Méthode ensembliste de détection et isolation de défauts de capteurs: Application à la localisation indoor

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Funding

- Project FUI 14 collectivités E-monitor'âge
- Purpose : to improve the safety of elderly people in nursing homes.

Publications

- Mohamed-Hédi Amri, Yasmina Becis, Didier Aubry, Nacim Ramdani "Indoor Human/Robot Localization using Robust Multi-modal Data Fusion" accepted for publication in the Proceedings of 2015 IEEE International Conference on Robotics and Automation (ICRA), May 26-30, 2015, Washington State Convention Center, Seattle, Washington.
- Mohamed-Hédi Amri, Didier Aubry, Yasmina Becis, Nacim Ramdani "Robust Fault Detection and Isolation applied to Indoor Localization" accepted for publication in the Proceedings of the 9th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes (SafeProcess), September 2-4, 2015, Paris, France.

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Key notions

- Residual generation [PM. Frank and X. Ding, 1996]
- Redundancy :
  - Hardware redundancy [V. Venkatasubramanian et al., 2003]
  - Analytical redundancy [J. Gertler, 1991]

Consistency check

- Active approach :
  - Unknown input observers [J. Chen and RJ. Patton, 1996]
  - Parity equation [S. Ploix and O. Adrot, 2006]
  - H_∞ [D. Henry, 2008]
  - Genetic algorithm [B. Samanta, 2003], etc.
- Passive approach

Set-membership methods

- Unknown but bounded error paradigm
- Feasible set :
  - Polytope [Blesa, 2010]
  - Ellipsoidal [A. Lesecq et al., 2003]
  - Parallelotope [A. Ingimundarson et al., 2005]
  - Orthotope [J. Watkins and S.Yurkovich, 1996]
  - Zonotope [S. Raka and C. Combastel, 2010]
  - Interval box [B. Marx et al. 2010]

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Problem formulation

- System model :

$$\begin{cases} x_{k+1} = f(x_k) + w_k \\ y_{k+1} = h(x_{k+1}) + v_{k+1} \end{cases} \quad (1)$$

$\rightarrow x_k \in \mathbb{R}^n$ $(x_0 \in X_0)$ et $y_{k+1} \in Y_k \subset \mathbb{R}^m$: state and measurement vectors,
$\rightarrow f(.)$ et $h(.)$: nonlinear functions,
$\rightarrow w_k \in W_k \subset \mathbb{R}^n$ and $v_k \in V_k \subset \mathbb{R}^m$,
$\rightarrow (X_0, W_k)$ and (Y_k, V_k) : bounded sets.

Set-membership estimator

- Prediction

$$[X_k^+] = f([X_{k-1}]) + W_k \tag{2}$$

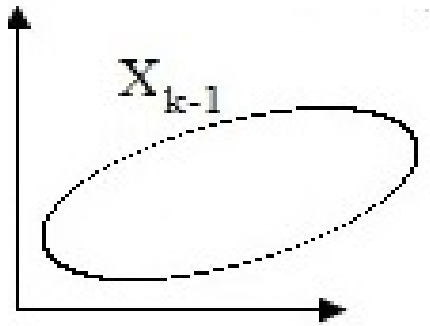
- Correction

$$[X_k^-] = h^{-1}([Y_k]) \tag{3}$$

Prediction phase

- Prediction phase :

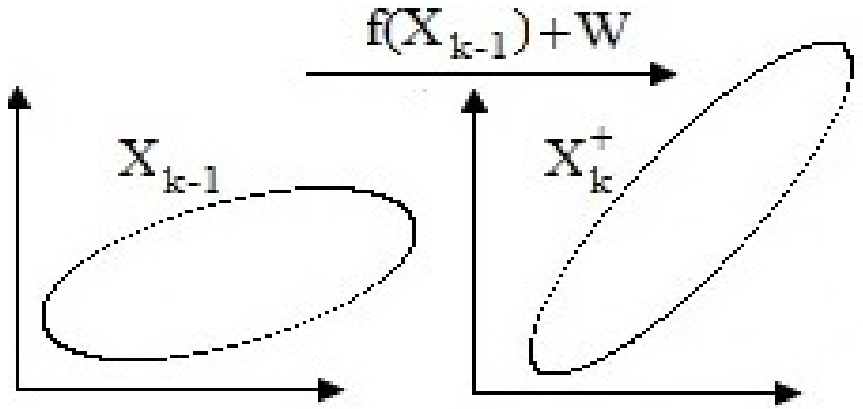
$$[X_k^+] = f([X_{k-1}]) + W_k \tag{4}$$



Prediction phase

- Propagation phase :

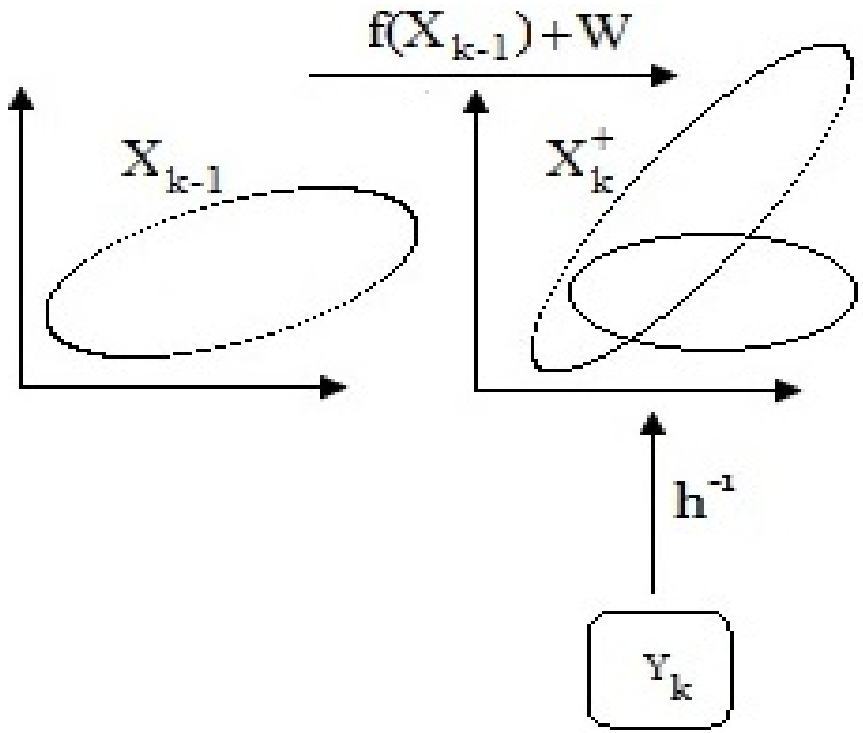
$$[X_k^+] = f([X_{k-1}]) + W_k \tag{5}$$



Correction phase

- Correction phase :

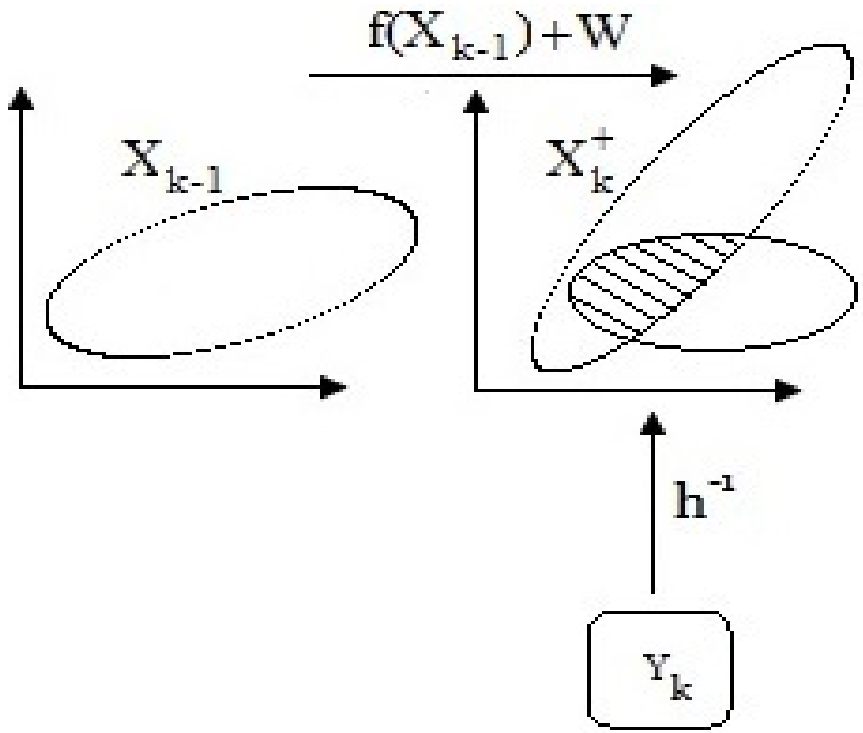
$$[X_k^-] = h^{-1}([Y_k]) \tag{6}$$



Correction phase

- Feasible set :

$$[X_k] = [X_k^+] \cap [X_k^-] \tag{7}$$



Consistency test

- Empty intersection
- Inappropriate choice of :
  - System model
  - Initial set
  - Bounds for noise sets
  - Faulty measurements

Relaxed set intersection

- **Proposed method :** q-relaxed intersection [L. Jaulin, 2009][V. Drevelle et P. Bonnifait, 2010]
- **Notation :** $X^{\{q\}} = \bigcap^{\{q\}} X_i$
- **Principle :**
  - Tolerating a given number q of outliers out of m measurements
  - Solution set : the set compatible with $m - q$ measurements.

q-relaxed intersection

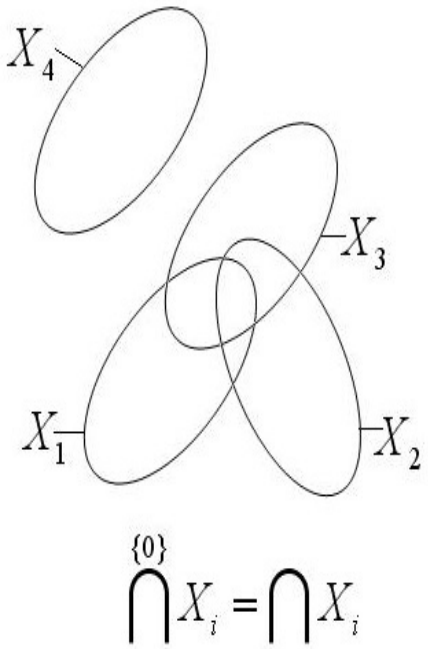


Figure: q-relaxed intersection

q-relaxed intersection

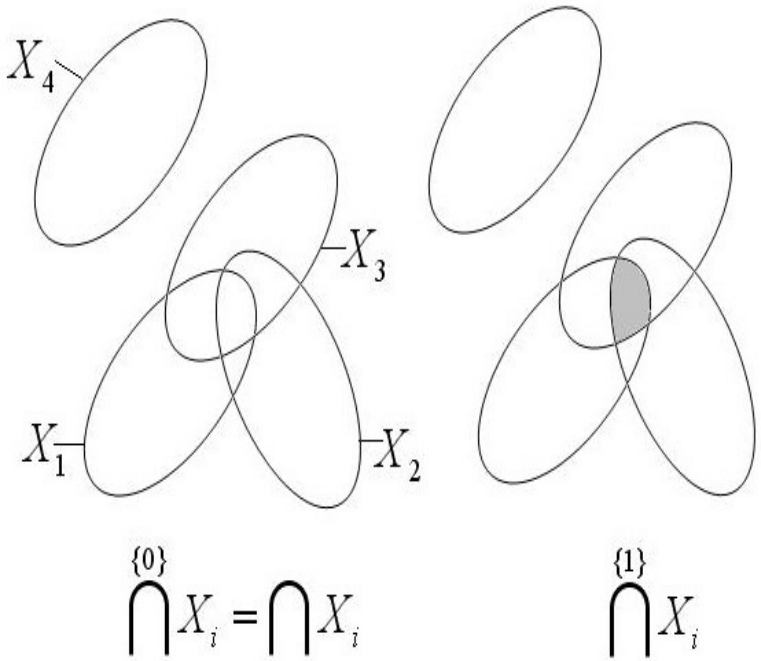


Figure: q-relaxed intersection

q-relaxed intersection

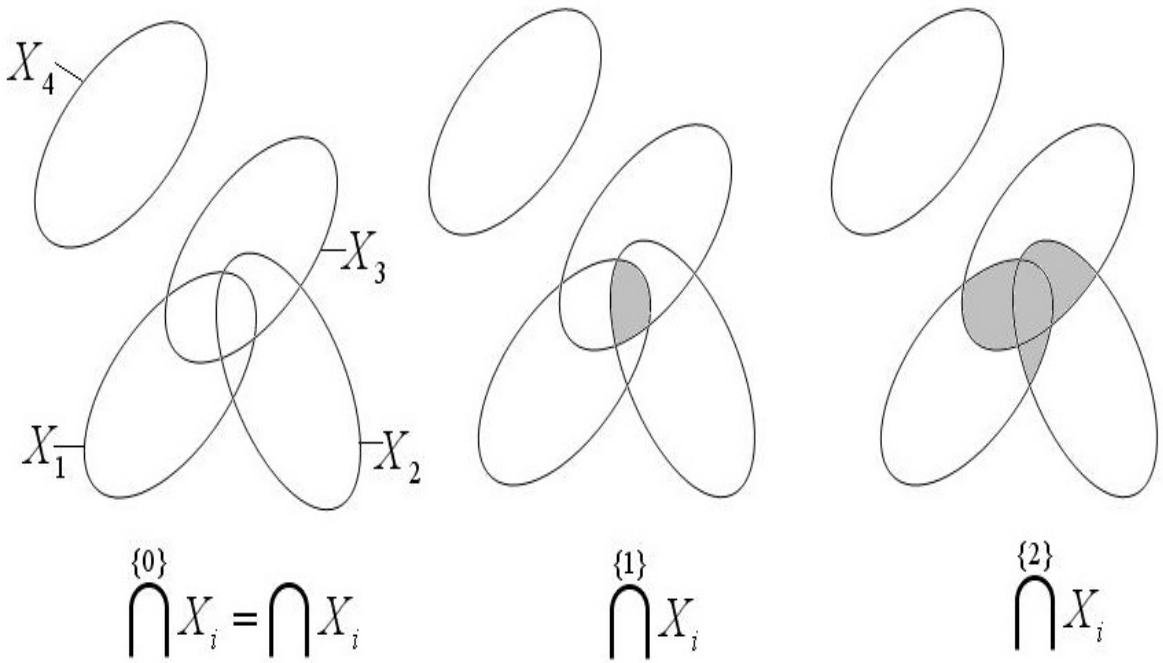


Figure: q-relaxed intersection

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Interval analysis

- Real interval $[x]$:

$$[x] = [\underline{x}, \bar{x}] = \{x \in R \backslash \underline{x} \leq x \leq \bar{x}\}$$

- A box :

$$[x] = [x_1] \times \ldots \times [x_n] = [\underline{x}_1, \bar{x}_1] \times \ldots \times [\underline{x}_n, \bar{x}_n]$$

Interval analysis

- Extension of classical operations of real arithmetic to intervals
- Soit $[x]$ et $[y]$ and $\circ \in \{+, -, \times, /\}$

$$[x] \circ [y] = [\inf(\{x \circ y \backslash x \in [x], y \in [y]\}), \\ \sup(\{x \circ y \backslash x \in [x], y \in [y]\})]$$

Interval analysis : Examples

- $[-2,5]+[3,4]=[1,9]$
- $[-2,5]\times[3,4]=[-8,20]$
- $[-2,5]\,/\,[3,4]=\left[-\frac{2}{3},\frac{5}{3}\right]$

Computing the q-relaxed intersection

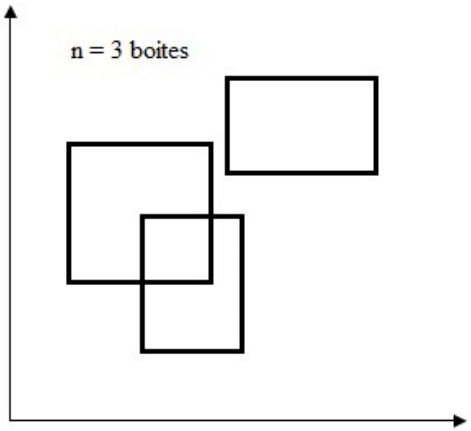
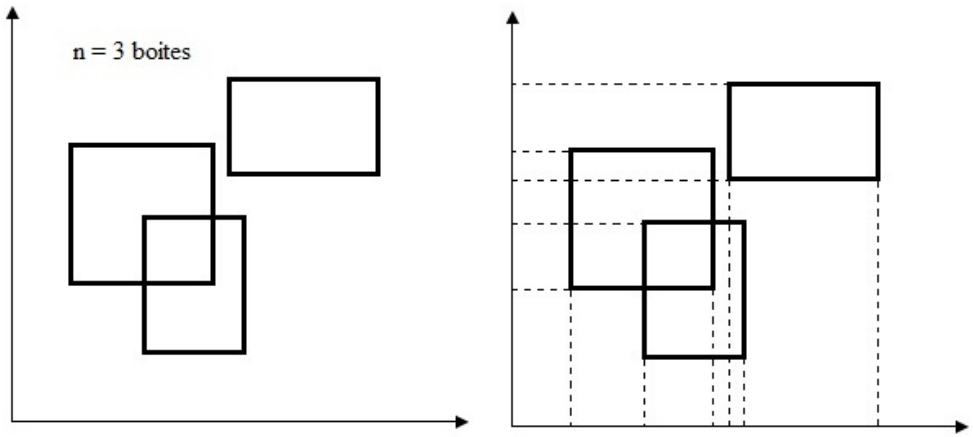


Figure: Computing the q-relaxed intersection [L. Jaulin, 2009]

Computing the q-relaxed intersection



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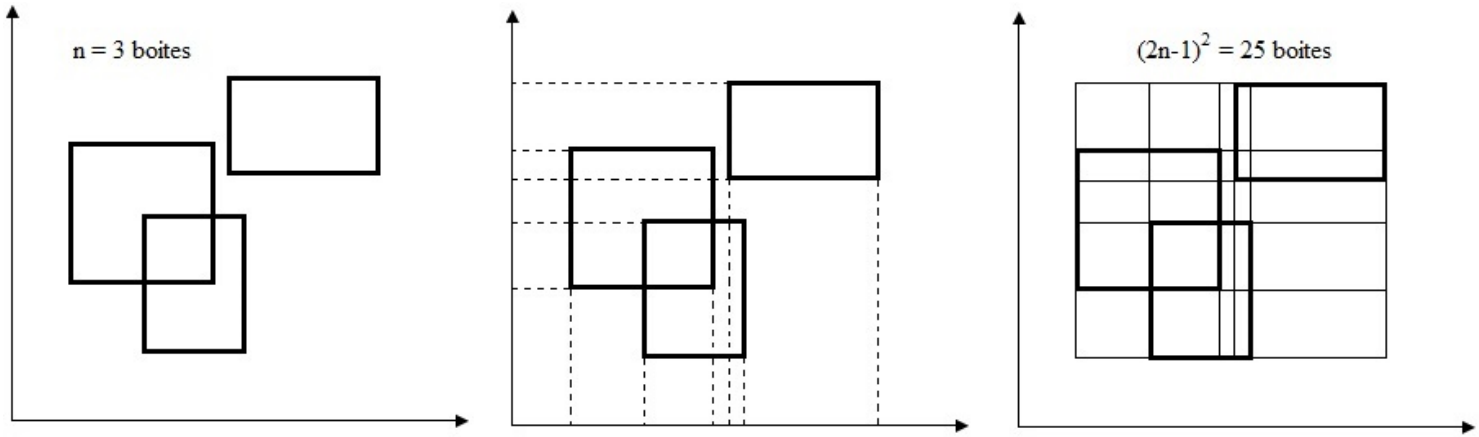
Computing the q-relaxed intersection



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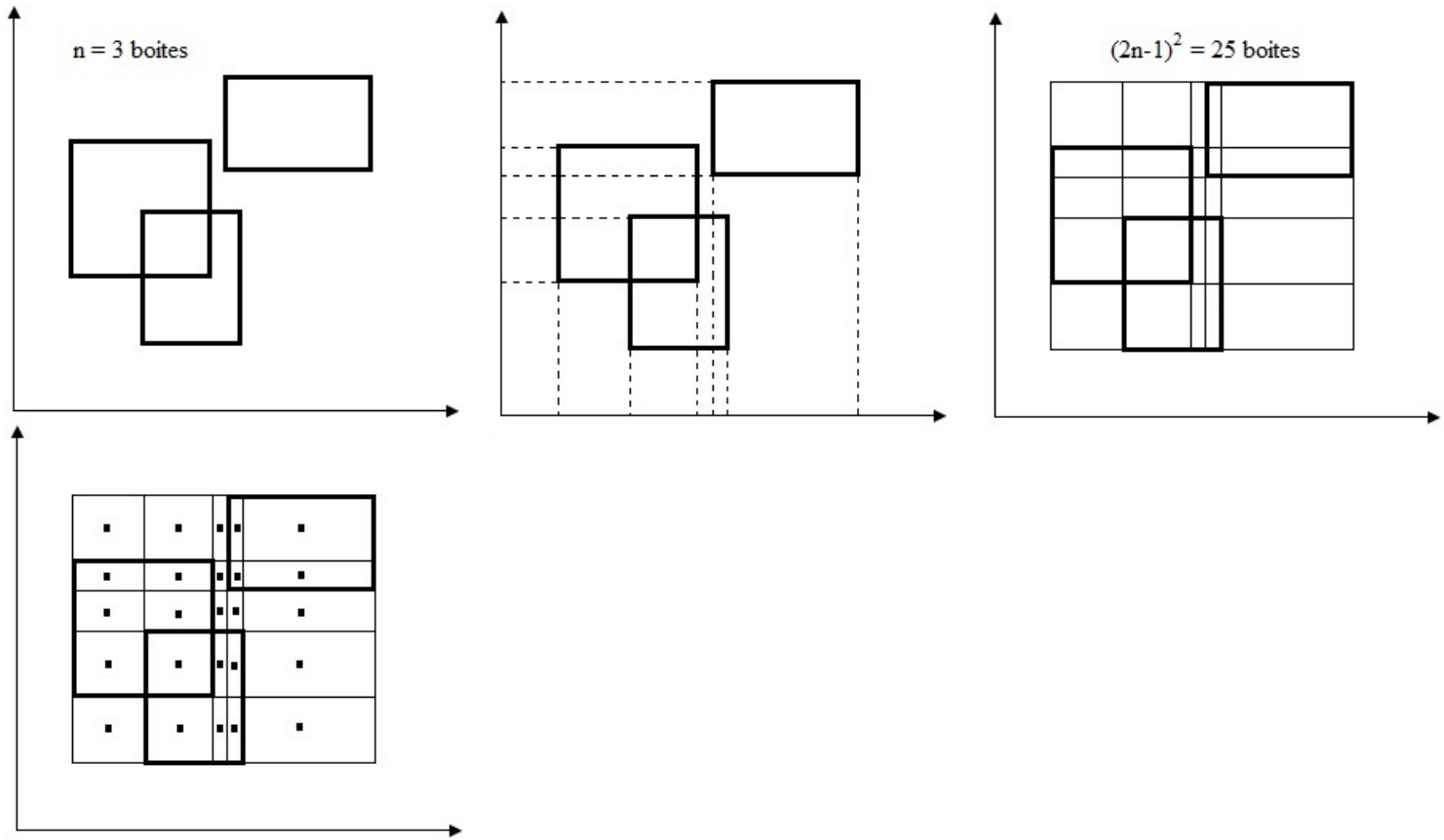
Computing the q-relaxed intersection



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Computing the q-relaxed intersection

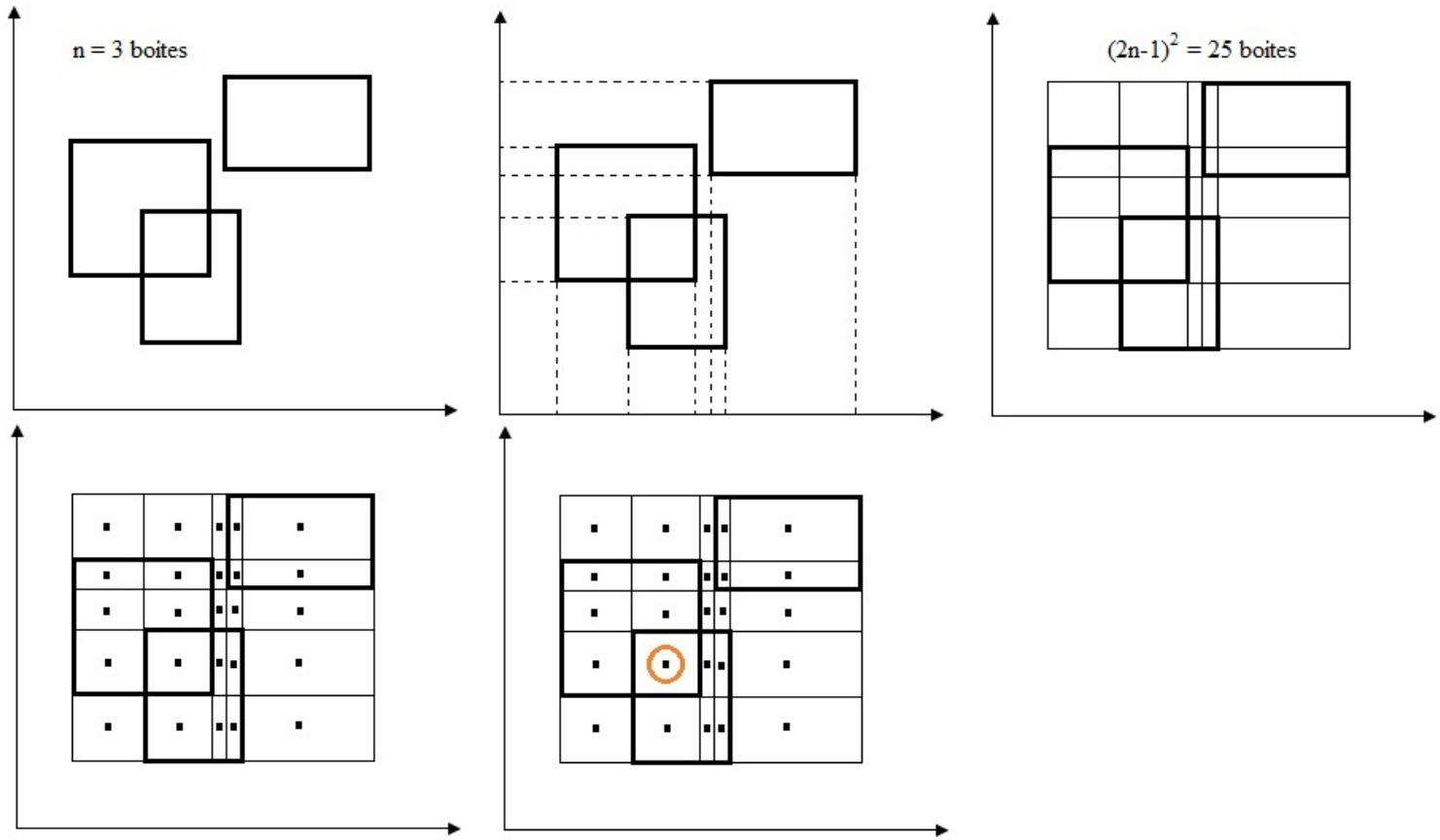

Figure: Computing the q-relaxed intersection [L. Jaulin, 2009]

Computing the q-relaxed intersection

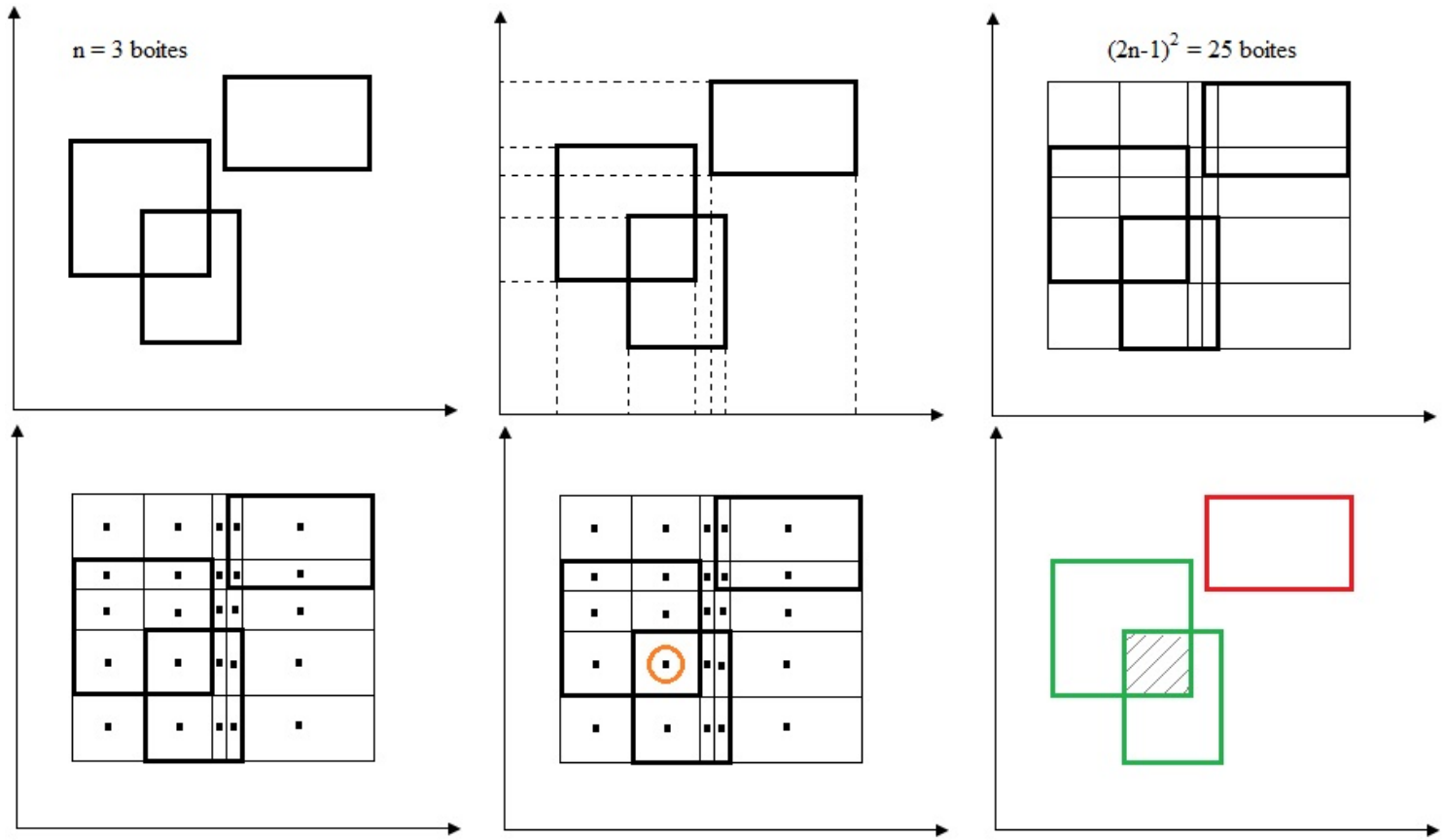

Figure: Computing the q-relaxed intersection [L. Jaulin, 2009]

Possible situations

- No outlier
- Outlier detected and identified
- Outlier detected but not identified

No outlier

- $q = 0 \rightarrow \bigcap_{i=1,3}^{\{q\}} m_i \neq 0$

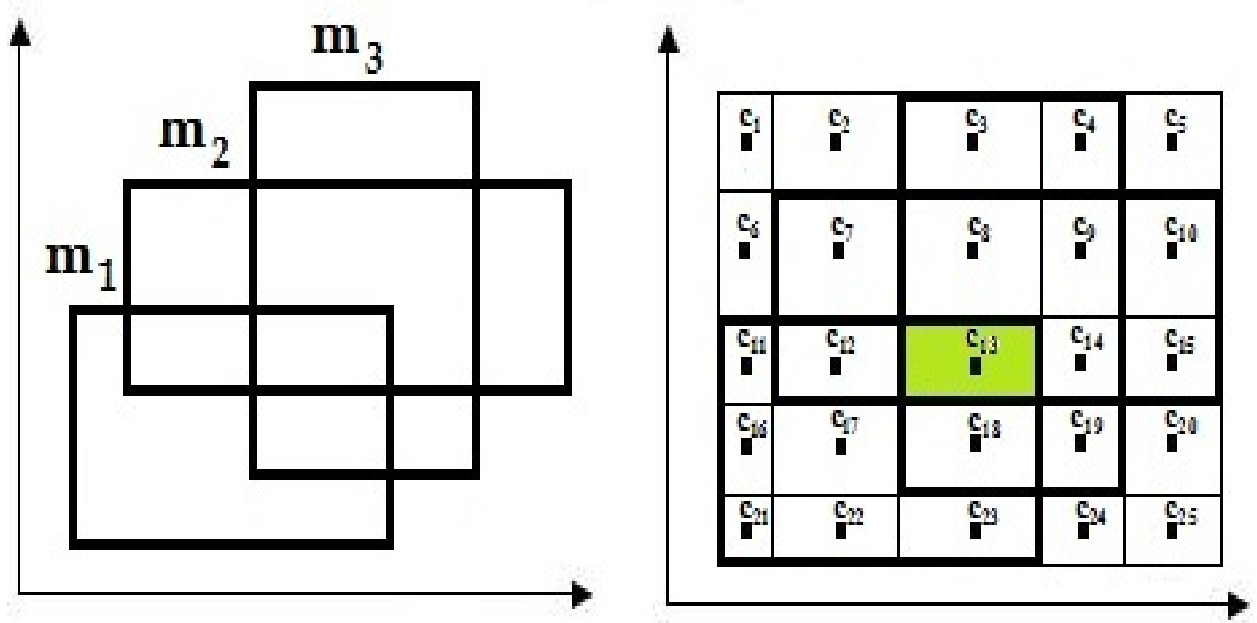

Figure: No outlier

No outlier

Center \ Measurement	[m1]	[m2]	[m3]	Sum
c_1	0	0	0	0
c_4	0	0	1	1
c_7	0	1	0	1
c_8	0	1	1	2
c_{11}	1	0	0	1
c_{12}	1	1	0	2
c_{13}	1	1	1	3
c_{18}	1	0	1	2
c_{25}	0	0	0	0

Figure: No outlier

No outlier

Center \ Measurement	[m1]	[m2]	[m3]	Sum
c_1	0	0	0	0
c_4	0	0	1	1
c_7	0	1	0	1
c_8	0	1	1	2
c_{11}	1	0	0	1
c_{12}	1	1	0	2
c_{13}	1	1	1	3
c_{18}	1	0	1	2
c_{25}	0	0	0	0

Center \ Measurement	[m1]	[m2]	[m3]	[s]
c_{13}	1	1	1	1
Result	1	1	1	1
No outliers				

Figure: No outlier

Outlier detection and identification

- $q = 0 \rightarrow \bigcap_{i=1,3}^{\{q\}} m_i = \emptyset \Rightarrow q = 1 \rightarrow \bigcap_{i=1,3}^{\{q\}} m_i \neq \emptyset$

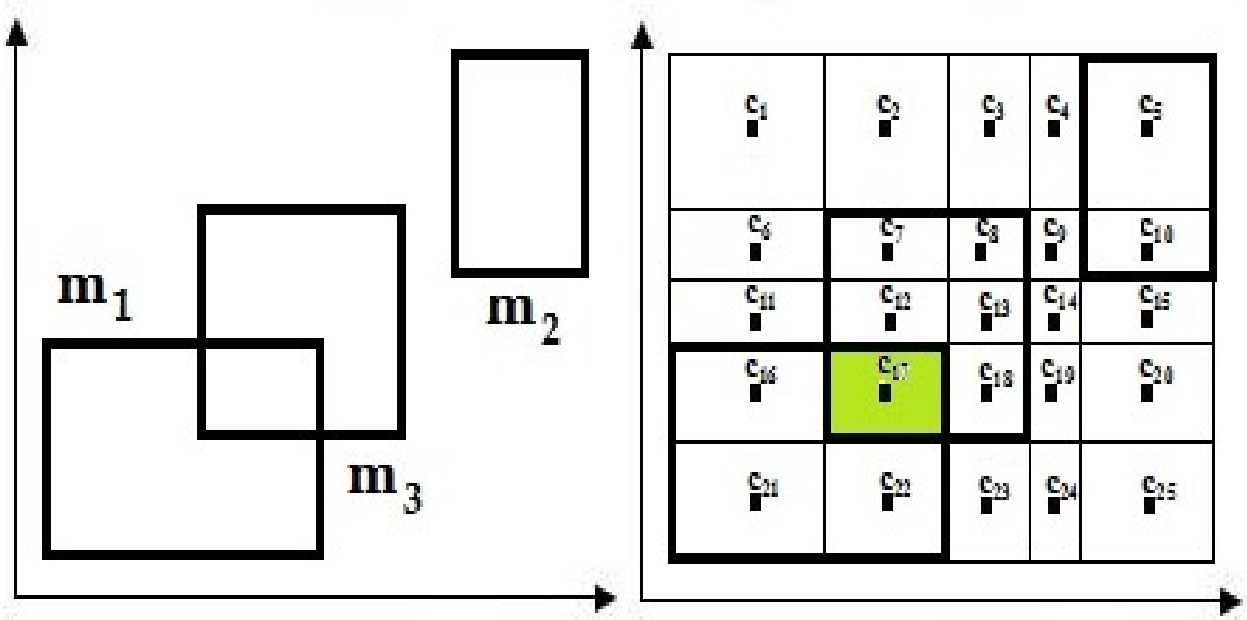

Figure: Outlier detection and identification

Outlier detection and identification

Center \ Measurement	[m1]	[m2]	[m3]	Sum
c_1	0	0	0	0
c_5	0	1	0	1
c_7	0	0	1	1
c_{16}	1	0	0	1
c_{17}	1	0	1	2
c_{25}	0	0	0	0

Figure: Outlier detection and identification

Outlier detection and identification

Center \ Measurement	[m1]	[m2]	[m3]	Sum
c_1	0	0	0	0
c_5	0	1	0	1
c_7	0	0	1	1
c_{16}	1	0	0	1
c_{17}	1	0	1	2
c_{25}	0	0	0	0

Center \ Measurement	[m1]	[m2]	[m3]	[s]
c_{17}	1	0	1	0
Result	1	0 Outlier	1	0 Detection
Detection and identification				

Figure: Outlier detection and identification

Outlier non identification

- $q = 0 \rightarrow \bigcap_{i=1,3}^{\{q\}} m_i = \emptyset \Rightarrow q = 1 \rightarrow \bigcap_{i=1,3}^{\{q\}} m_i \neq \emptyset$

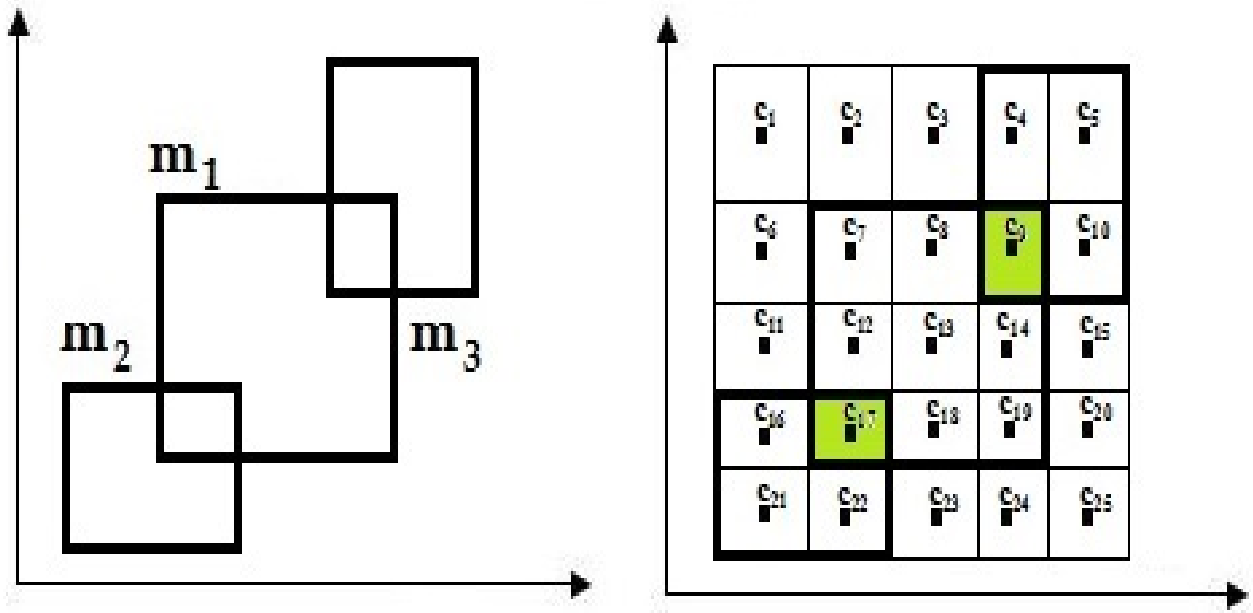

Figure: Outlier non identification

Outlier non identification

Center \ Measurement	[m1]	[m2]	[m3]	Sum
c_1	0	0	0	0
c_4	0	0	0	1
c_7	1	0	0	1
c_9	1	0	1	2
c_{16}	0	1	0	1
c_{17}	1	1	0	2
c_{25}	0	0	0	0

Figure: Outlier non identification

Outlier non identification

Center \ Measurement	[m1]	[m2]	[m3]	Sum
c_1	0	0	0	0
c_4	0	0	0	1
c_7	1	0	0	1
c_9	1	0	1	2
c_{16}	0	1	0	1
c_{17}	1	1	0	2
c_{25}	0	0	0	0

Center \ Measurement	[m1]	[m2]	[m3]	[s]
c_9	1	0	1	0
c_{17}	1	1	0	0
Result	1	1	1	0 Detection
Outlier non identification				

Figure: Outlier non identification

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Mobility model

- Random Walk model [T. Camp 2002], [F. Mourad et al., 2012]
- Minimum assumptions

Mobility model

- Formulation :

$$(x(t) - x(t-1))^2 + (y(t) - y(t-1))^2 = (\Delta t.v_{\max})^2$$

- or :

$$\begin{cases} x(t) = x(t-1) + \Delta t.v.\cos(\theta) \\ y(t) = y(t-1) + \Delta t.v.\sin(\theta) \end{cases}$$

- $\theta \in [0, 2\pi]$, $v \in [0, v_{max}]$.

Observation model

- Zones representing the coverage detection of infrared sensors
- Naturally described in an error bounded framework

Propagation phase

- Computing the predicted set using the mobility model :

$$\begin{cases} [x](t) = [x](t-1) + [-\Delta t.v_{\max}, +\Delta t.v_{\max}] \\ [y](t) = [y](t-1) + [-\Delta t.v_{\max}, +\Delta t.v_{\max}] \end{cases}$$

Propagation phase

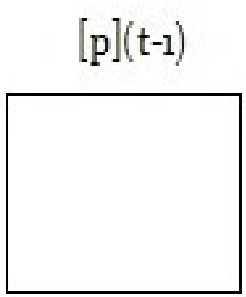

Figure: Propagation phase

Propagation phase

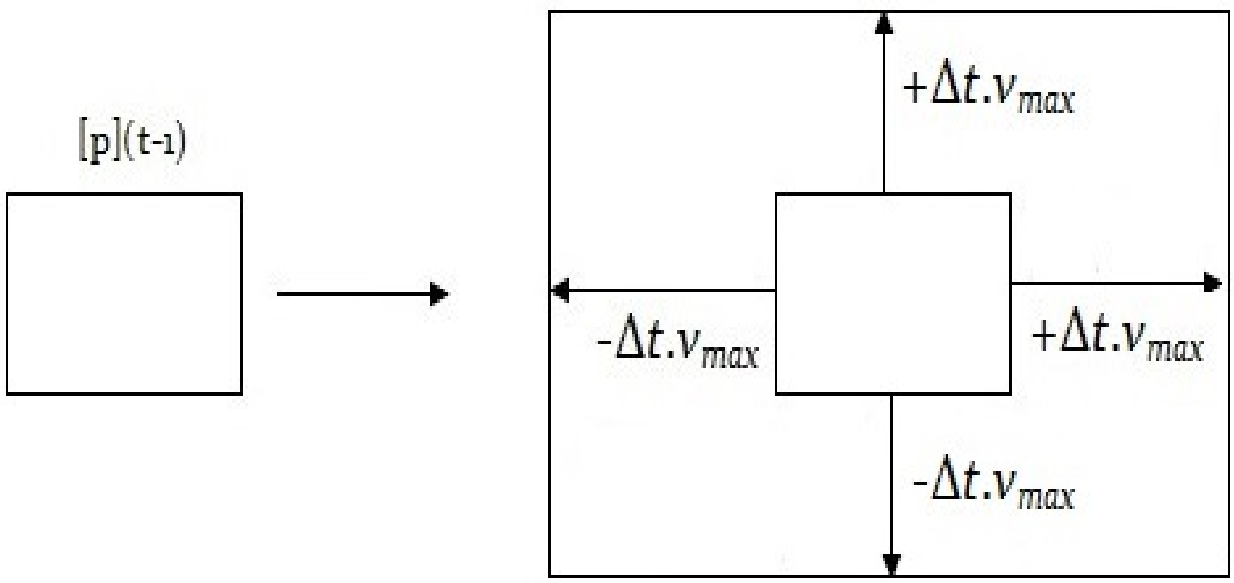

Figure: Propagation phase

Correction phase

- The predicted set is refined using the q-relaxed intersection with measurements :

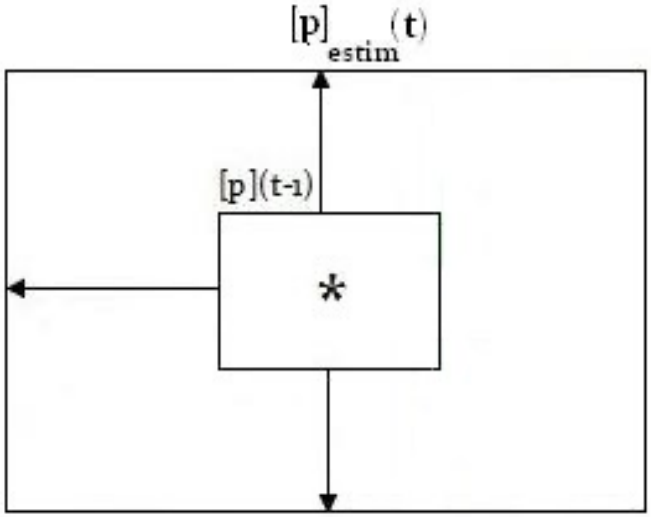

Figure: Correction phase

Correction phase

- The predicted set is refined using the q-relaxed intersection with measurements :

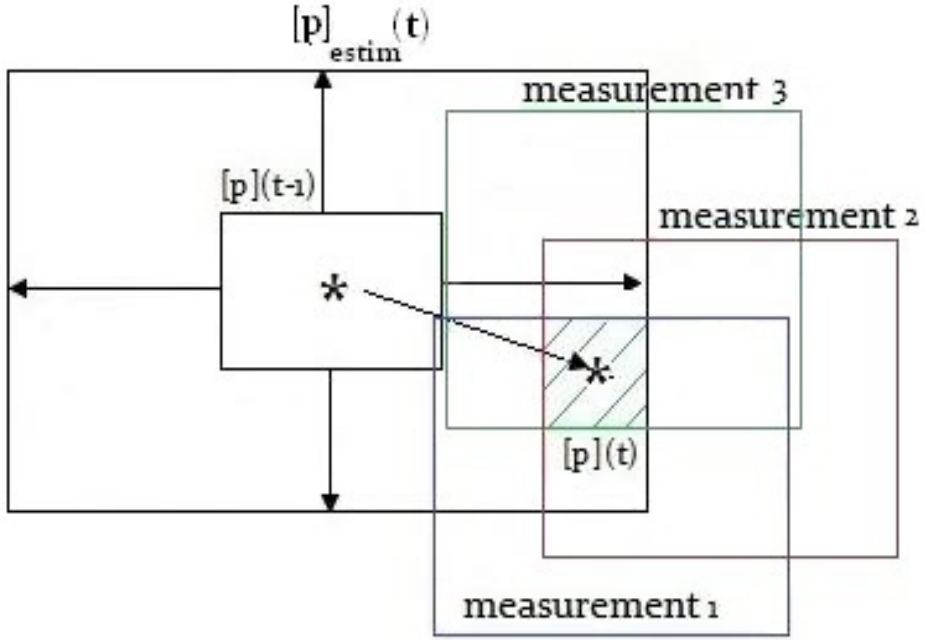

Figure: Correction phase

Cas particuliers

- Absence of infrared sensors measurements ⇒ No movement detected

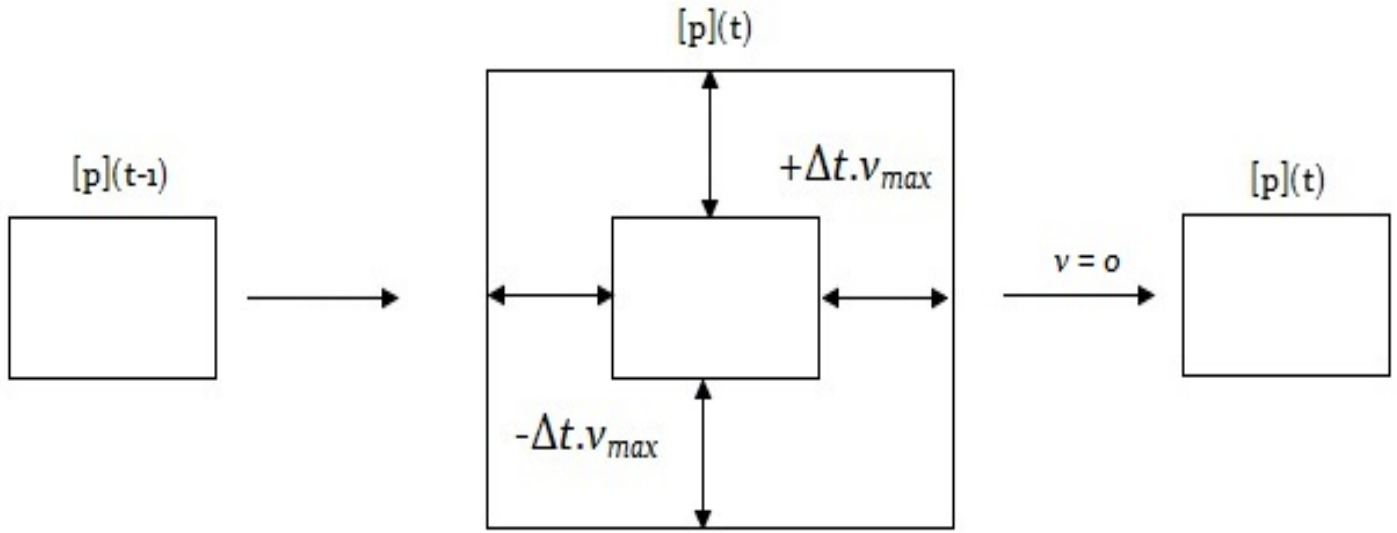

Figure: No movement detected

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The Living Lab



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

Zoning of the area

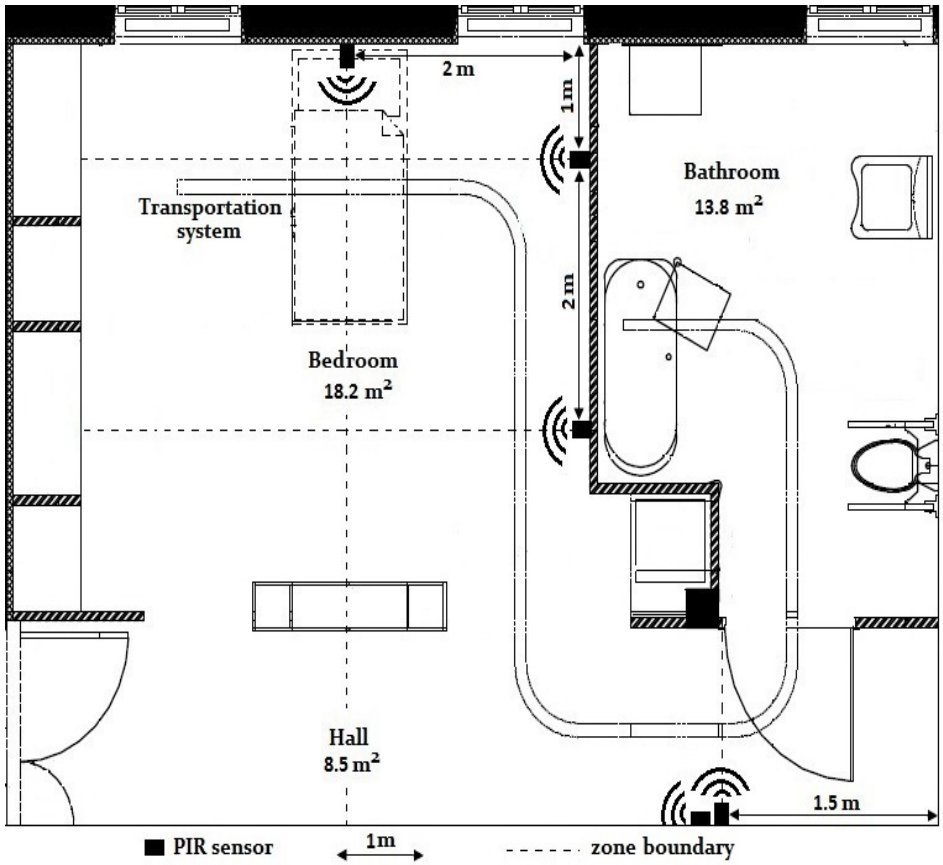

Figure: Zonage de l'espace

Results

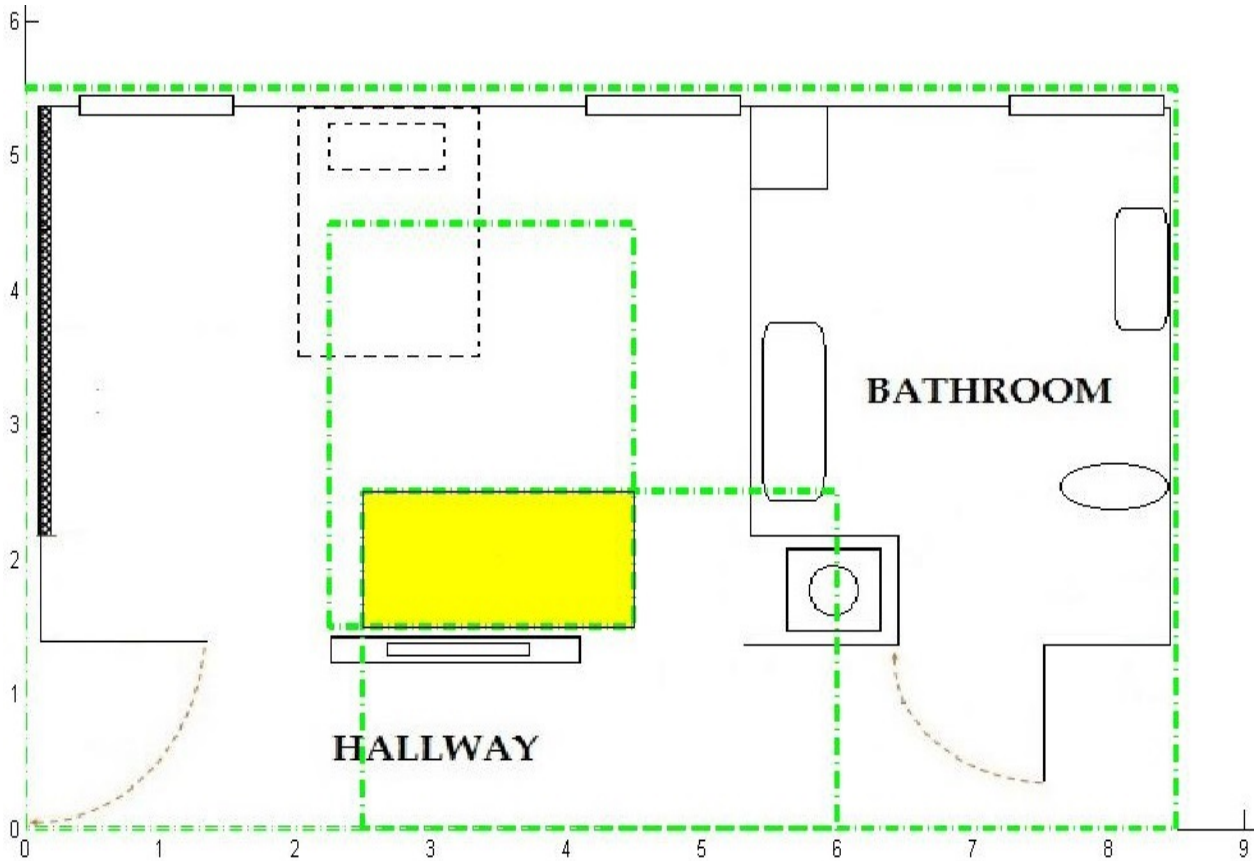

Figure: No faulty measurement detected

Results

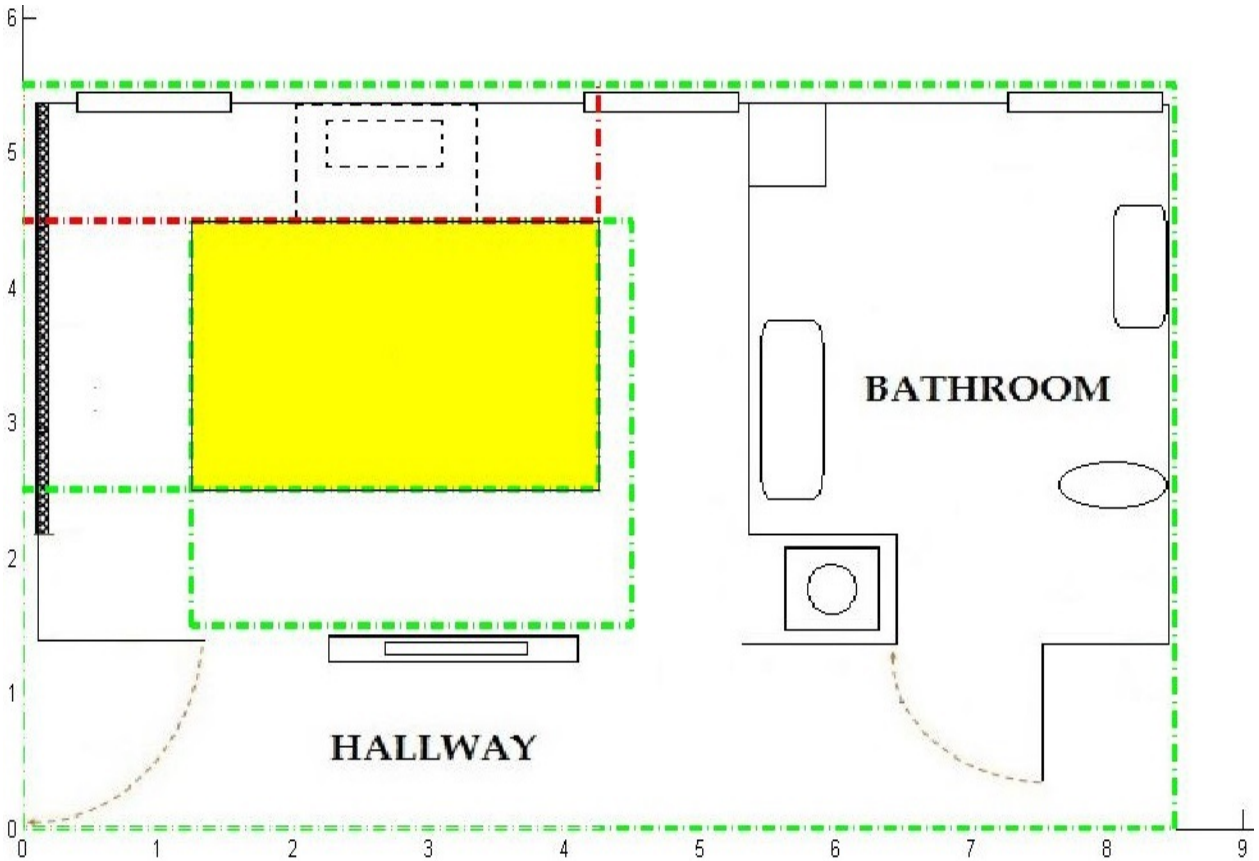

Figure: One outlier is detected and identified

Results

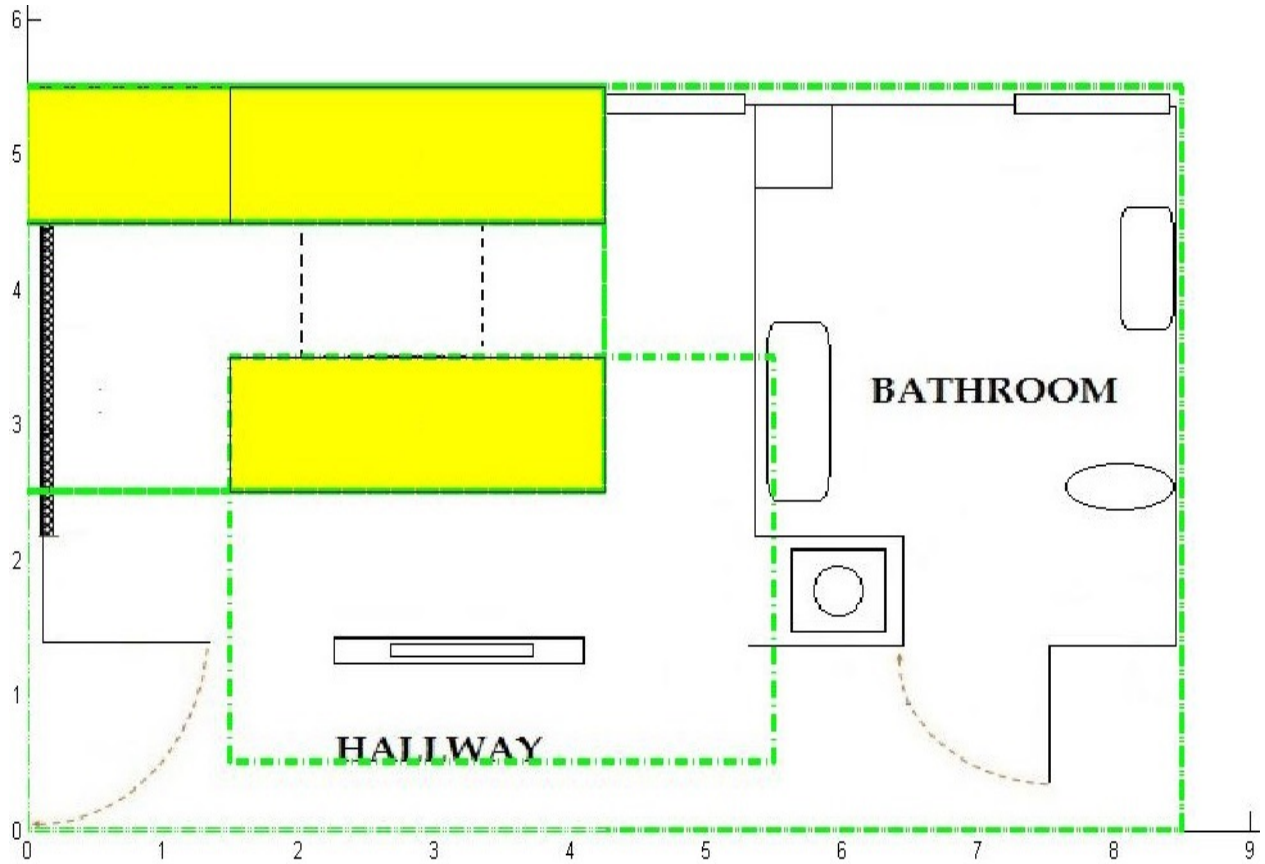

Figure: One outlier is detected but cannot be identified

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Conclusion and future work

- Multimodal fusion
- Bounded error and probabilistic uncertainties.