CS649
Sensor Networks
Lecture IP-11: Sensor Control and Tasking

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Sensor Control and Tasking

- Dynamically control or task sensors with multiple modes or search patterns to optimize overall performance
  - Application driven performance metrics such as detection probability, probability of false alarm, track quality, or more general utility functions
  - Energy consumption and lifetime of the network
  - Covertness in military applications
- Specific Sensor Control Actions
  - Simple on-off control to preserve energy
  - Local signal processing algorithms
  - Schedule and configure sensing actions
    - “Ping” scheduling for active sensors (active sonar, radar, etc.)
    - Pan-Tilt-Zoom control of cameras
- Sensor-Actuator Networks

Basic Approaches in Sensor Control and Tasking

- Distributed, Hierarchical, Centralized
- Task-Driven versus Information Driven
- Reactive versus Predictive
- On-line versus Off-line

Intelligent Light Control using Sensor Networks

V. Singhvi, A. Krause, C. Guestrin, J.H. Garrett Jr., and H.S. Matthews

SenSys 2005

Summary

Intelligent light control using a network of sensors (light sensors collocated with building occupants) and actuators (lamps with multiple settings):

- Coordinate illumination to optimize the trade-off between user preferences and energy efficiency
- Exploit external light sources by daylight harvesting
- Schedule sensing to preserve energy while providing necessary measurements for actuator control
- Address user mobility
- Evaluation with realistic experiments

Coordinated Illumination

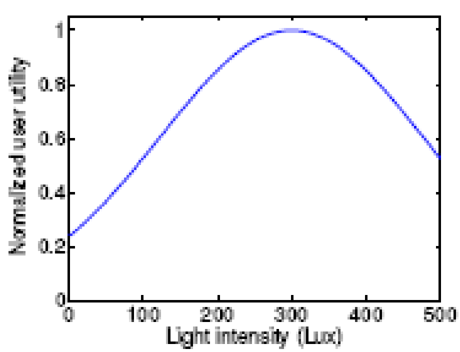
- Select the actions (a vector of lamp settings) to optimize a weighted combination of user utility and operator utility (energy)
- Exploit the locality/zoning to address the combinatorial issue with brute force search

$$U(\mathbf{a}, \mathbf{x}) = \sum_{i=1}^{n} \Phi_i(\mathbf{a}, x_i) + \gamma \Psi(\mathbf{a}),$$

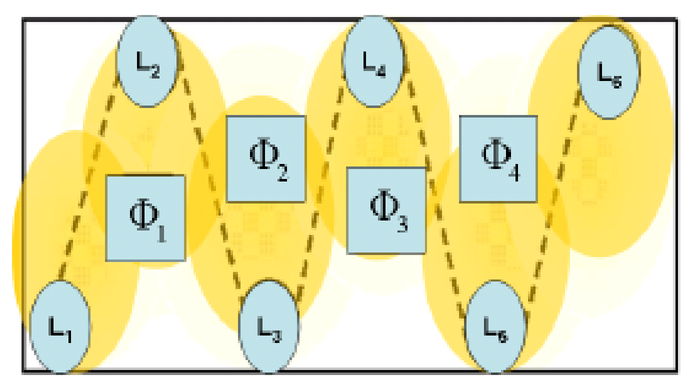
$$\mathbf{a}^* = \operatorname*{argmax}_{\mathbf{a}} U(\mathbf{a}, \mathbf{x}).$$

$$\mathbf{a}^*(\mathbf{x}) = \operatorname*{argmax}_{\mathbf{a}} \sum_{i=1}^{n} \Phi_{i,\mathbf{x}}(a_{i_1}, \ldots, a_{i_k}) + \gamma \sum_{j=1}^{m} \Psi_j(a_j)$$

Factorization due to locality



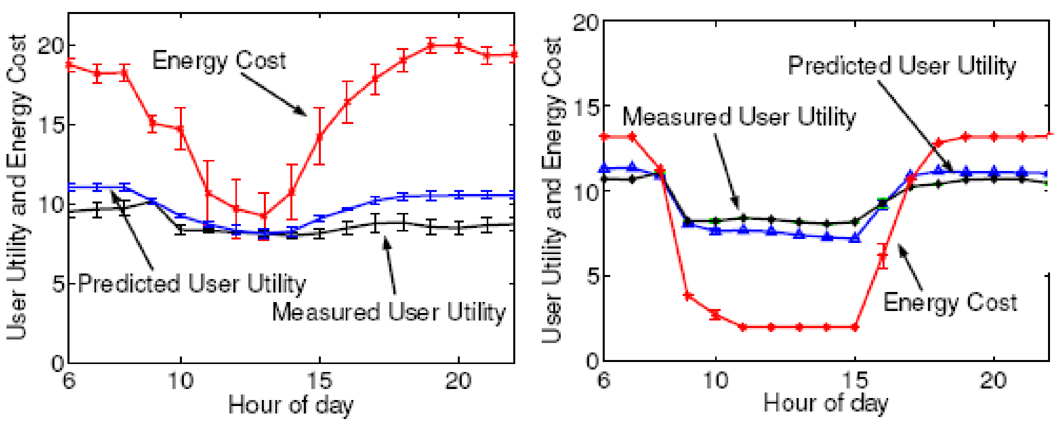
(a) *Utility function*



(b) *Zoning scheme*

Adaptive, Closed-Loop Control

- Adapting lamp settings to changing weather conditions and time of the day through feedback with sensor measurements
- Estimate the sunlight intensity by subtracting the intensity contributed by lamps (calibrated) from the measured intensity



(a) $(\gamma = 0.01)$ (b) $(\gamma = 0.4)$

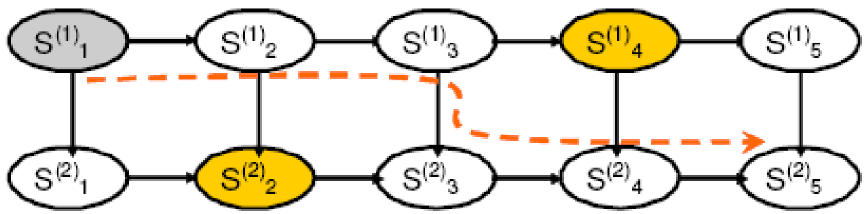
$$\mathbf{a}^*(t, \mathbf{x}) = \underset{\mathbf{a}}{\operatorname{argmax}}\, U(\mathbf{a}, t, \mathbf{x}),$$

$$U(\mathbf{a}, t, \mathbf{x}) = \sum_{i=1}^{n} \Phi_{i,\mathbf{x}_i}(\mathbf{a}, \Theta(t, x_i)) + \gamma \sum_{j=1}^{m} \Psi_j(a_j).$$

sunlight intensity

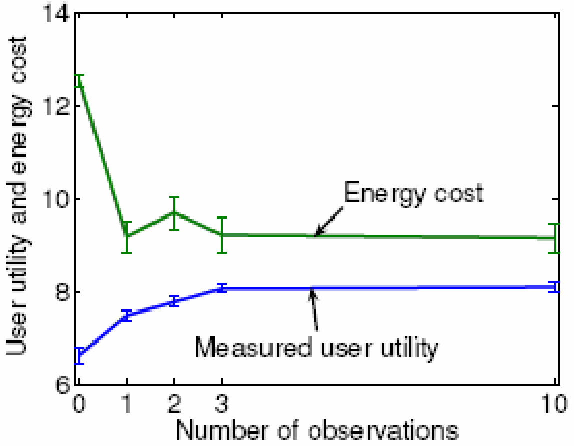
Active Sensing

- Schedule sensor measurements (only a subset at each time) to preserve energy while providing sufficient information for control (with a given budget)
- Select the sensors based on maximum expected utility
- Approximate the intractable dynamic programming problem by limiting the dependency of decisions on the most recent measurements



$$O^* = \operatorname*{argmax}_O \mathcal{J}(O),$$

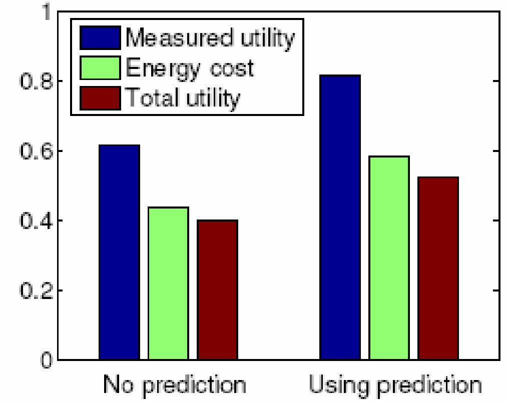
$$\mathcal{J}(O) = \sum_{\mathbf{o}} P(O = \mathbf{o}) \left(\sum_{t \in T} \max_{\mathbf{a}} EU(\mathbf{a}, t, \mathbf{x} \mid O^{(1:t)} = \mathbf{o}^{(1:t)}) \right)$$

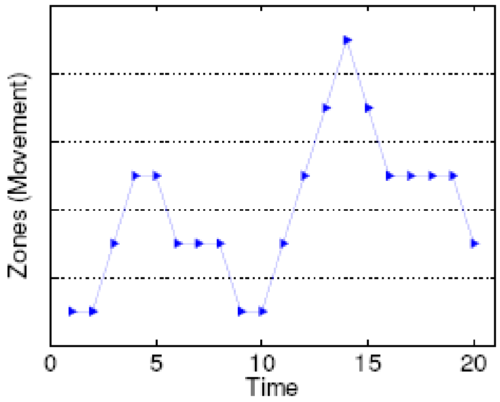


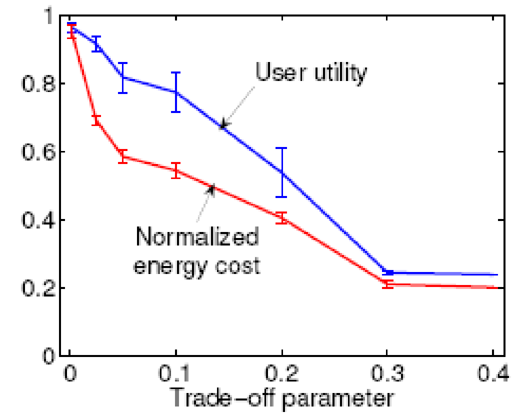
Predictive Light Control to Address User Mobility

- Assume probabilistic and independent models for occupants' movements
- Use predicted occupant location distribution in calculation of expected utility

$$EU(\mathbf{a}, t, \mathbf{x}^{(t)}, \mathbf{x}^{(t-1)}) = \gamma \sum_{j=1}^{m} \Psi_j(a_j) +$$
$$\sum_{i=1}^{n} \sum_{x} P(x_i^{(t+1)} = x_i) \mathbb{E}[\Phi_{i,x_i}(\mathbf{a}, \Theta(x_i, t))].$$







Discussions

- Utility-based approach provides a general framework for tasking and control in sensor actuator networks
- Proper choices of utility to reflect users' preferences (potentially dynamic and probabilistic) can be challenging
- Appropriate trade-off among multiple objectives (multiple tasks, energy etc.) difficult to model (how to pick the right γ)
- Stability issue with adaptive control strategies
- Distributed implementation robust to link/sensor failures necessary for large-scale deployments

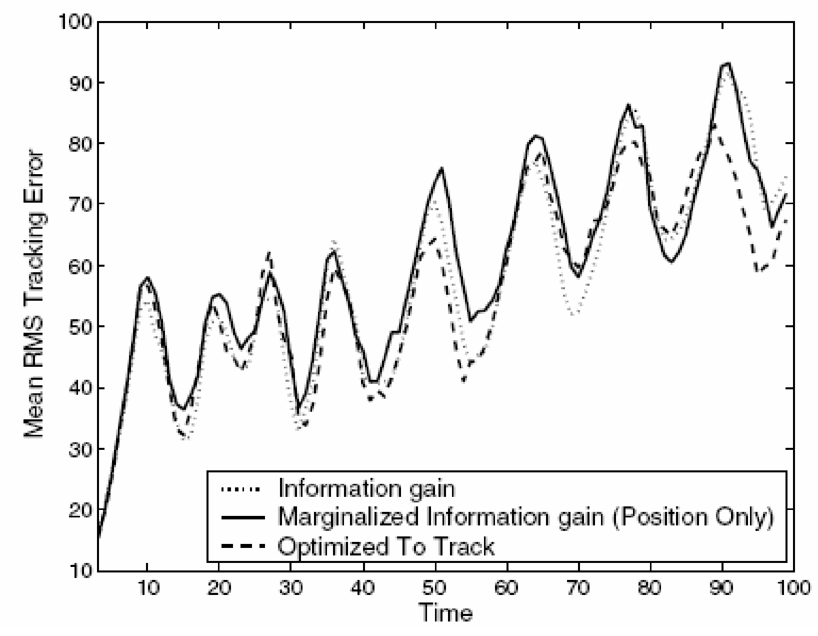
Task Driven versus Information Driven Sensor Management*

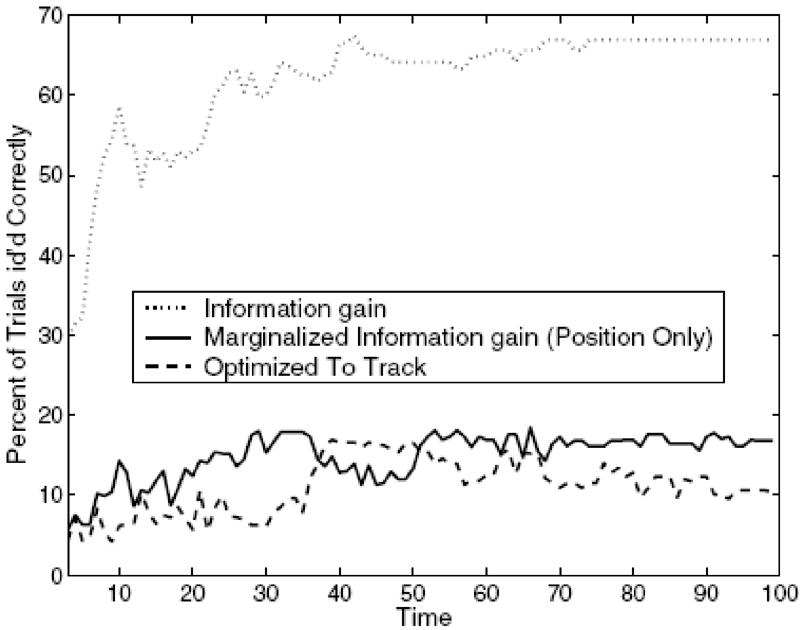
- Task-Driven Approach: Control sensing to optimize performance directly derived from the task
  - Typically involves multiple objectives
  - Often lead to a global combinatorial optimization problem
  - Performance metrics are defined over a horizon
- Information Driven Approach: Make sensing decisions based on expected information gain
  - Information gain is estimated by information theoretic measures for each feasible action (Rényi divergence, KL divergence)
  - For tacking problem with sensors preserving locality, the approach leads to more tractable local optimization

*C. Kreucher, A. Hero, and K. Kastella, "A Comparison of Task Driven and Information Driven Sensor Management for Target Tracking," *IEEE CDC,* 2005.

Comparisons for Tracking Tasks

- Task-driven approach is expected to perform better with a single performance criterion
- Theoretically, information driven approach is nearly optimal when
  - performance metric is weakly dependent on the state; and
  - the incremental information gain from each measurement is small





Tasking for Camera Sensor Networks

- Effective sensor tasking is crucial due to the significant costs of communications and computations associated with camera nodes
- *Locality* assumption often fails to hold: lead to global combinatorial optimization problems
- D. B. Yang, J. Shin, A.O. Ercan, and L.J. Guibas, "Sensor Tasking for Occupancy Reasoning in a Network of Cameras," *BASENETS 2004*.