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Report Documentation Page

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Dynamic Sensor Coverage

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Outline



- Introduction, motivation and applications
- Related previous work
- Problem description
- Results for the single sensor case
- Conclusions and future work

Introduction

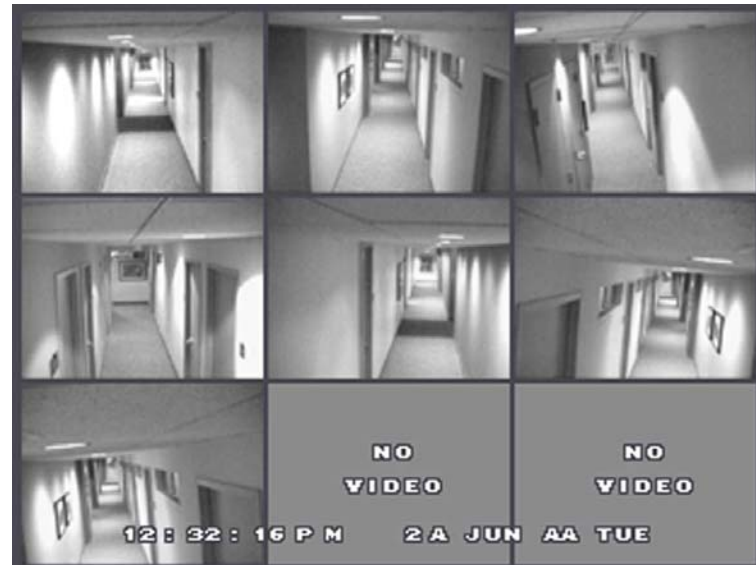


- **Given:**
 - A region with multiple points of interest
 - A “FEW” “limited range” “mobile” sensors
- **Task:** Maintain an appreciable estimate of uncertain parameters at each point in the region

Motivation/Applications



Weather monitoring
Parameters : Temperature,
Pressure, Humidity, Wind
speed/direction.



Surveillance
Parameters : Motion

Past Work



- Static coverage techniques based on Voronoi partitions. (Cortes et. al.) ITAC 2004
- Dynamic sensor coverage experiments. (Batalin, Sukhatme). SPIE '02
- Kalman filtering with intermittent observations. (Sinopoli et. al.) CDC'03
- Markov chains for search and surveillance. (Jeffcoat, Stone).
- Stochastic sensor selection algorithms (Gupta, Chung et. al.) Submitted Automatica Sept'04

Problem Description

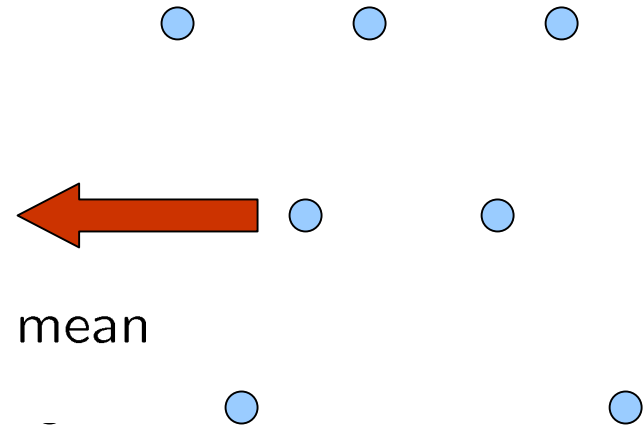


N discrete time systems

$$x_{i,t+1} = A_i x_{i,t} + w_{i,t}$$

$$y_{i,t} = C_i x_{i,t} + v_{i,t}$$

w_i, v_i : Gaussian random vectors, zero mean and covariance matrices Q_i and R_i .



Assumptions

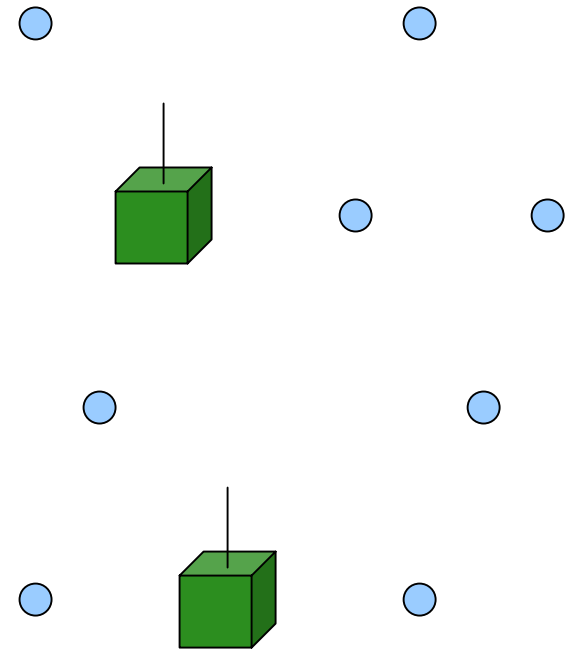
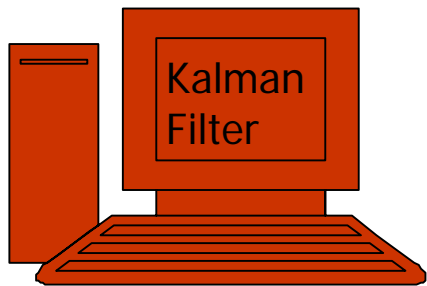
- Systems are decoupled
- Noise processes are independent at different locations

Problem Description



Limited range: A sensor has access to the measurement of system i , if and only if it is currently at system i

Algorithm: Sensors send their measurements to a base station which employs a Kalman filter to estimate the states of all N systems



Sensor at system i → Execute both time and measurement updates.
No sensor at system i → Execute only time update .

Problem Statement



Defn.: We say that the dynamic sensor coverage problem has been **successfully solved** if for any probability distribution of the sensors $\bar{\pi}$ the N limits

$$\lim_{t \rightarrow \infty} E[P_{i,t}], \quad i \in \{1, 2, \dots, N\}$$

are finite for any set of initial conditions $P_{i,0} \geq 0$.

If there exists an $i \in \{1, 2, \dots, N\}$ such that $\lim_{t \rightarrow \infty} E[P_{i,t}]$ is unbounded for some $P_{i,0} \geq 0$, then the sensors have failed to solve the dynamic coverage problem.

Single sensor case



N discrete time systems

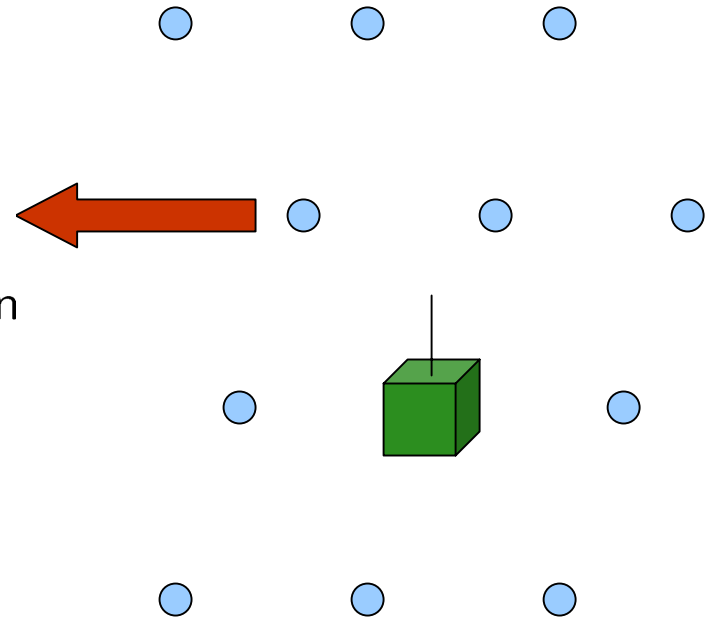
$$x_{i,t+1} = A_i x_{i,t} + w_{i,t}$$

$$y_{i,t} = C_i x_{i,t} + v_{i,t}$$

w_i, v_i : Gaussian random vectors, zero mean and covariance matrices Q_i and R_i .

Assumptions

- The systems are decoupled.
- The noise processes are independent at different locations.



Failure result



Let $(A_i, Q_i^{\frac{1}{2}})$ be controllable, (A_i, C_i) be detectable and A_i be unstable for all i .

$$\sum_{i=1}^N \frac{1}{\alpha_i^2} < N - 1, \quad (1)$$

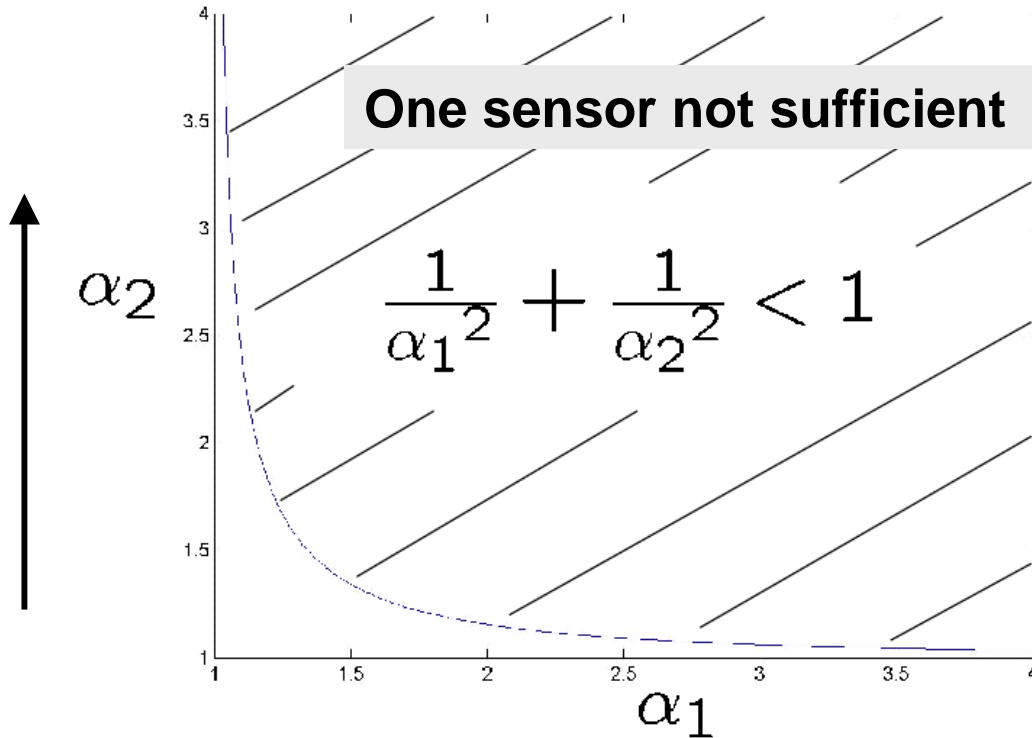
where $\alpha_i = \max_j |\lambda_{i,j}|$, and $\lambda_{i,j}$ are the eigenvalues of A_i , then a single sensor fails to solve the dynamic coverage problem under any random algorithm.

Results for a single sensor



$N = 2$

System
Dynamics



<http://www.cds.caltech.edu/~atiwari/>

Conclusions



- **What's new?** : A framework for the Dynamic Coverage problem
- **Insightful** : Results are intuitive and provide deeper insight
- **Experiments** : Infrastructure exists
- **Scalability** : The approach can be easily extended to multiple sensors and systems (Dependent case under investigation)

Future Work



- Stability region in the coupled environment case.
- Synthesis of the transition probability matrix for the Markov case.
- Multiple sensor case.
- Convergence to static coverage results as the number of sensors increases.
- Experiments. (Multi Vehicle Wireless Testbed).