A Manifold Regularization Approach to Calibration Reduction for Sensor-Network Based Tracking

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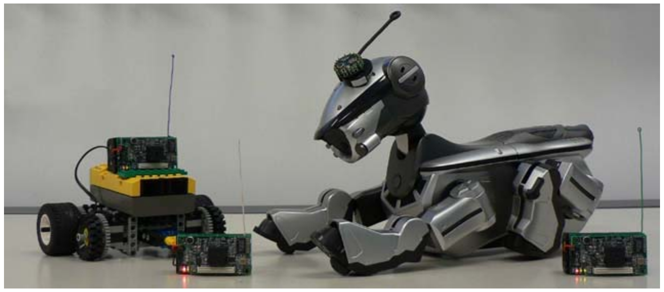
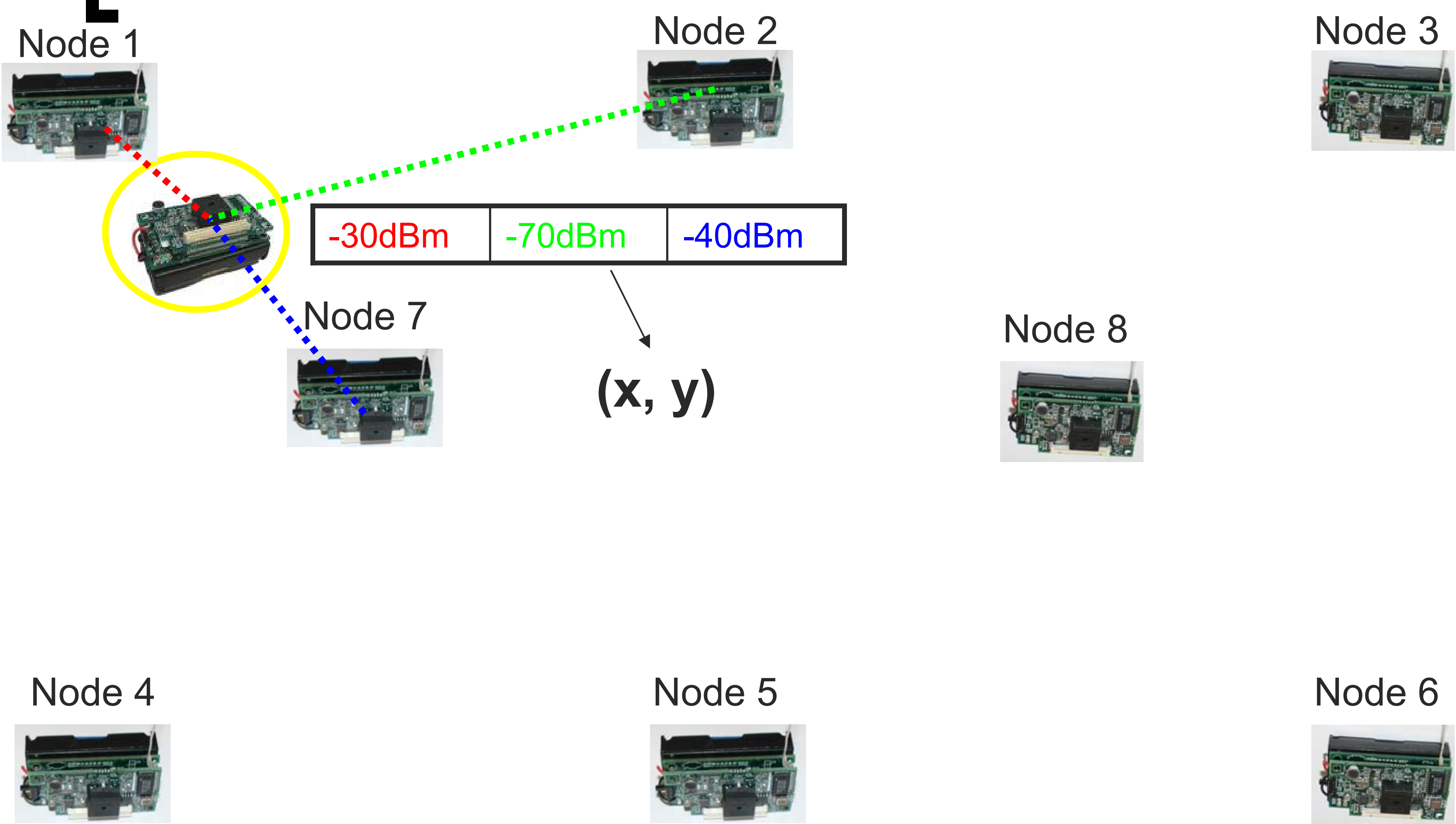


Signal-Strength-Based Tracking



Application Scenario

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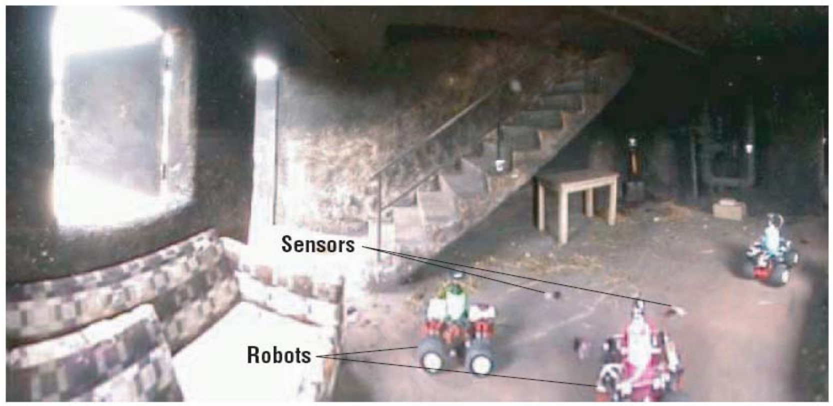
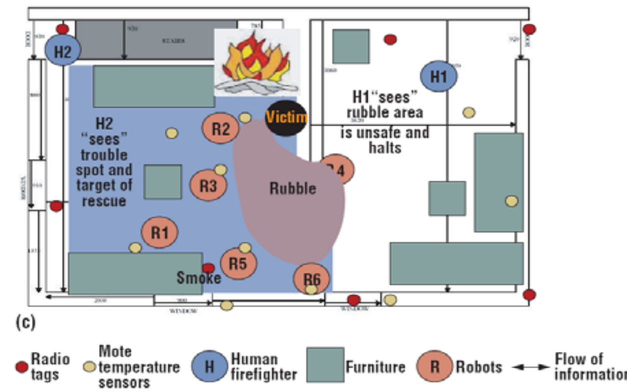
- Robots and Sensor Networks Collaboration

▪Source of Photo
V. Kumar, D. Rus and S. Singh, Robot and Sensor Networks for First Responders. IEEE Pervasive Computing, 2004

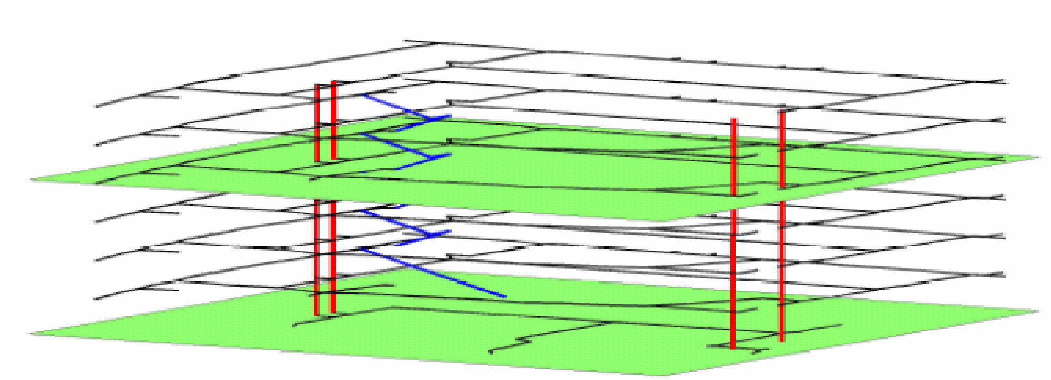




- Indoor Location Guidance

▪Source of Photo
J. Letchner, D. Fox and A. LaMarca. Large - Scale Localization from Wireless Signal Strength. AAAI2005

Photo www.bucu.ac.uk



Calibration – Labeling Data

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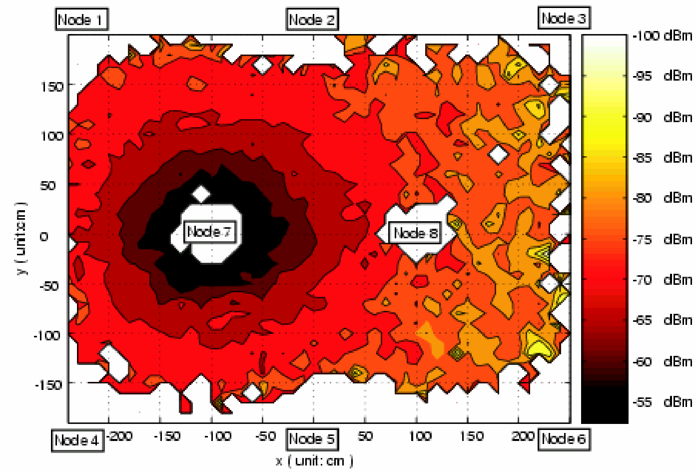
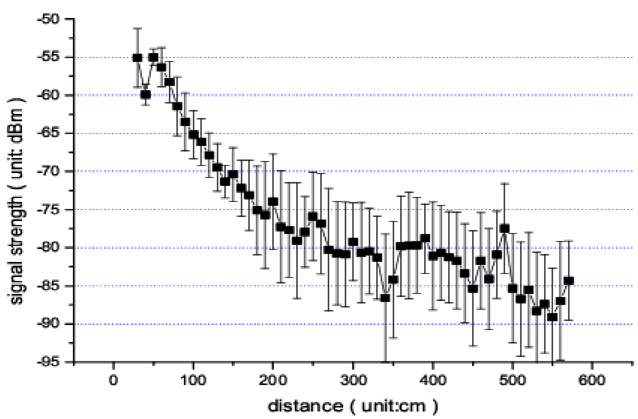
- Calibration
  - Special Devices
    - GPS, Laser, Ultrasonic
    - Expensive, not Ubiquitous
  - Manually Labeling
    - Carry a device and mark down location
    - Time Consuming
- Our focus
  - Use cheap and ubiquitous Radio-Signal-Strength
  - Reduce calibration effort / Reasonable Accuracy

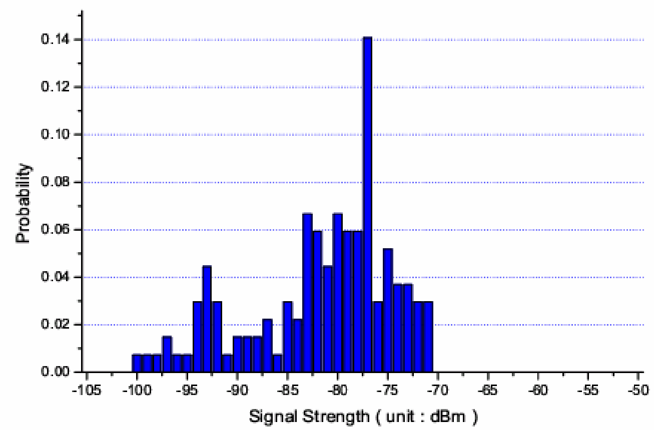
Radio Signal Characteristics



Signal distribution of *beacon* node 7



Signal attenuation along with distance



Signal Distribution at a fixed location

Learning-based Location Estimation

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- Two phases: offline Training and online Localization
- **Offline phase** – collect samples to build a mapping function F from signal space S to location space L

Loc.	Time	(N1, N2, N3)
(1,0)	1s	(-60,-50,-40) dBm
(2,0)	2s	(-62,-48,-35) dBm
…..	….	(… , … , …)dBm
(9,5)	9s	(-50,-35,-42) dBm

Training… → Mapping function F

- **Online phase** – given a new signal s , estimate the most likely location l from F
  - s = (-60,-49,-36)dBm , compute F(s) as the estimated location

Roadmap

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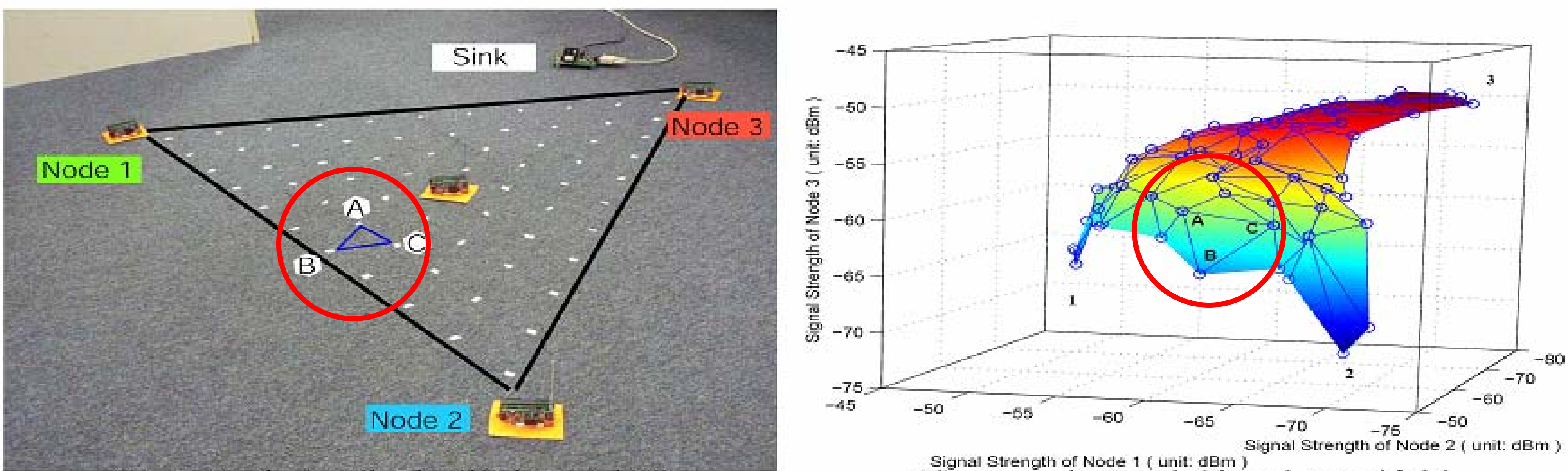
- Radio-Signal-Strength-based Tracking
  - Application Scenario
  - Tracking Problem
  - Radio Characteristics
- *LeMan* Algorithm
  - Basic Idea
  - The Algorithm
- Experiments
  - Experimental Setup
  - Experimental Result
- Conclusion and Future Works

Basic Idea-Neighborhood Preserving

- Labeled data is expensive to get
  - (-60dBm,-50dBm,-70dBm) => (x,y)
- Unlabeled data is easy to obtain
  - (-60dBm,-50dBm,-70dBm)

Could we use a small amount of Labeled data + a bunch of Unlabeled data ?

Basic Idea-Neighborhood Preserving



(c) Experimental Physical Test-bed (d) Experimental Signal Manifold

Two Kinds of Neighborhoods

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Neighbored Data Over Signal Space

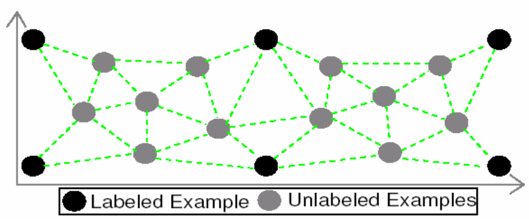
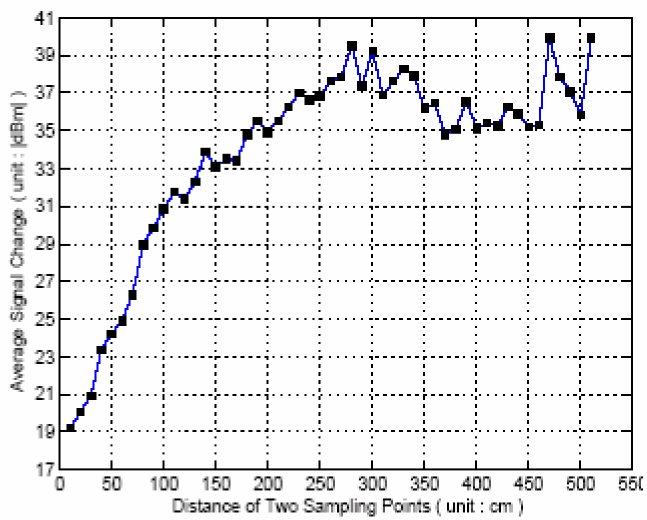
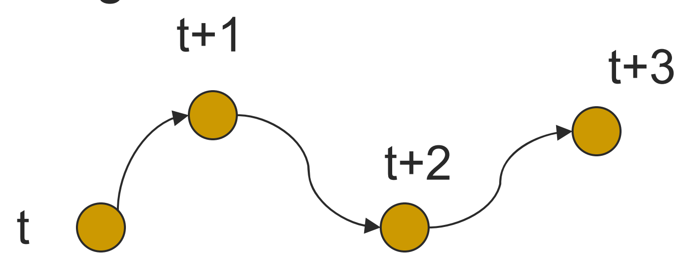


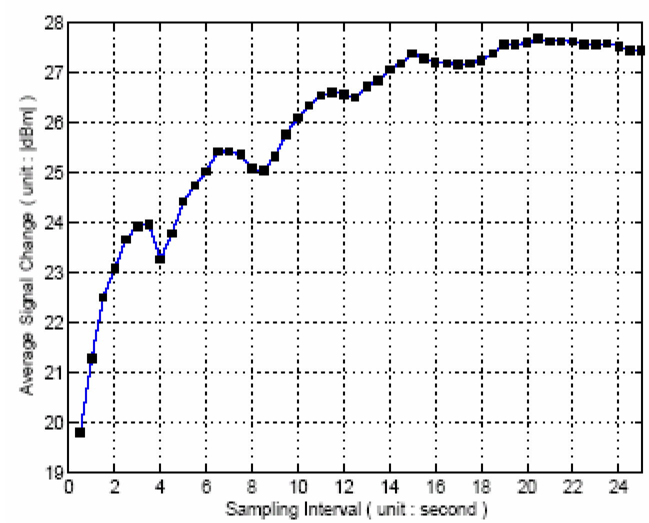
Figure 1: The use of labeled and unlabel examples



(b) Signal change over space

Neighbored Data Over Time





(c) Signal change over time

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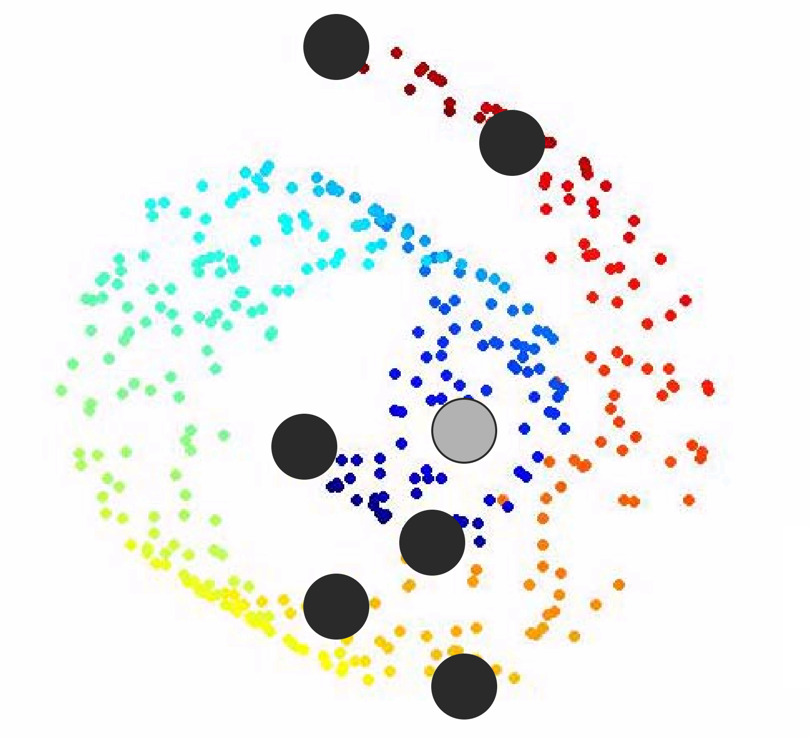
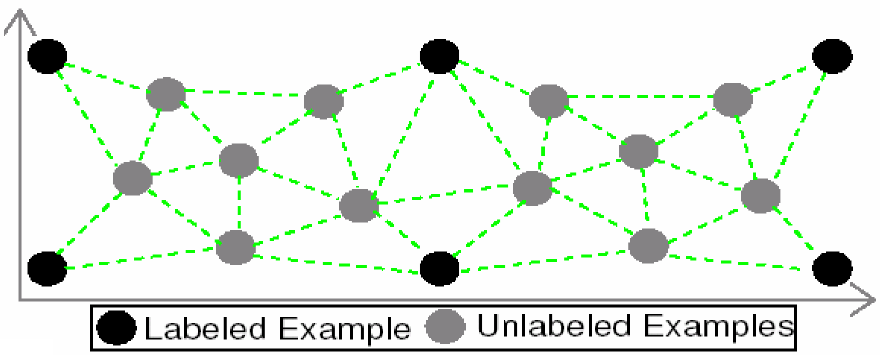
Manifold Regularization





The use of labeled and unlabel examples

- Belkin, M.; and Niyogi, P; and Sindhwani, V. On manifold regularization. AISTAT ' 2005

Manifold Regularization (Cont')

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- Basic Assumption
  - If two points are close in the intrinsic geometry (manifold) of the marginal distribution, their conditional distributions are similar
    - Classification – Similar Labels
    - Regression – Similar Values
- Infer the unlabeled data by
  - Taking a look at the neighbor points

Manifold Regularization (Cont')

- The Objective is to Optimize,

$$f^* = \arg\min_{f \in \mathcal{H}_K} \frac{1}{l} \sum_{i=1}^{l} V(r_i, z_i, f) + \gamma_A \|f\|_K^2 + \frac{\gamma_I}{(u+l)^2} \hat{f}^T L \hat{f},$$

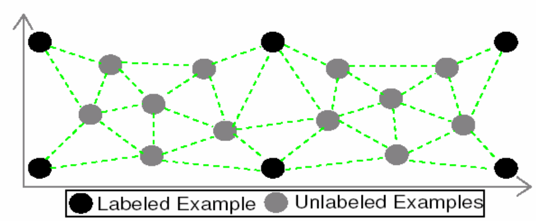
Fitting Error (labeled data)	Function Complexity in Ambient Space	Function Complexity along Manifold (un/labeled)
Squared Fitting Error	**Squared Function Norm**	**L is the graph Laplacian**
$V(r_i, z_i, f) = (z_i - f(r_i))^2$	$\|f\|^2 = \alpha' K \alpha$	

Figure 1: The use of labeled and unlabel examples

Manifold Regularization (Cont')

- The Objective is to Optimize,

$$f^* = \arg\min_{f \in \mathcal{H}_K} \frac{1}{l} \sum_{i=1}^{l} V(r_i, z_i, f) + \gamma_A \|f\|_K^2 + \frac{\gamma_I}{(u+l)^2} \hat{f}^T L \hat{f},$$

- By Representer Theorem,

$$f^*(r) = \sum_{i=1}^{l+u} \alpha_i K(r_i, r).$$

- The Optimal solution is give by

$$\alpha^* = (JK + \gamma_A l I + \frac{\gamma_I l}{(u+l)^2} LK)^{-1} Z,$$

The *LeMan* Algorithm

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- Offline Training Phase
  - Collect l labeled and u unlabeled signal examples
  - Construct graph Laplacian L Kernel Matrix K
  - Solving for α

$$\alpha^* = (JK + \gamma_A l I + \frac{\gamma_I l}{(u+l)^2} LK)^{-1} Z,$$

- Online Localization Phase

$$f^*(r) = \sum_{i=1}^{l+u} \alpha_i K(r_i, r).$$

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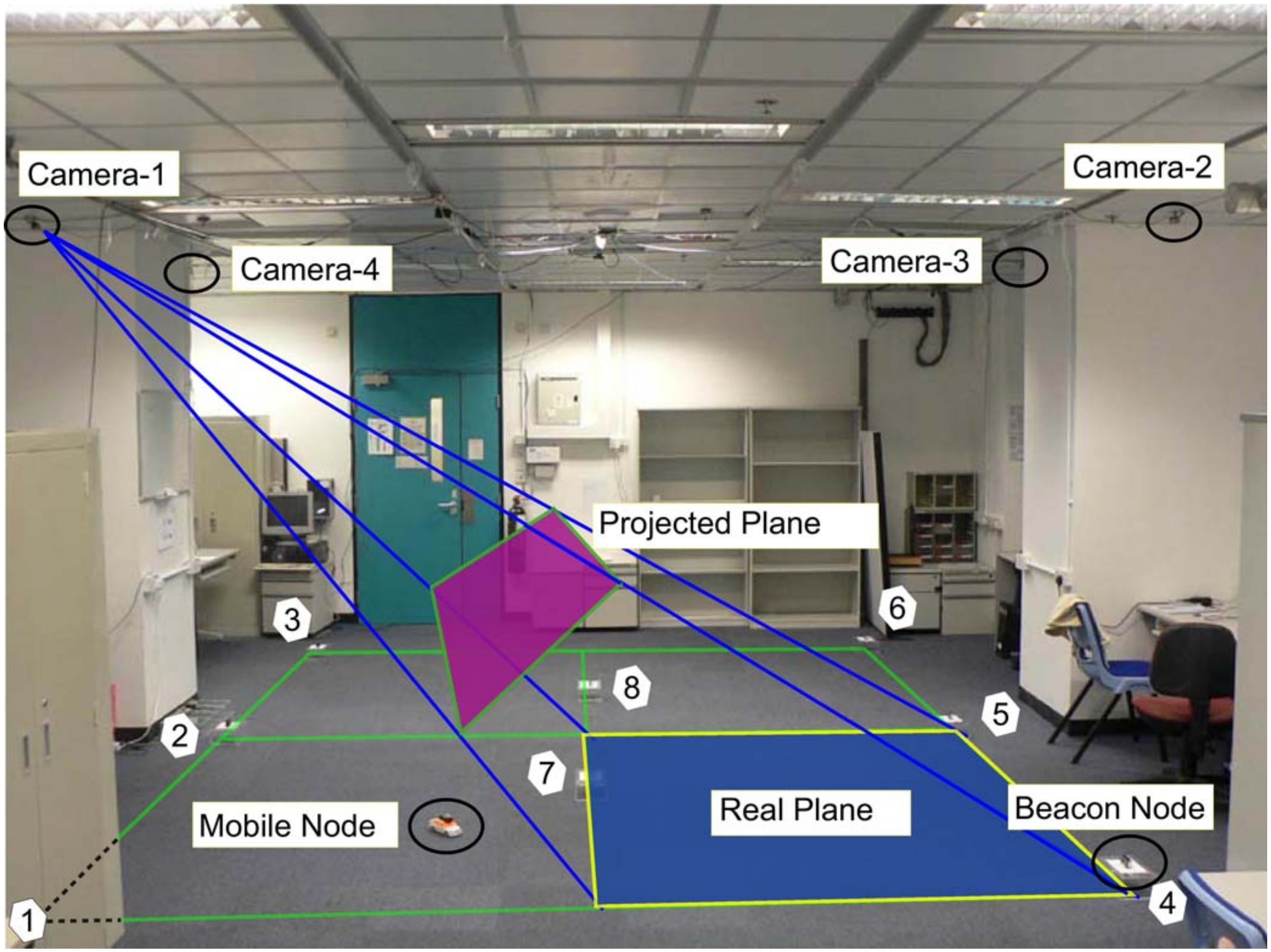
Test-bed Setup



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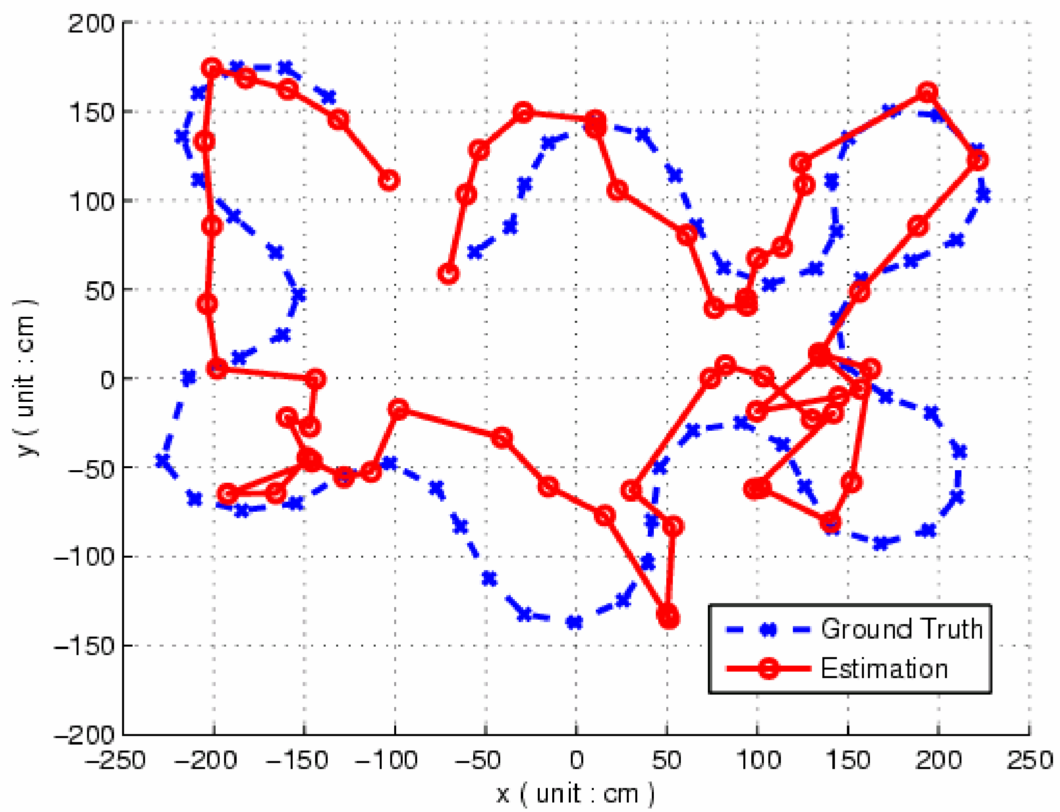
Estimated Trajectory Demo



(b) An estimated trajectory of LeMan

Location Estimation Accuracy

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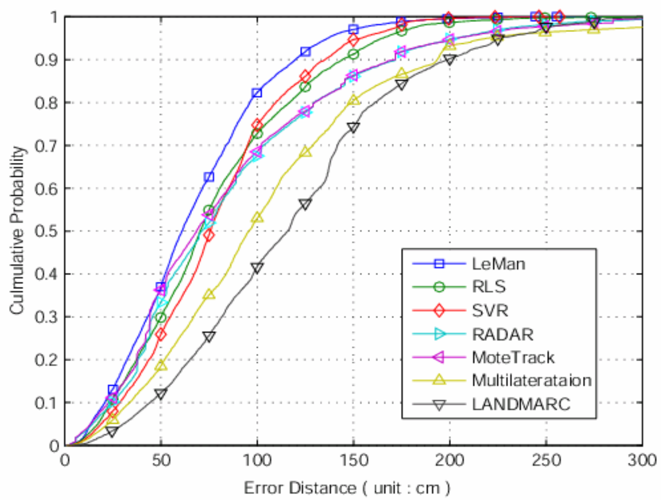
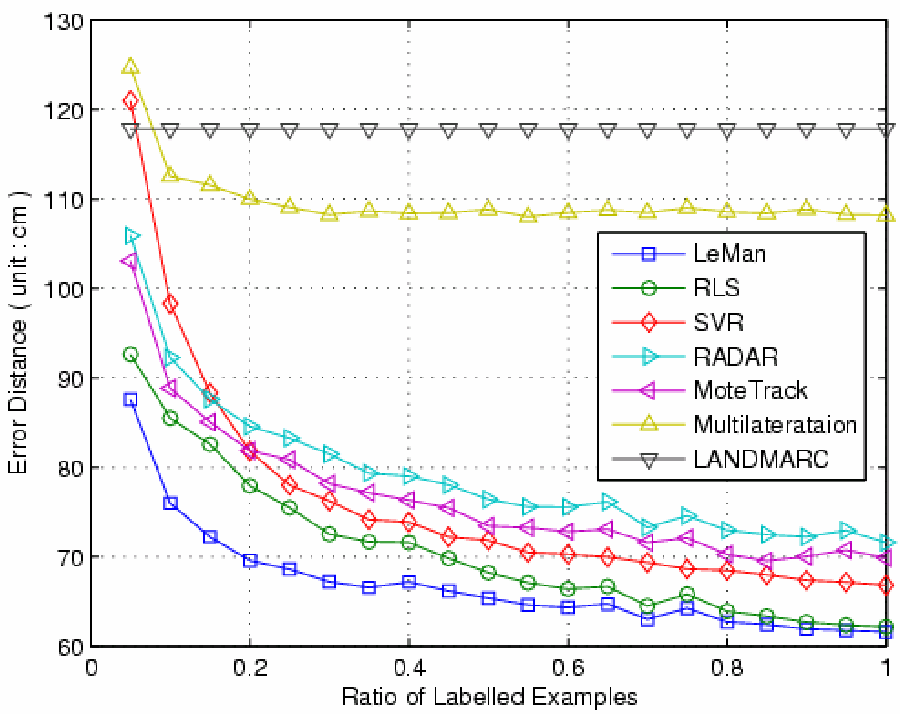
Table 1: Performance of Different Methods

Method	Mean (cm)	Std. (cm)	Max (cm)	Accuracy at 100cm	Time (ms)
LeMan	* 67	* 39	290	* 82%	0.242
RLS	78	46	358	73%	0.047
SVR	79	40	* 257	75%	0.045
RADAR	86	59	391	68%	0.106
MoteTrack	85	61	418	69%	0.106
Multilateration	108	77	1592	53%	0.125
LANDMARC	118	59	372	42%	0.085

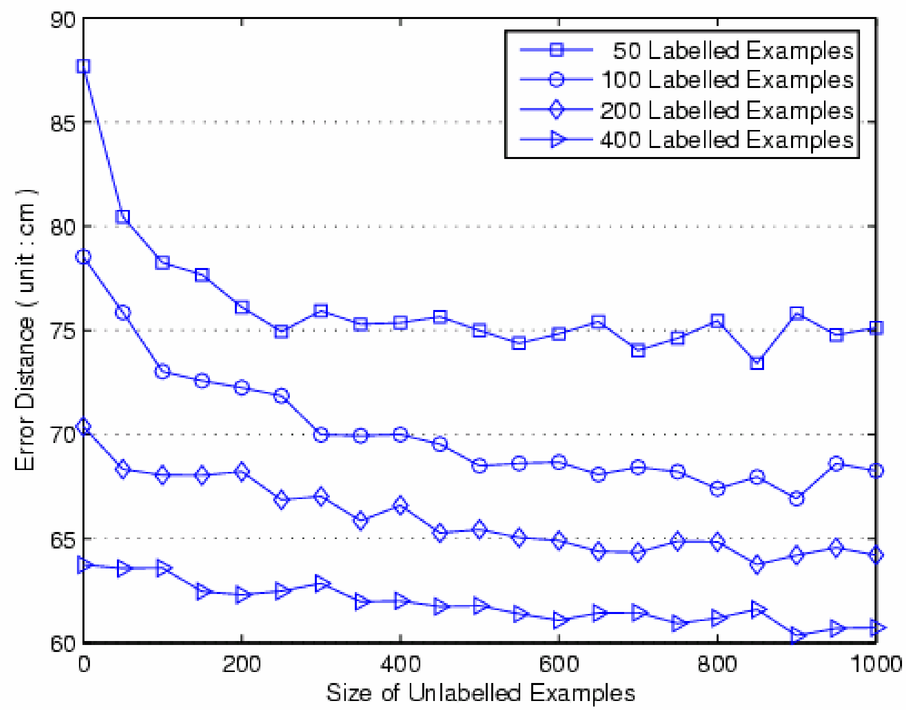


(a) Comparison of accuracy

Vary Labeled and Unlabeled Data



(e) Vary the ratio of labeled examples



(d) Vary the number of unlabeled examples

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Conclusion & Future Works

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Conclusion

- The Algorithm
  - Based on Manifold Regularization
  - Using Labeled and Unlabeled Examples
  - Tracking Mobile Sensor Node

Future Works

- Try New Experimental Test-bed
  - From Lab to a More Realistic Environment
- Consider Distributed Algorithm
  - Distributed Computing
  - Distributed Storage
  - Use Baysian Filters as a Post-processing step for smoothing

- Detail can be found in http://www.cs.ust.hk/~panjf

The End

Thank You

Question ?