}^2_{00} + \hat{\delta}^2_{01} + \hat{\delta}^2_{10} + \hat{\delta}^2_{11}) + \frac{4}{2}Log(n_{samples})$$

Implementation



Future Work

- Optimization of mutual uncertainty of time & Space
- Incorporation of measurement costs.
- Development of continuous map models replacing piecewise continuous models.
- Multi-robot mapping
- Multi-variable mapping
- Mobile and static sensor collaboration
- Application of path planning methods to reduce frame time and minimize spatiotemporal error.
- Mapping in full three dimensional space