Title
ACT6: Strategies for Sampling the Environment

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Strategies for Sampling the Environment

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Explore different sampling strategies for achieving high fidelity with limited resources

Motivation

- Fundamental challenges
  - Phenomena show high rate of spatiotemporal variation
  - High fidelity reconstruction is required
  - Extensive resource allocation is expensive
- Solution
  - Probe capability of diverse sensing resources
  - Examine features in the environment
  - Adapt by exploiting actuated sensing nodes

Primary Strategies

- **Multiscale sampling**
  - Applied when *diverse sensing resources* are available
  - Examples
    - Solar radiation: Resources include fixed sensor and actuated imager
    - Environmental temperature: Resources include fixed and actuated temperature sensors and infrared imager
- **Adaptive sampling**
  - Applied when only *one type of sensing resource* is available
  - Examples:
    - CO_2 Flux
    - Water contamination

Strategy design

- **Multiscale sampling**
  - Sparse multiscale/multimode sensing can yield accuracy equivalent to exhaustive sampling
  - Advantages and disadvantages of each mode:
    - Image sensor offers high speed, but, low accuracy
    - Fixed or actuated PAR (intensity) sensor offers high accuracy, low speed
  - Strategy based on field variable model
  - One multiscale sampling level directs another level based on model results

- **Space-Filling Design**
  - Optimize filling of sample points
  - Sample points with maximum distance
  - Bounded convergence on expected value
  - Modulate density by sampling cost
  - Cost includes
    - Sampling cost (time)
    - Navigation cost

$$\frac{Condition(x \mid S)}{T_M + d(x_0, x)/v}$$

- **Adaptive Design**
  - Track most "interesting" features
  - Adaptivity requires bootstrap information
  - Balance competition between feature tracking and space filling
  - Gradual relaxation

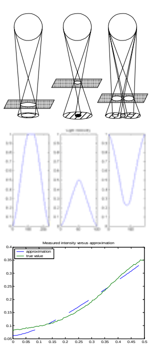
$$\frac{Condition(x \mid S) + \lambda \times Features(x \mid S)}{T_M + d(x_0, x)/v}$$

$$\lambda(i) = \lambda_\infty \times (1 - e^{-(i/\tau)})$$

Experimental Results

Multiscale Field Partitioning

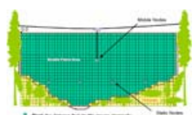
- Inhomogeneous variable field
- May be partitioned into homogeneous subarea classifications: bright, dark, and penumbra



- Bright and dark areas are approximately uniform
- Penumbra effect
  - Due to extended light source
  - Light intensity changes continuously
  - Intensity distribution can be approximated by linear function

- **Calibration**
  - Outliers in image due to varying reflectivity
  - Transformation between PAR sensor coordinate system and image coordinate system
- **Collaboration between nodes**
  - Camera image provides global information
  - In-situ static PAR sensor detects local intensity
  - Mobile PAR sensor complements static sensor
  - Image sensing tasks mobile sensor to obtain new measurement

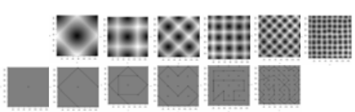
Space Filling Design



- Digitize the environment
  - Limit computation cost
  - Occupancy map overlay for complex shapes
- Algorithm:
  - Ω Sample Space
  - S sampled point
    - Static, mobile sensor
  - x is robot position and d(x,y) is distance to a candidate sample point in Ω
  - Select each sample point such that this criteria is maximum:

$$Condition\ (x \mid S) = \min_{y \in \Omega} d(x, y)$$

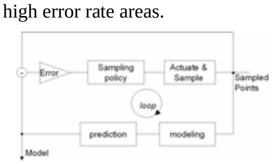
- **Voronoi Tessellation**
  - Maximum distance
  - Continuously refinable
  - Regular convergence of estimation error



- **Effect of sensor delay**
  - From continuous design to a disconnected design

Adaptive Design

- Track features
- In the case of light, error dominated by bias or curvatures
- Find model error, compensate model error by increased sample density in high error rate areas.



- **Field Reconstruction**
  - More points alongside edges
  - Silhouette is the location of the maximum error