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Robust indoor location tracking via interval analysis

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Outline

- Motivations
- Set membership estimation
- Indoor location tracking
- Experimental evaluation
- Research directions

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Monitoring for Healthcare

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Smart Homes

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Motivations

- Smart home sensors + Robust data fusion
  = Indoor location tracking,
  = Activity Dailing Living characterization.

- Indoor location tracking
  = set-membership state reconstruction
- Robust to sensor failures

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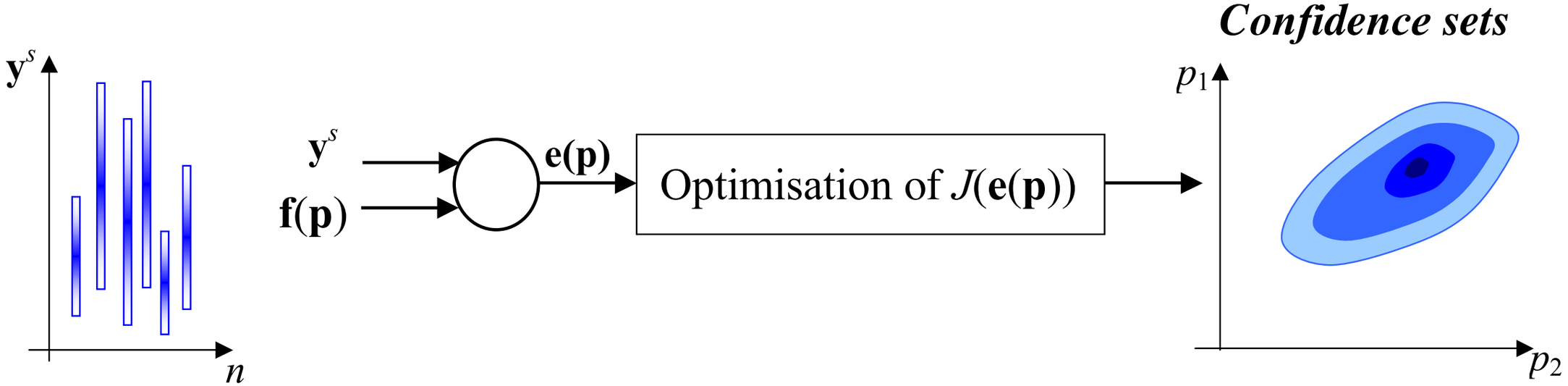
Classical Estimation

- Classical estimation is probabilistic

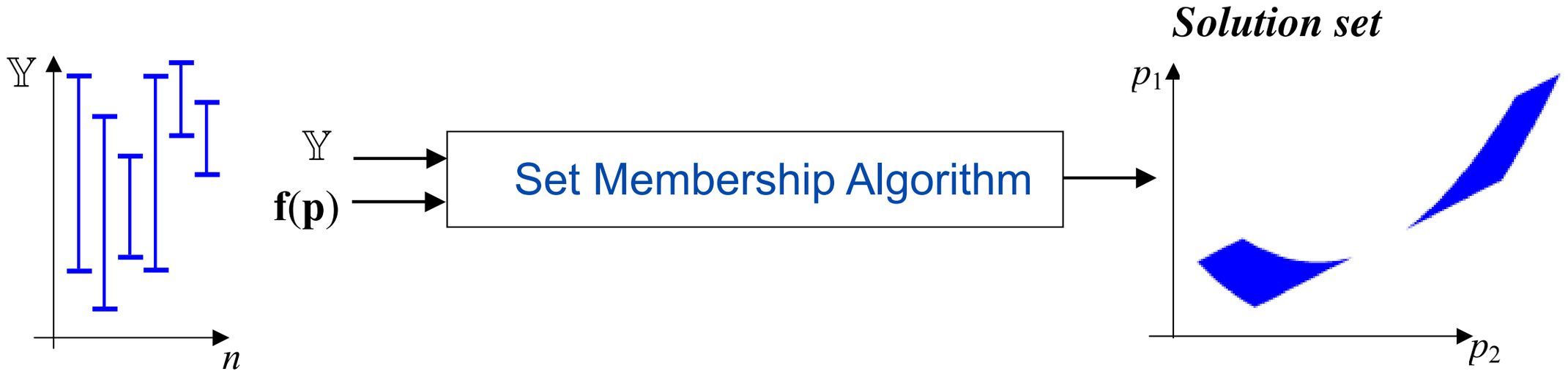


Yield valid results only if

- Perturbations, errors and model uncertainties with statistical properties known *a priori*
- Model structure is correct, no modeling errors

Set Membership Estimation

- Unknown but bounded-error framework



Hypothesis

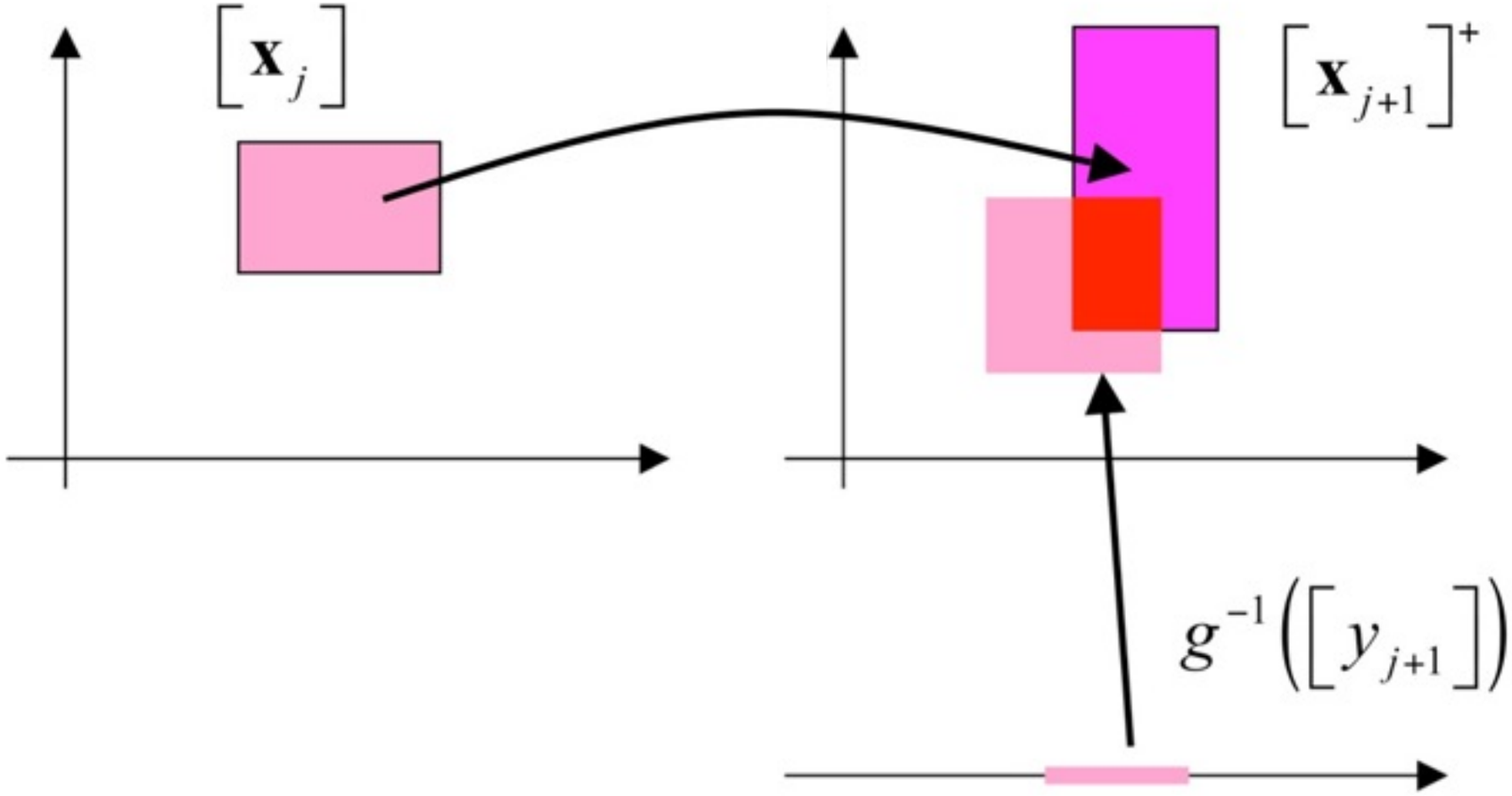
Uncertainties and errors are bounded with known prior bounds

A set of feasible solutions

$$\mathbb{S} = \{\mathbf{p} \in \mathbb{P} | \mathbf{f}(\mathbf{p}) \in \mathbb{Y}\} = \mathbf{f}^{-1}(\mathbb{Y}) \cap \mathbb{P}$$

Set Membership Estimation

- **State estimation with continuous systems**
  - Prediction - Correction / Filtering approaches
    - (Kieffer, et al., 1999) …



Set Membership Estimation

Set inversion. Parameter estimation

- Branch-&-bound, branch-&-prune, interval contractors …

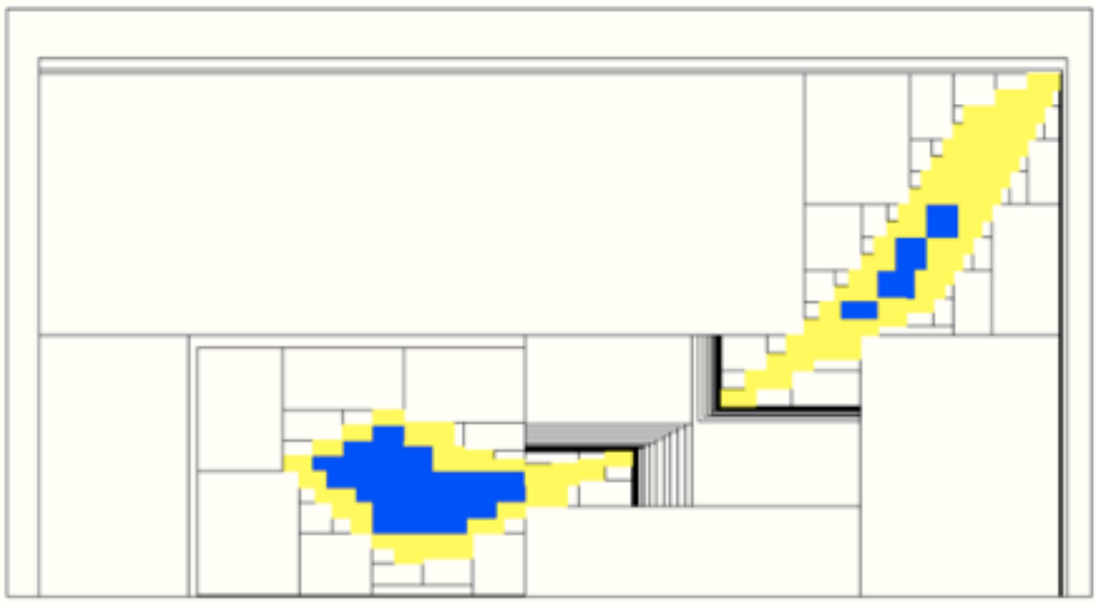
  (Jaulin, et al. 93) (Raïssi et al., 2004)

$$\mathbb{S} = \{\mathbf{z} \in \mathcal{Z}, \mid f(\mathbf{z}) \in \mathcal{Y}\} \quad \rightarrow \underline{\mathbb{S}} \subseteq \mathbb{S} \subseteq \overline{\mathbb{S}}$$

$f([\mathbf{z}]) \subseteq \mathcal{Y}$ $\Rightarrow [\mathbf{z}] \subseteq \underline{\mathbb{S}}$: inner approximation

$f([\mathbf{z}])) \cap \mathcal{Y} = \emptyset$ $\Rightarrow [\mathbf{z}] \not\subseteq \overline{\mathbb{S}}$: outer approximation $\Rightarrow [\mathbf{z}] \subseteq \mathcal{Z} \backslash \overline{\mathbb{S}}$

otherwise partition . . .



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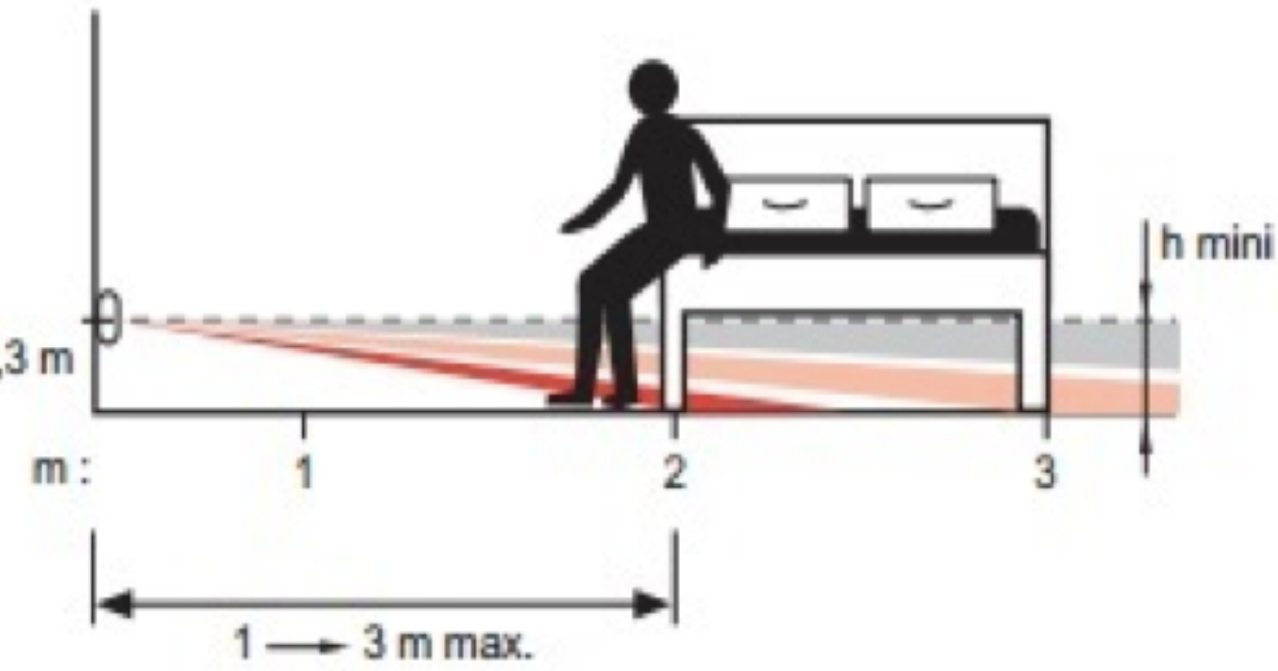
Binary sensors



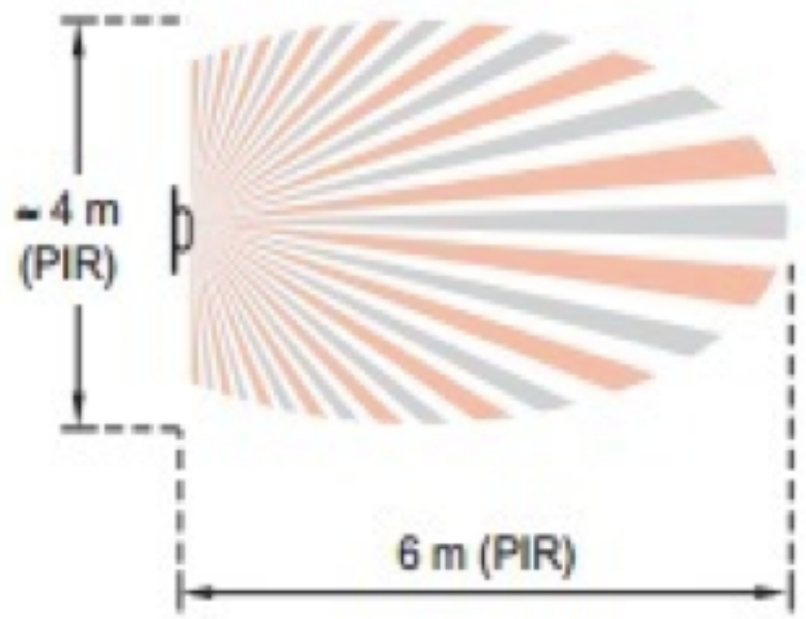


Figure: Infra-red sensor coverage

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Binary sensors

Figure: The Living Lab : GIS Madonnah at Bourges (France)

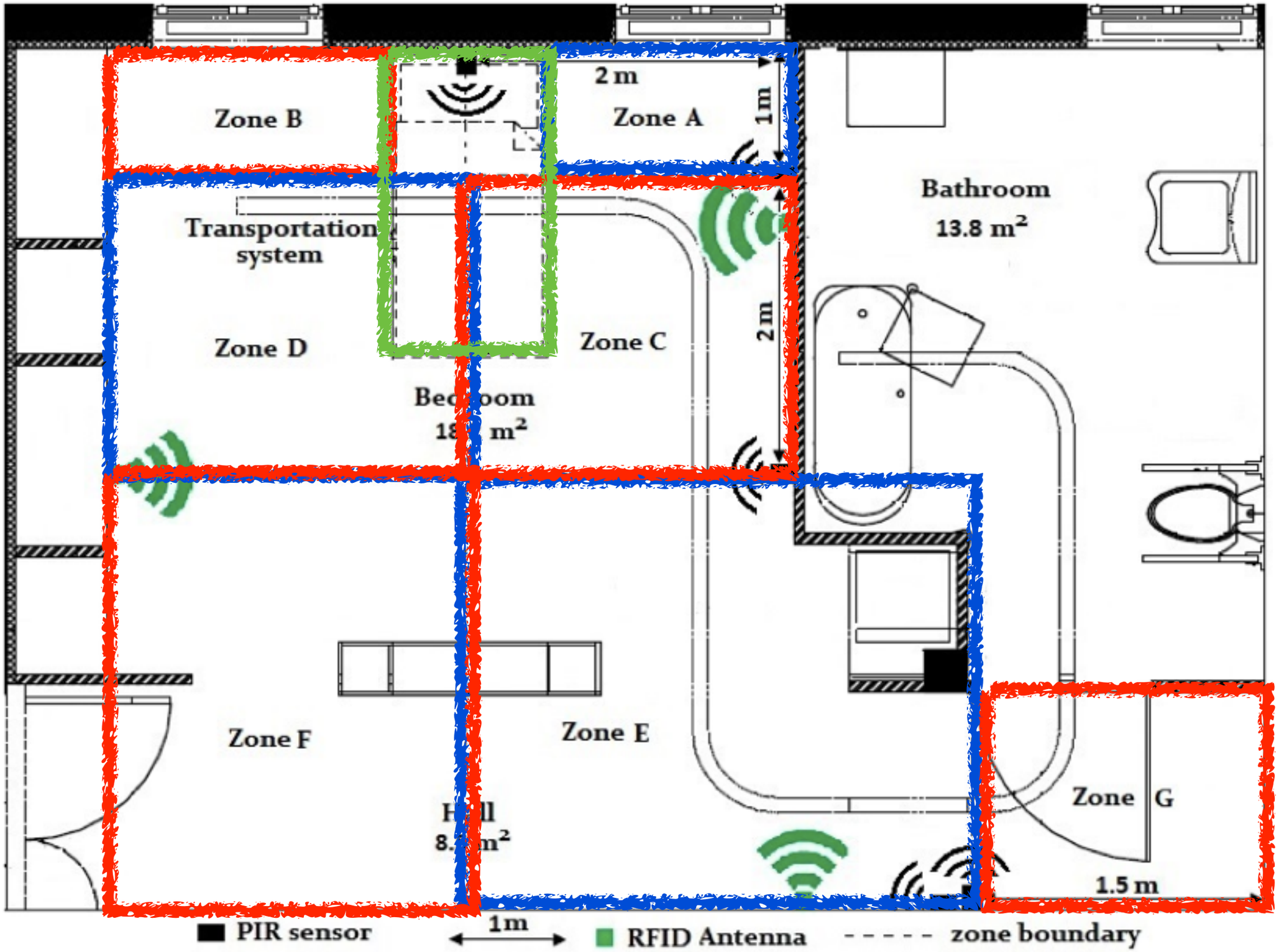

Figure: repartition of sensors and zoning areas

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System modeling

$$x_{k+1} = (p(y_{k+1}) \wedge (f_1(x_k) + \omega_{1k})) \vee (\neg p(y_{k+1}) \wedge (f_2(x_k) + \omega_{2k}))$$

$$y_{k+1} = h(x_{k+1}) + v_{k+1}$$

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Predictor-Corrector Approach

Prediction step

$$X_{k+1}^{+} = (p(y_{k+1}) \wedge f_1(X_k)) \vee (\neg p(y_{k+1}) \wedge f_2(X_k)) + W_{k+1}$$

Correction step

$$X_{k+1}^{-} = h^{-1}(y_{k+1} + V_{k+1})$$

Prediction step : random walk

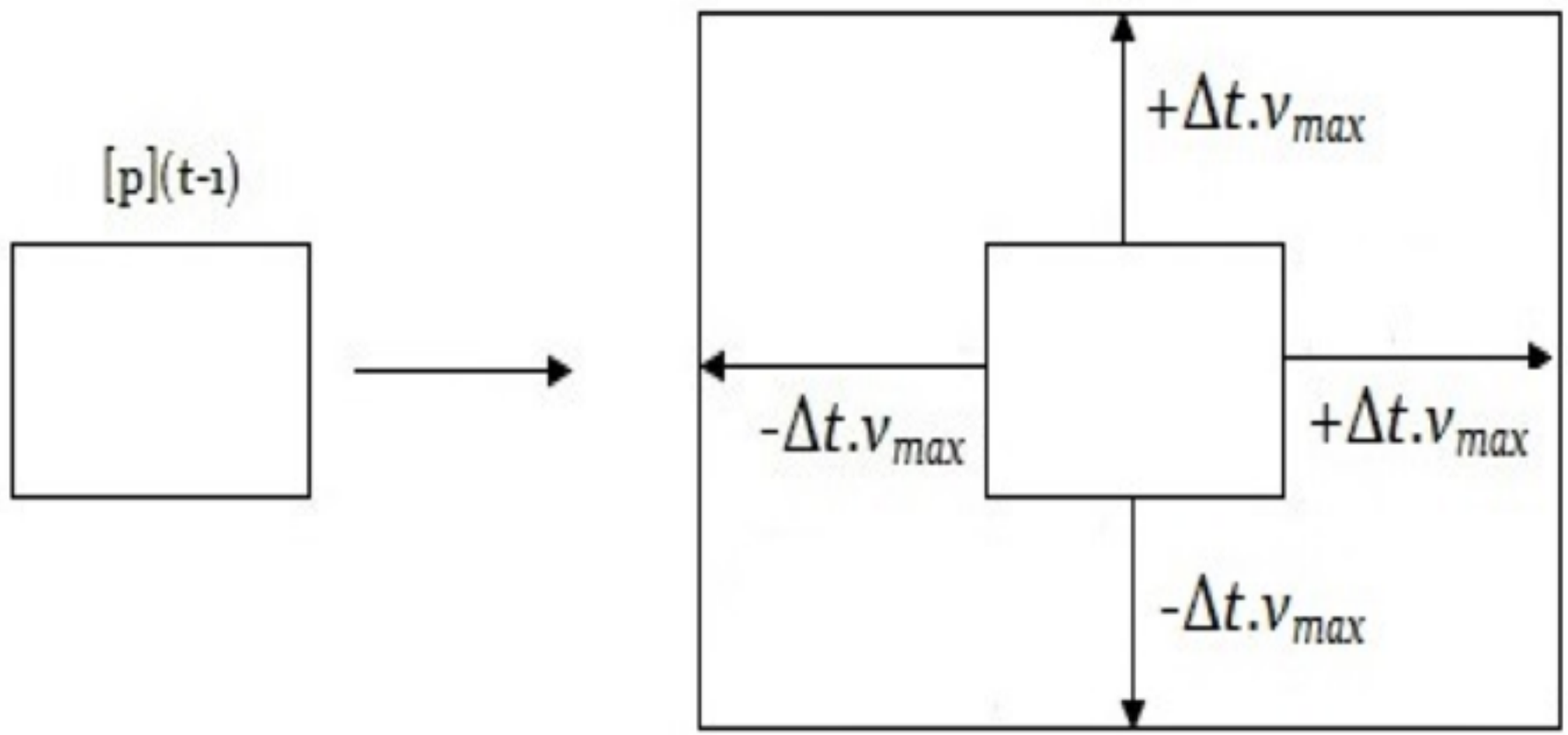

Figure: Prediction step

Prediction step, no motion detected

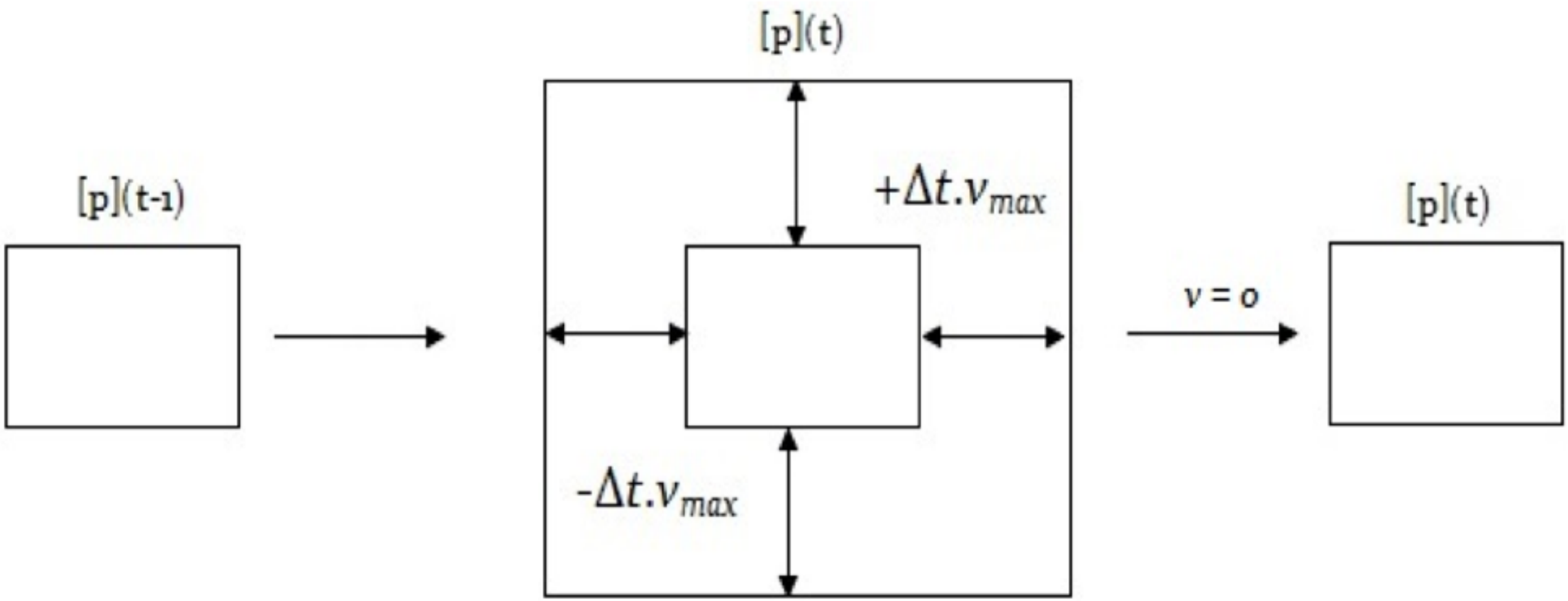

Figure: No movement detected

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Use of RFID sensors

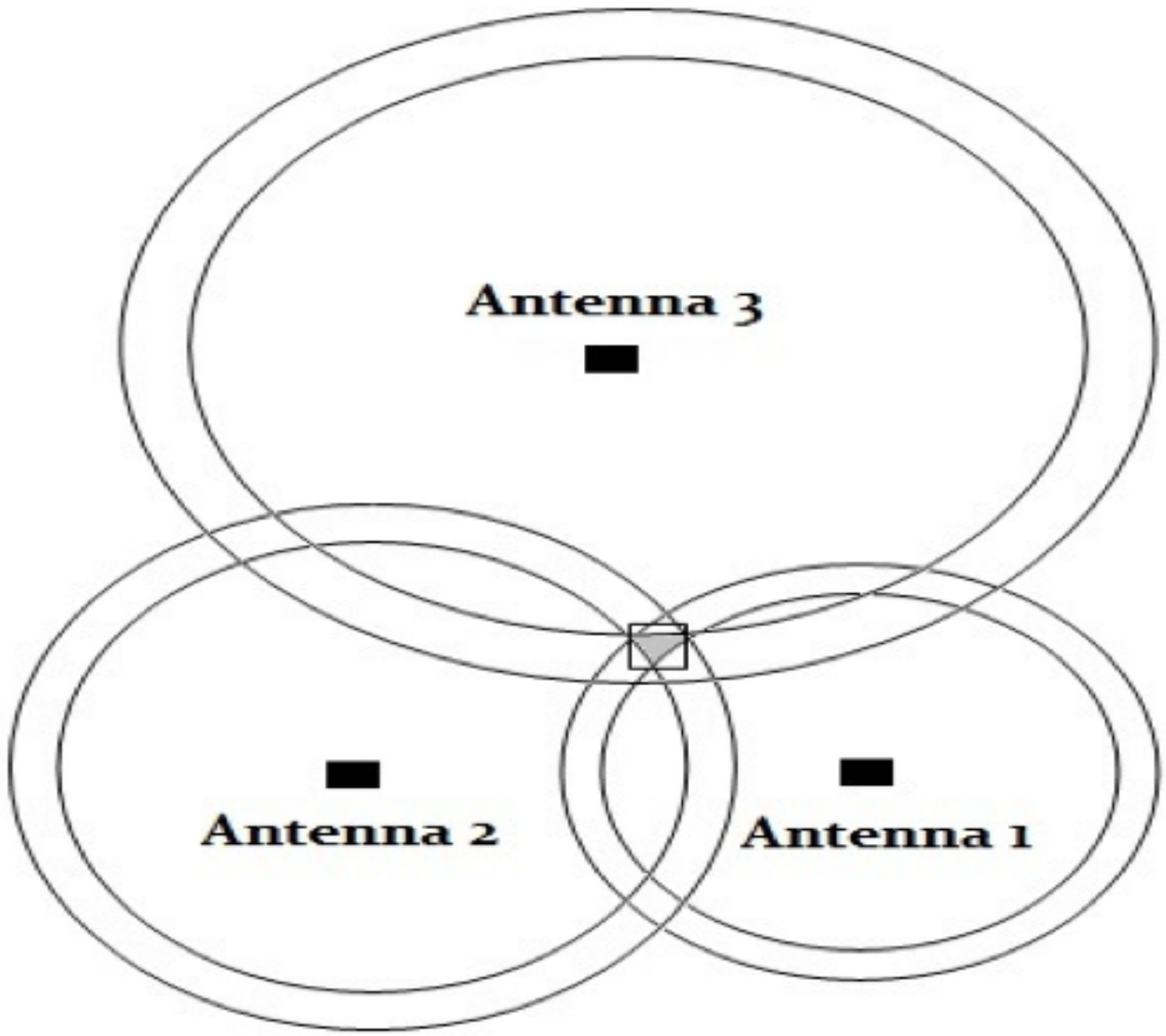


Figure: Result of three rings intersection

Correction step

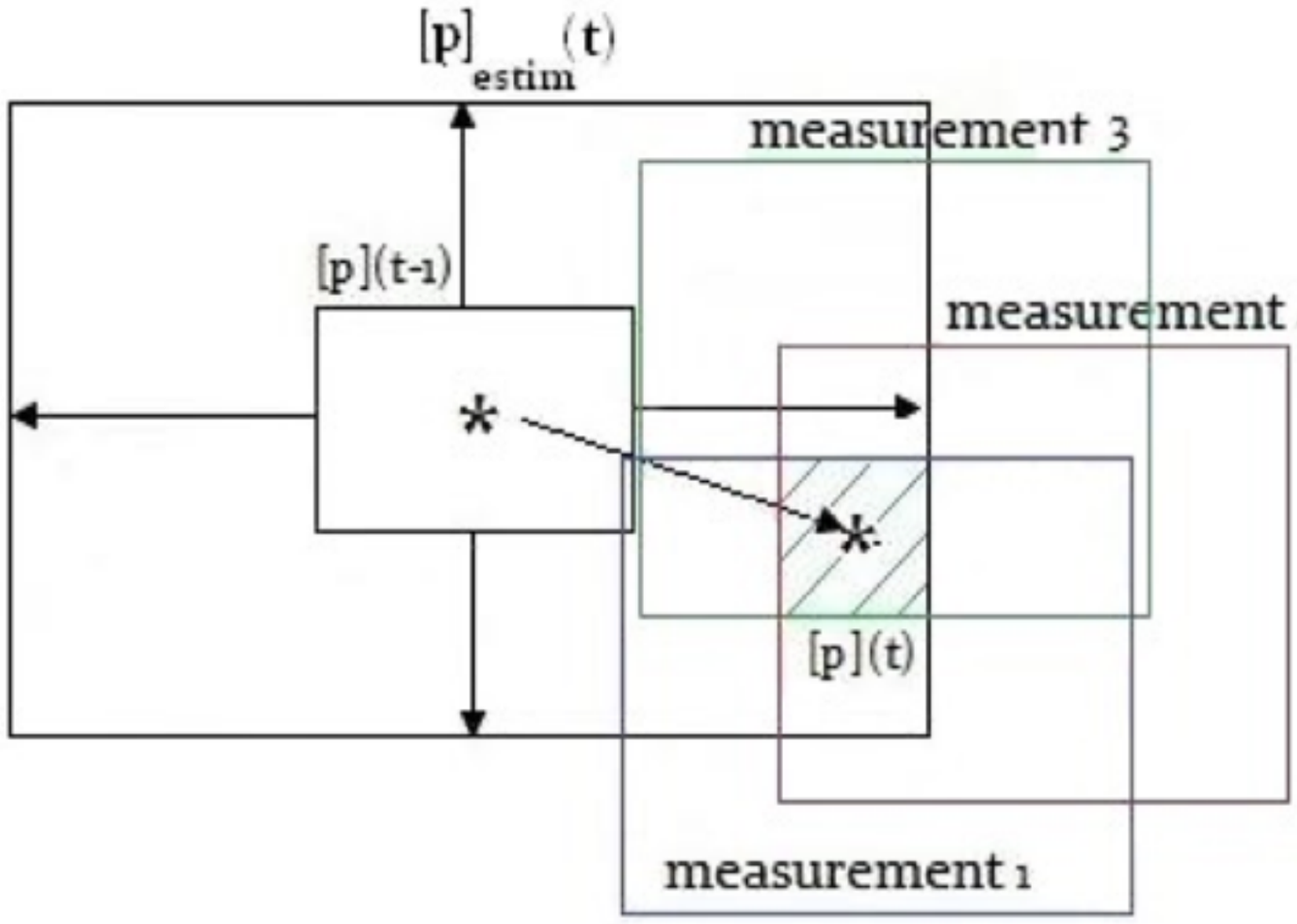
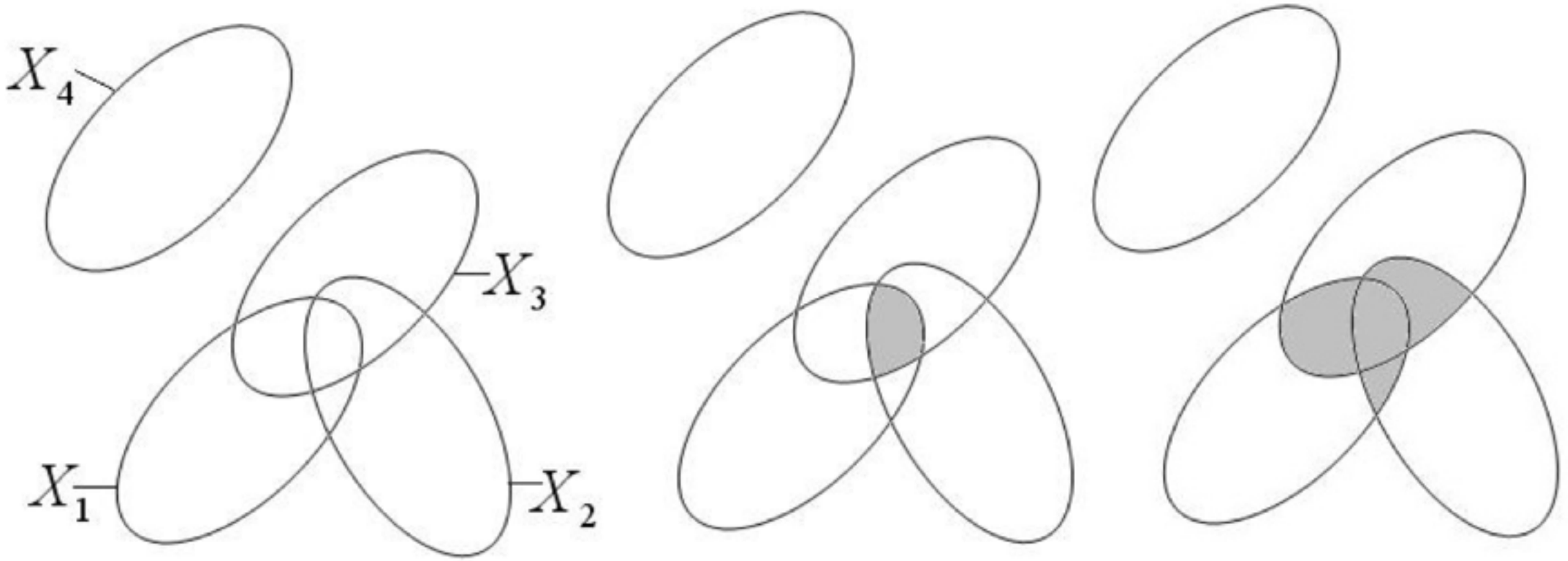


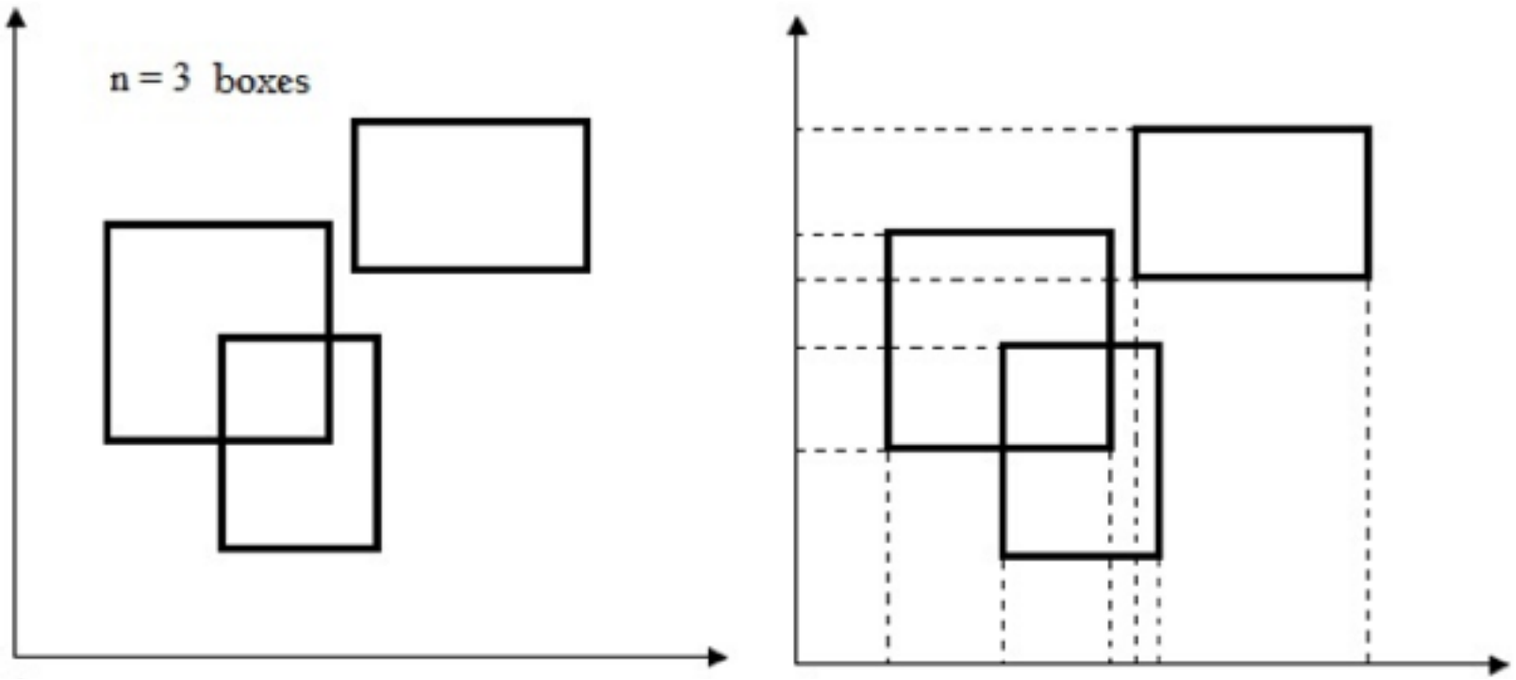
Figure: Correction step

q-Relaxed intersection

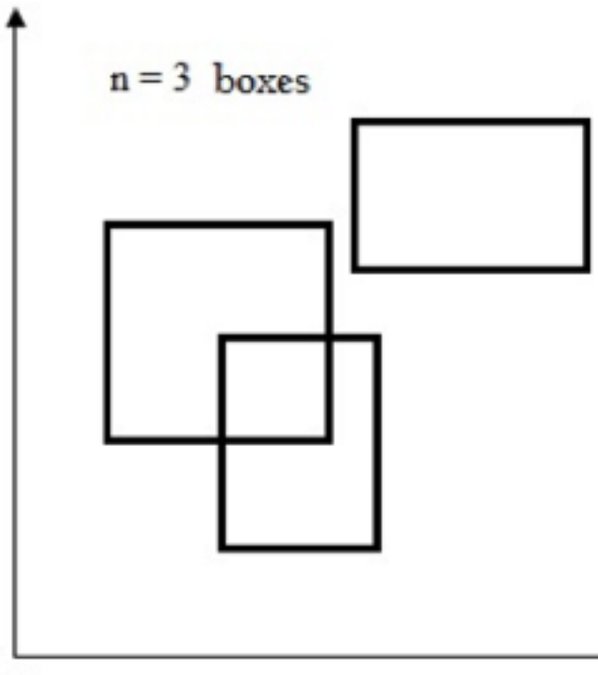


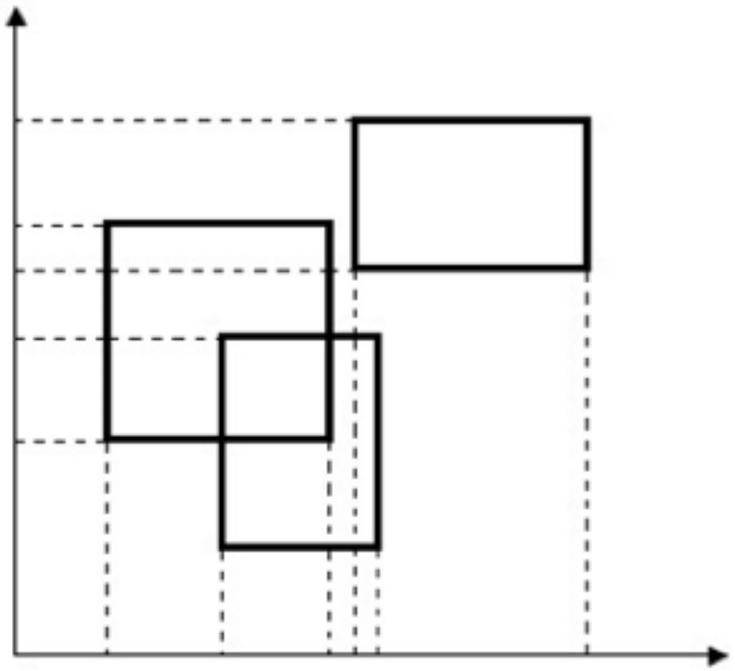
$$\bigcap^{\{0\}} X_i = \bigcap X_i \qquad \bigcap^{\{1\}} X_i \qquad \bigcap^{\{2\}} X_i$$

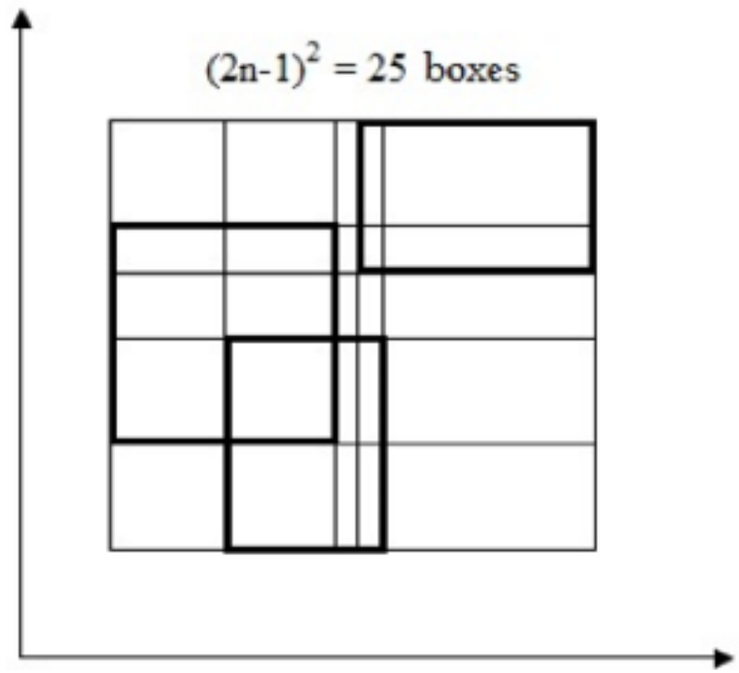
q-Relaxed intersection (Jaulin, 2009)



q-Relaxed intersection (Jaulin, 2009)







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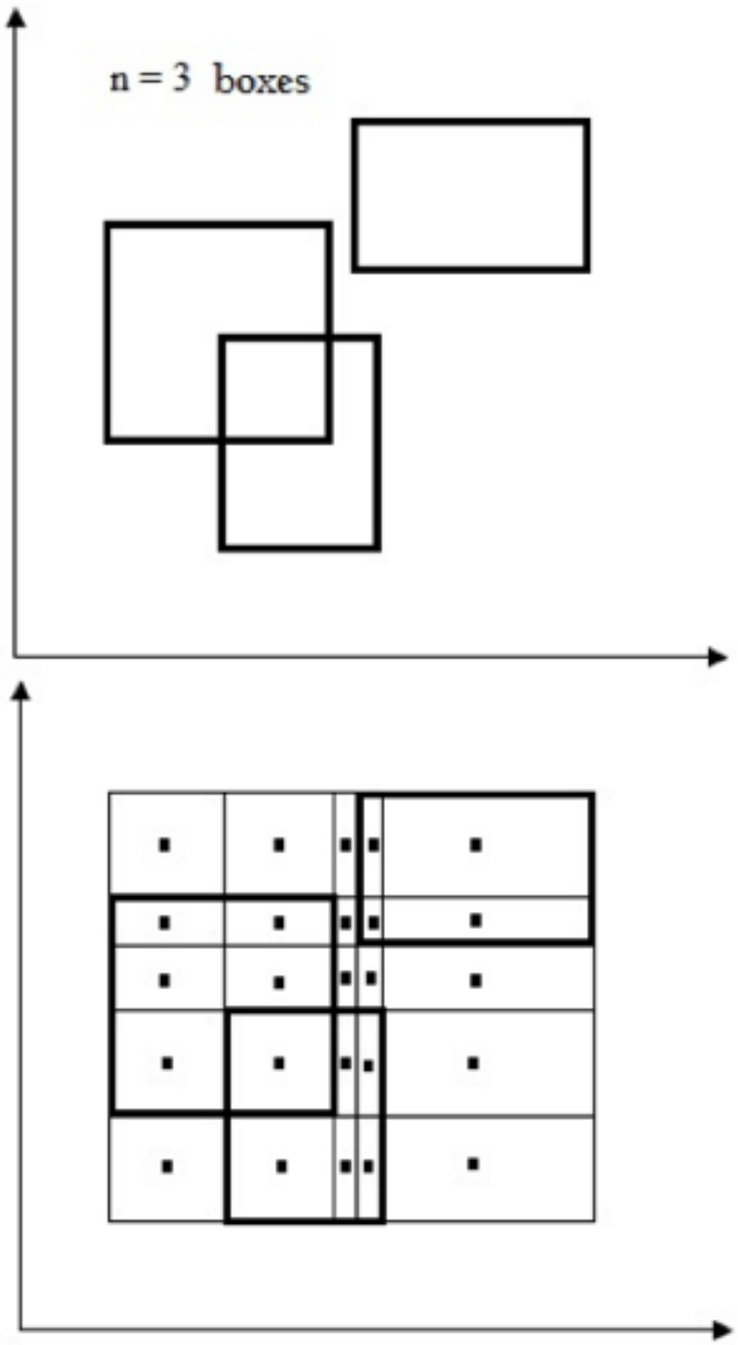

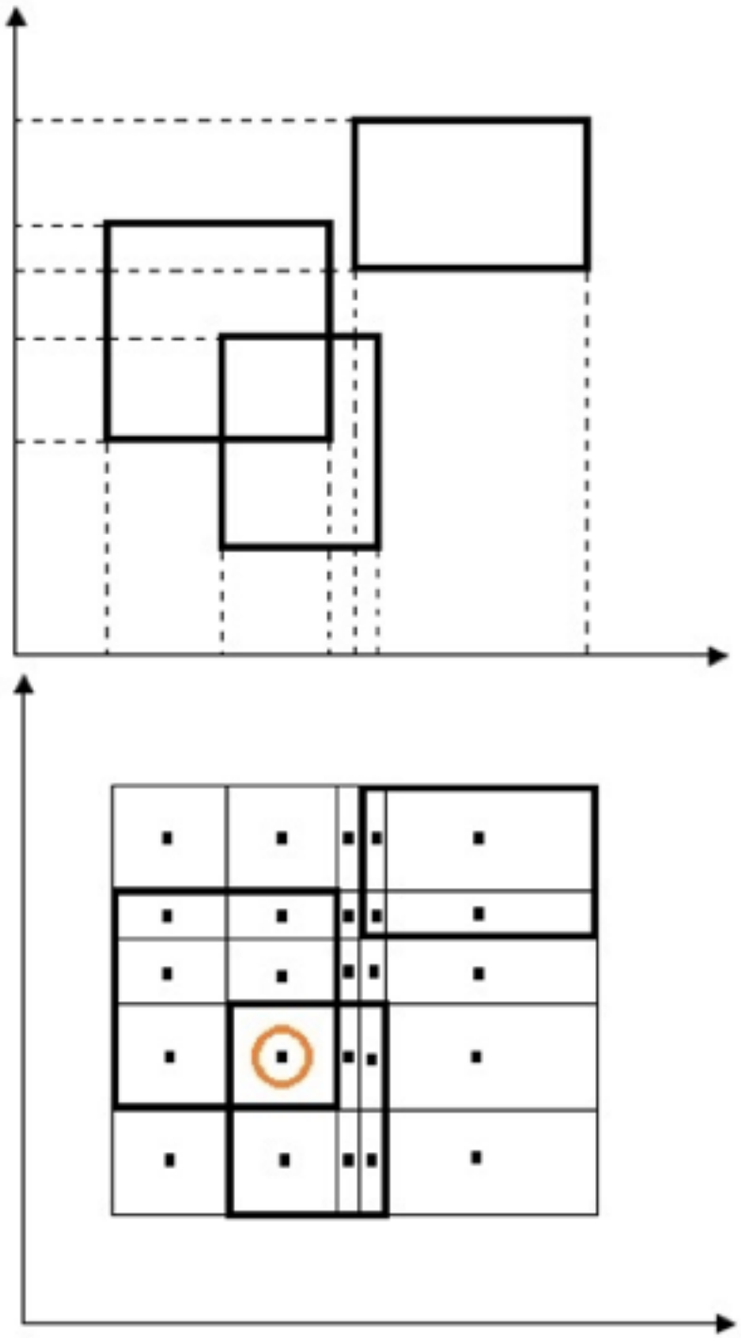

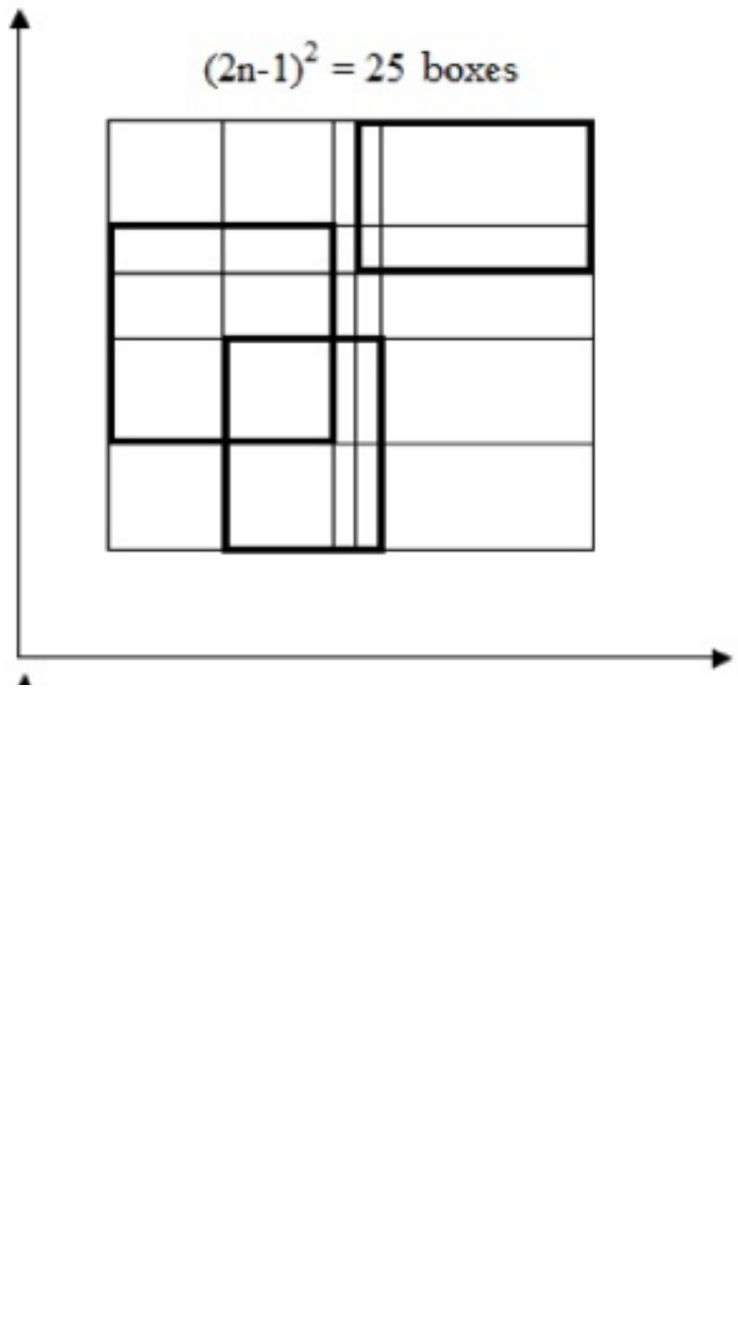

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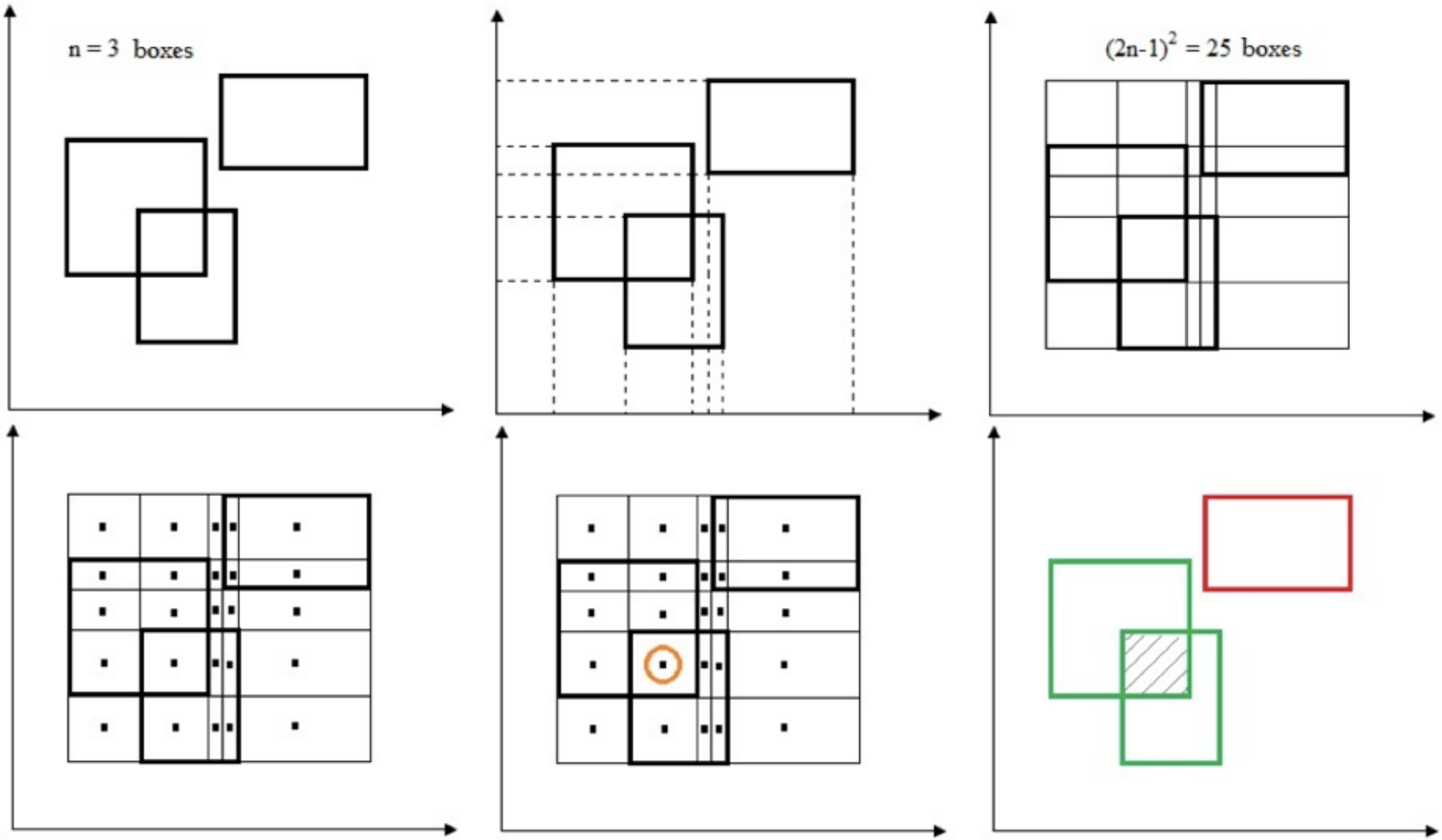
q-Relaxed intersection (Jaulin, 2009)



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Location Tracking using binary sensors only

Figure: Reconstructed location zones

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Location Tracking using binary sensors + RFID RSSI

Figure: Impact of the use of RFID sensors

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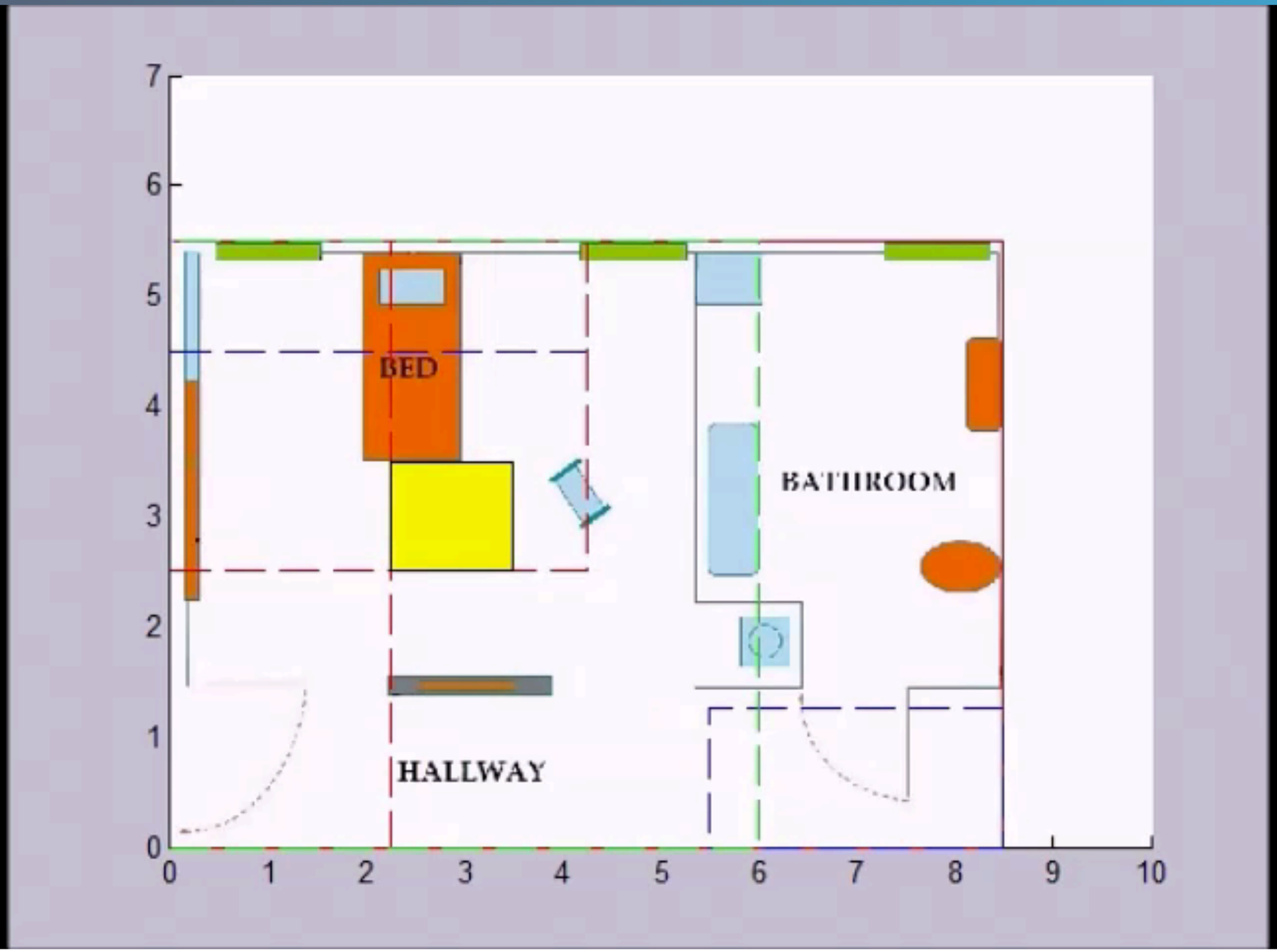
Location tracking of single inhabitant (IEEE ICRA 2015)



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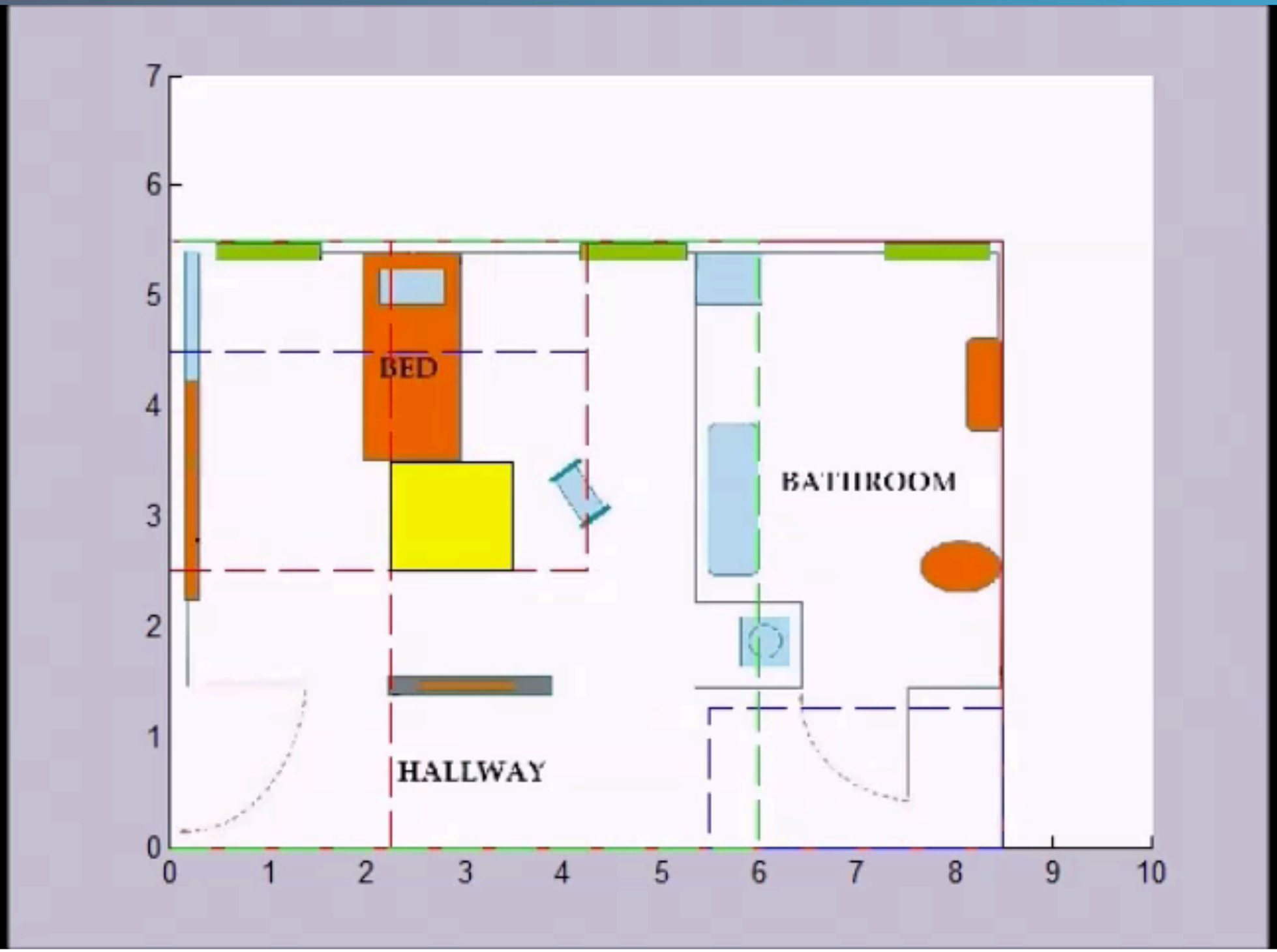
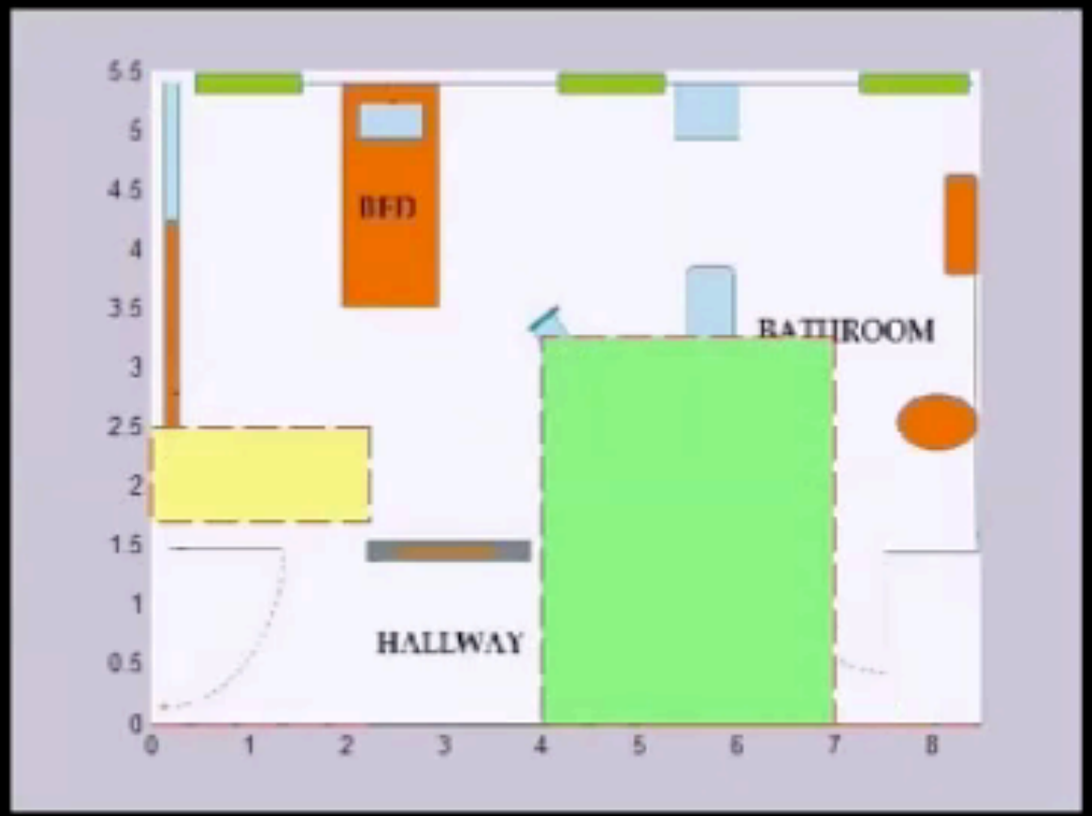
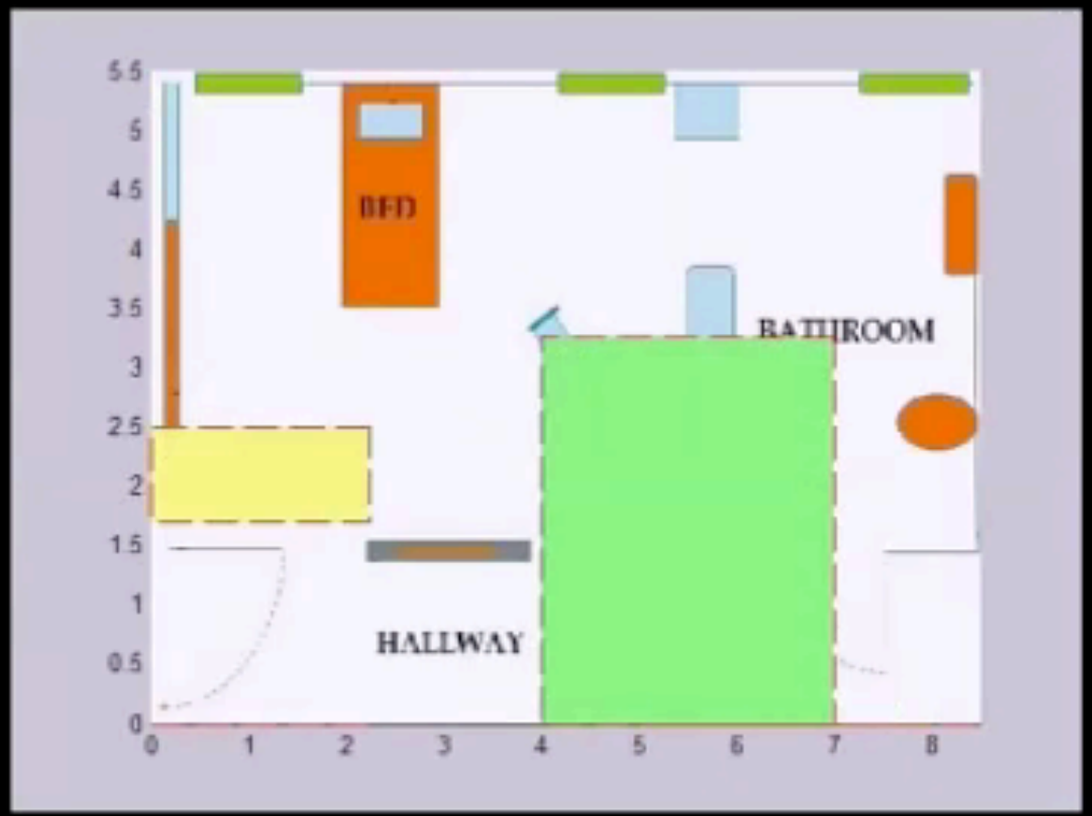
Location tracking of single inhabitant (IEEE ICRA 2015)



Location tracking of two inhabitants (IEEE CASE 2015)



Location tracking of two inhabitants (IEEE CASE 2015)



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Research directions

- Use forward-backward predictions
- Extend to multiple inhabitants
- Use with multi-modality
- Apply to FDI (IFAC SafeProcess 2015)
- Combine set-membership and stochastic modeling of errors.

Focused References

- M.H. Amri, Y. Becis, D. Aubry, N. Ramdani, M. Fränzle,
  Robust Indoor Location Tracking of Multiple Inhabitants Using Only Binary Sensors.
  IEEE CASE 2015, Gothenburg, Accepted.
- M.H. Amri, D. Aubry, Y. Becis, N. Ramdani,
  Robust Fault Detection and Isolation applied to Indoor Localization.
  IFAC SafeProcess 2015, Paris, Accepted.
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  N. Ramdani, Indoor Human/Robot Localization using Robust Multi-modal Data Fusion,
  IEEE ICRA 2015. Accepted.