A Fuzzy Constraint Satisfaction Approach for Landmark Recognition in Mobile Robotics

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Presentation

The problem

Landmarks and patterns

Pattern modelling

Experimental results

Conclusions

Future work

- The problem: landmark detection
- The patterns caused by landmarks
- Pattern modelling: MFTP model
- Experimental results
- Conclusions and future work

The problem

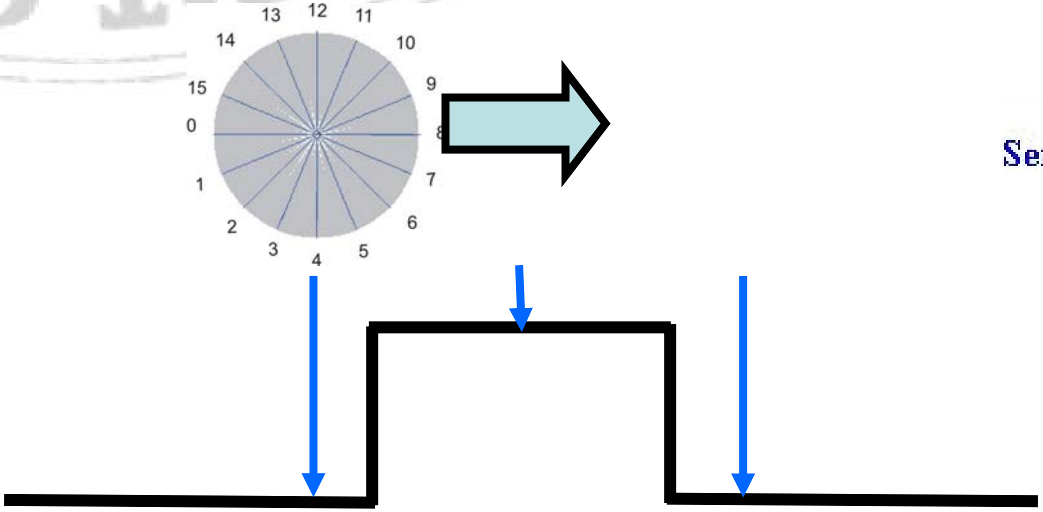
- Landmark detection is helpful to obtain a compact and structured representation of the enviroment.
- Most useful landmarks are the ones with high semantic content, as they help defining environment's structure: corridors, doors, corners…
- US sensors are the most common in mobile robotics, due to their simplicity, low cost and energy consumption.
  - However they present a high degree of noise and uncertainty, which usually leads to use more complex and expensive sensors for landmark detection tasks.

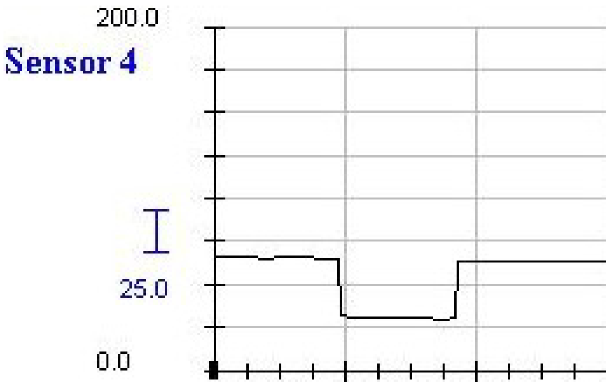
Our proposal

- We will show how US sensors can be employed to identify landmarks despite their noise and uncertainty.
- The keys to obtain a reliable detection in this circumstances will be in:
  - Dealing properly with the uncertainty of US sensors.
  - Integrating information arising from more than one sensor.
- We will employ in our test a mobile robot Nomad 200 equipped with a ring of 16 US sensors.

Landmarks and patterns

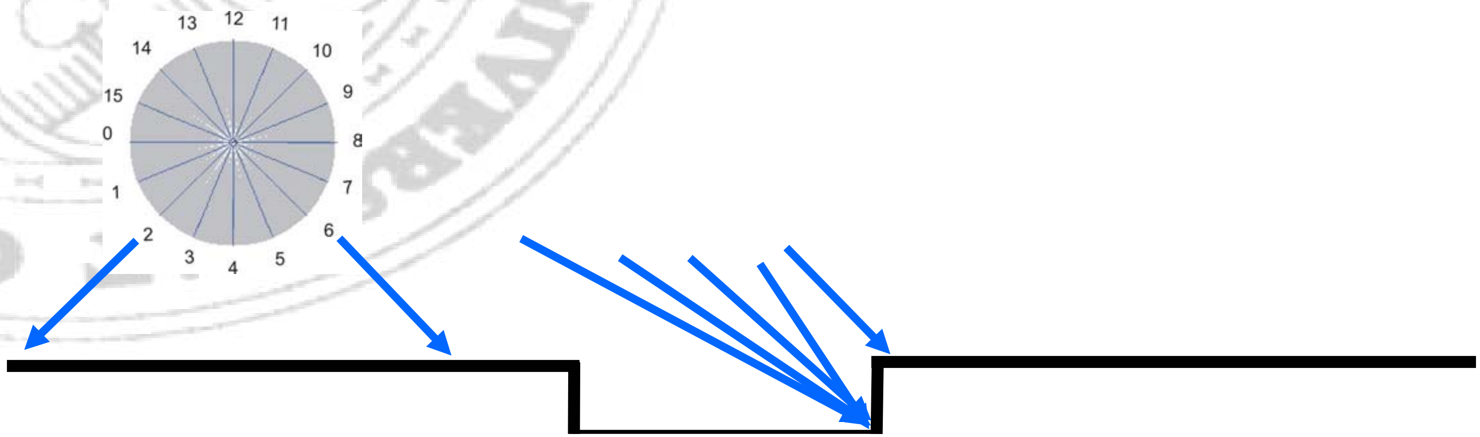
- Landmarks produce characteristic patterns over robot's sensors while they travel through the environment.
- By detecting these patterns we can recognize the landmarks that caused them.





Door pattern

- Doors also produce patterns, despite them not being so intuitive:



Sensor 6

Door pattern

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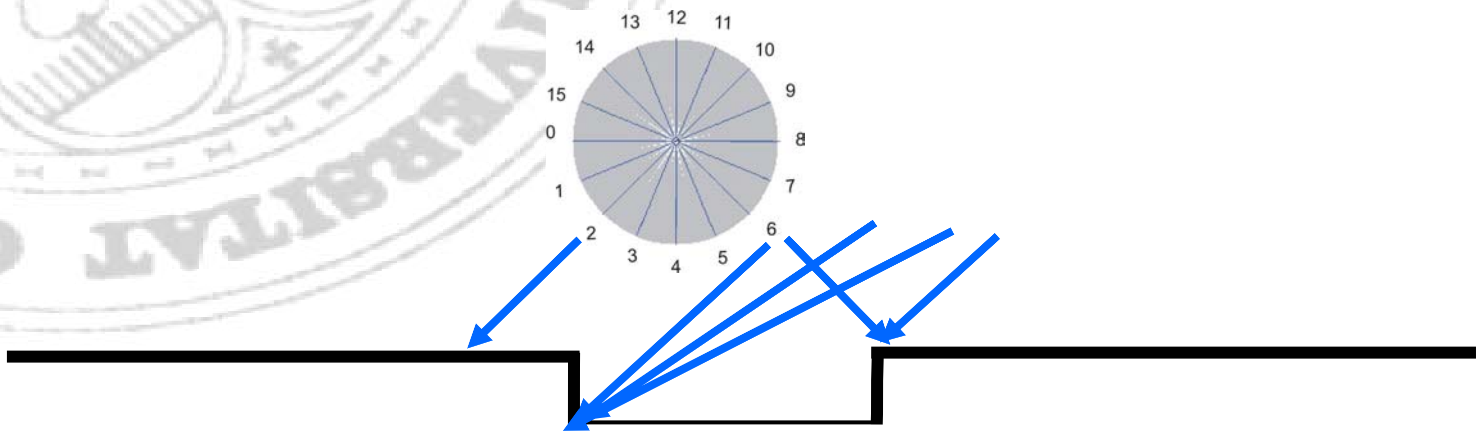
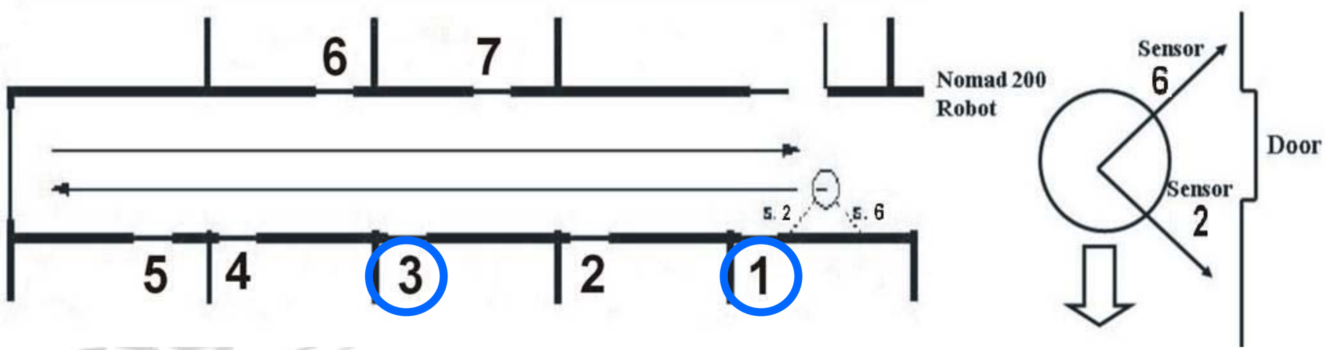


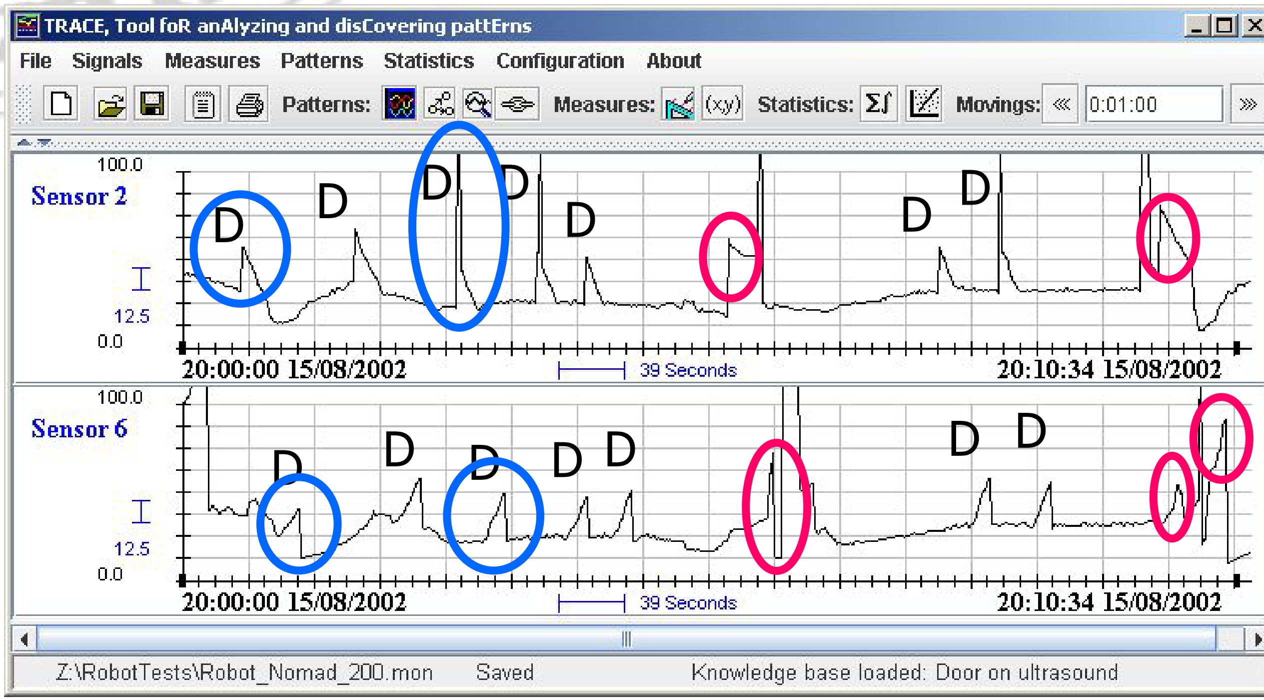
Sensor 2

Application: mobile robotics

- The problem
- **Landmarks and patterns**
- Pattern modelling
- Experimental results
- Conclusions
- Future work

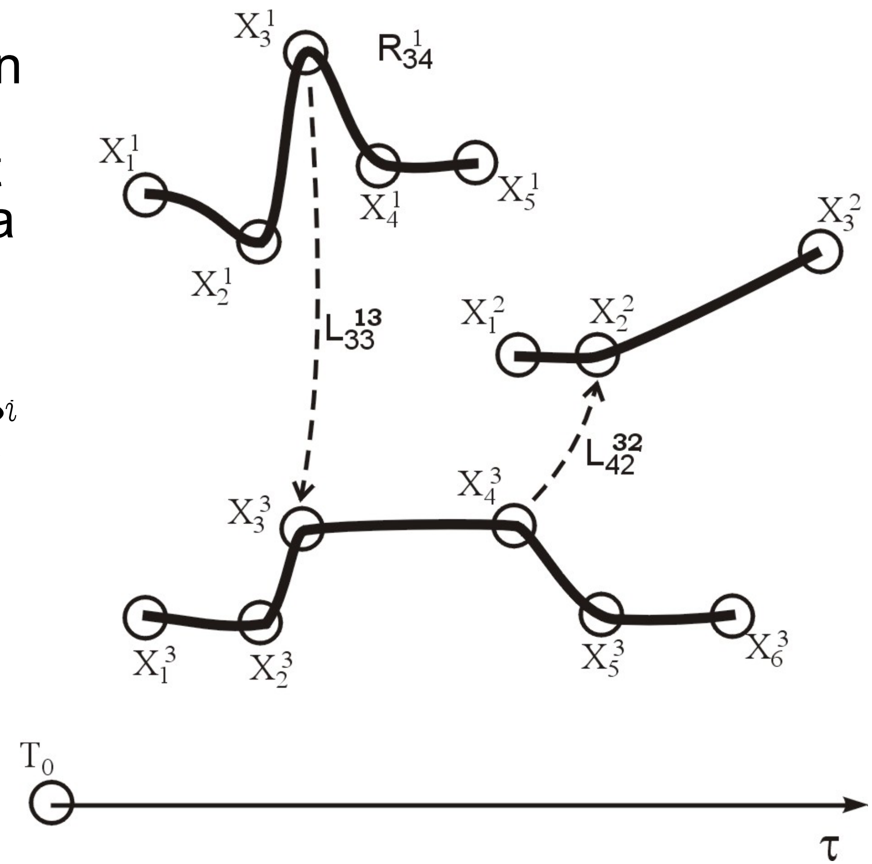
- Sonar sensors employed in the detection





Pattern modelling

- Multivariable Fuzzy Temporal Profile (MFTP) model allows the projection onto a computational model of knowledge about a pattern **M** defined over a set of parameters
  $P = \{P^1, \ldots, P^n\}$.
- In mobile robotics each P^i is given by the readings of one sensor.
- Based on CSP formalism and on the fuzzy set theory.
- Organizes information hierarchically.



Profile modelling

The problem

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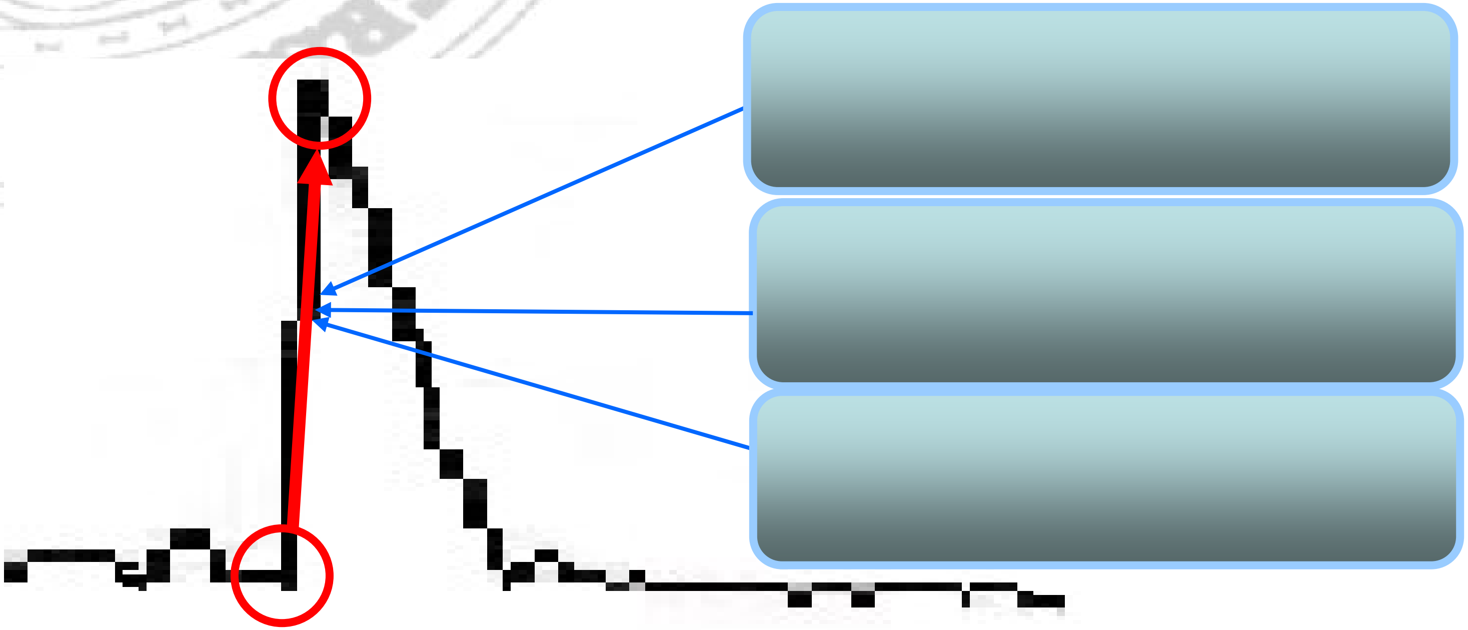
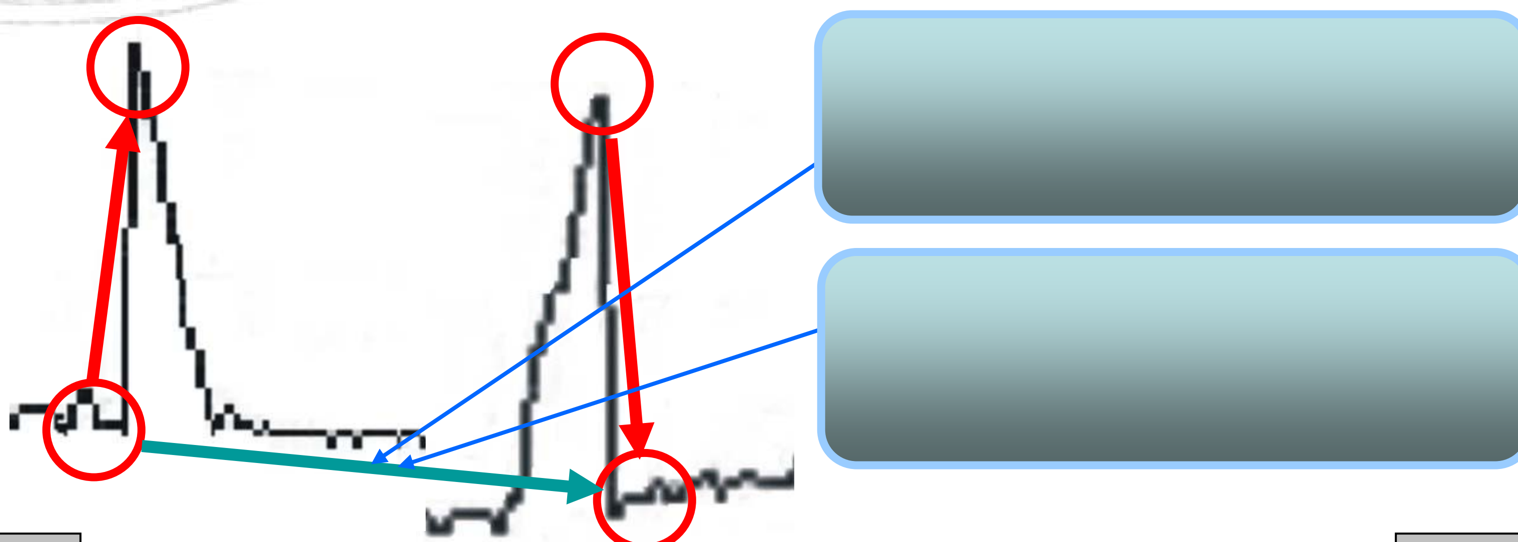
- A **Fuzzy Temporal Profile** $N^j = < X^j, R^j >$ is a finite set of
  - significant points $X^j = \{X_0^j, X_1^j, \ldots, X_n^j\}$; $X_i^j = < T_i^j, U_i^j >$
  - and fuzzy constraints $R^j = (R_0^j, R_1^j, \ldots, R_g^j)$ between them.
- It is represented by a graph.



Pattern modelling

- MFTP model extends FTP enabling constraints between significant points defined over different parameters.
- **Multivariable Fuzzy Temporal Profile** $\mathcal{M} = < W^{\mathcal{M}}, X^{\mathcal{M}}, R^{\mathcal{M}} >$ is defined as a finite set of:
  - MFTPs $W^{\mathcal{M}} = \{M_1^M, \ldots, M_s^M, \ldots\}$
  - significant points $X^{\mathcal{M}} = \{ X_1^j, \ldots, X_n^k \}$
  - fuzzy constraints $\mathcal{R}^{\mathcal{M}} = \{ R_1, \ldots, R_f \}$ between $W^{\mathcal{M}}$ and $X^{\mathcal{M}}$.



Pattern modelling

- The hierarchical structure of MFTP model endows it with
  - Modularity: one MFTP can be composed by several subMFTPs, and at the same time belong to several MFTPs.
  - Efficiency in the matching stage, regarding the matching of the MFTP as a whole.
- Usually $M=\{W^M,X^M,R^M\}$ such as $X^M=\phi$ and for any subMFTP $M_o=\{W^{M_o},X^{M_o},R^{M_o}\}$ with $W^{M_o}=\phi$.

Matching

- The ultimate aim of the MFTP model is to perform the matching of the pattern *M* over the temporal evolution *P* of the system.
- A **solution** *A* of a MFTP *M* is a set of assignments $A = \{A_0, A_1, \ldots, A_n\}$, where $A_i = (v^j_{[m]}, t^j_{[m]})$, $(v^j_{[m]}, t^j_{[m]}) \in P^j$, satisfying the constraints that make up *M*.
- The degree of satisfaction of a solution *A* is given by:

$$\pi^M(A) = \min\{\min_{M_h^M \in W^M}\{\pi^{M_h^M}(A^{M_h^M})\}, \min_{\mathrm{R_k} \in R^M}\{\pi^{\mathrm{R_k}}(A^{\mathrm{R_k}})\}\}$$

- Matching is carried out in as many stages as abstraction levels there are on the pattern.

Matching

- In both searchs we employ a non-binary extension of Forward Checking: nFC0 [Bessiere, 2002].
- The problem, in the general case, is NP-complete.
- However MFTP's hierarchical structure allows to easily achive real-time performance for real patterns.
  - Heuristics can be employed: prioritizing uncommon events, Minumun Value Remaining, knowledge from the domain…

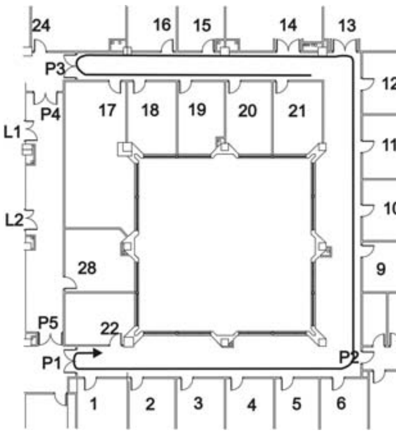
The tests

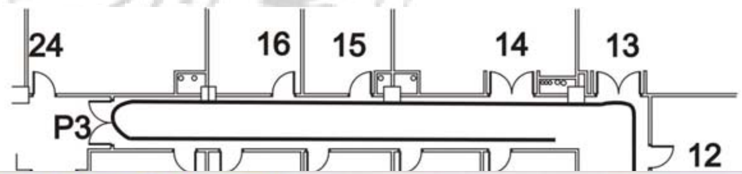
- We have tested our system employing a Nomad 200 robot.
- The robot navigates under a "wall-following" behaviour.
- Tests aimed to be as representative as possible of the different robot's modes of operation.

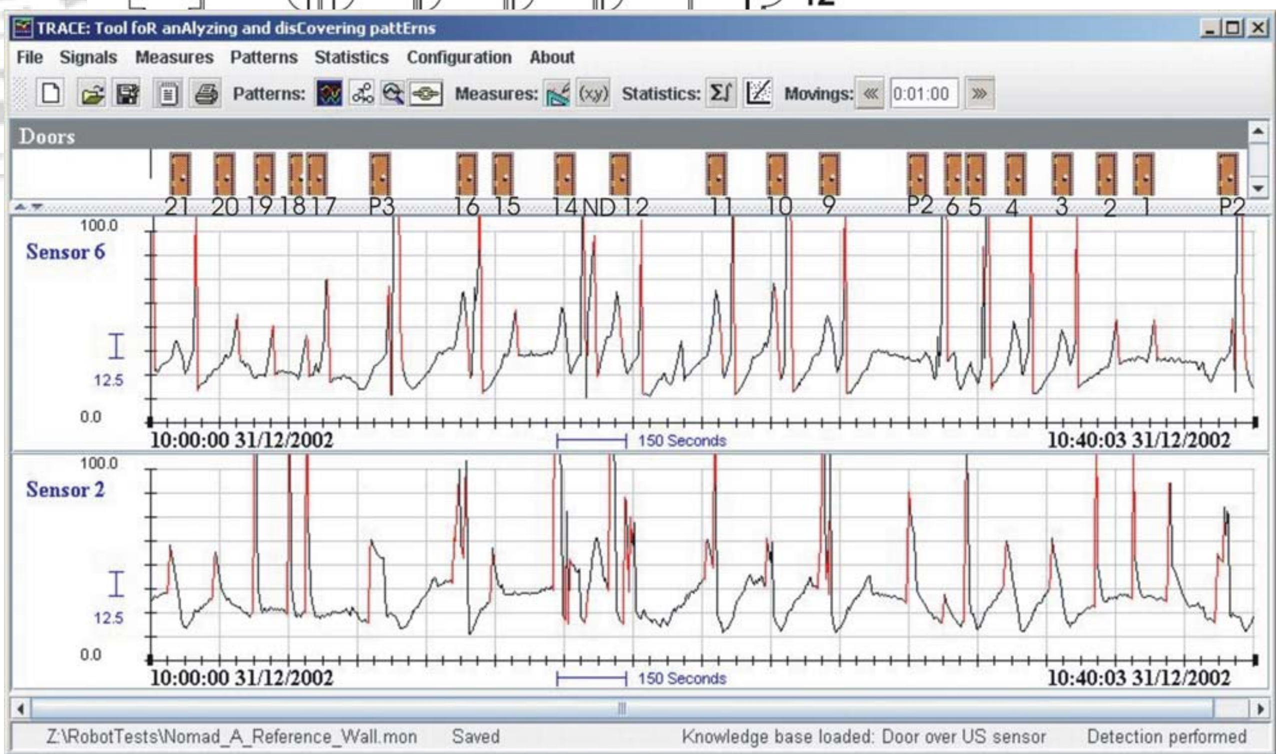
Nomad 200

Sample trajectory

- Outline followed :







Sample trajectory

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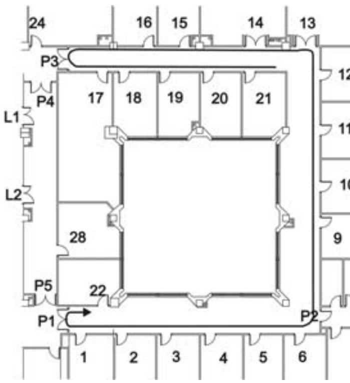
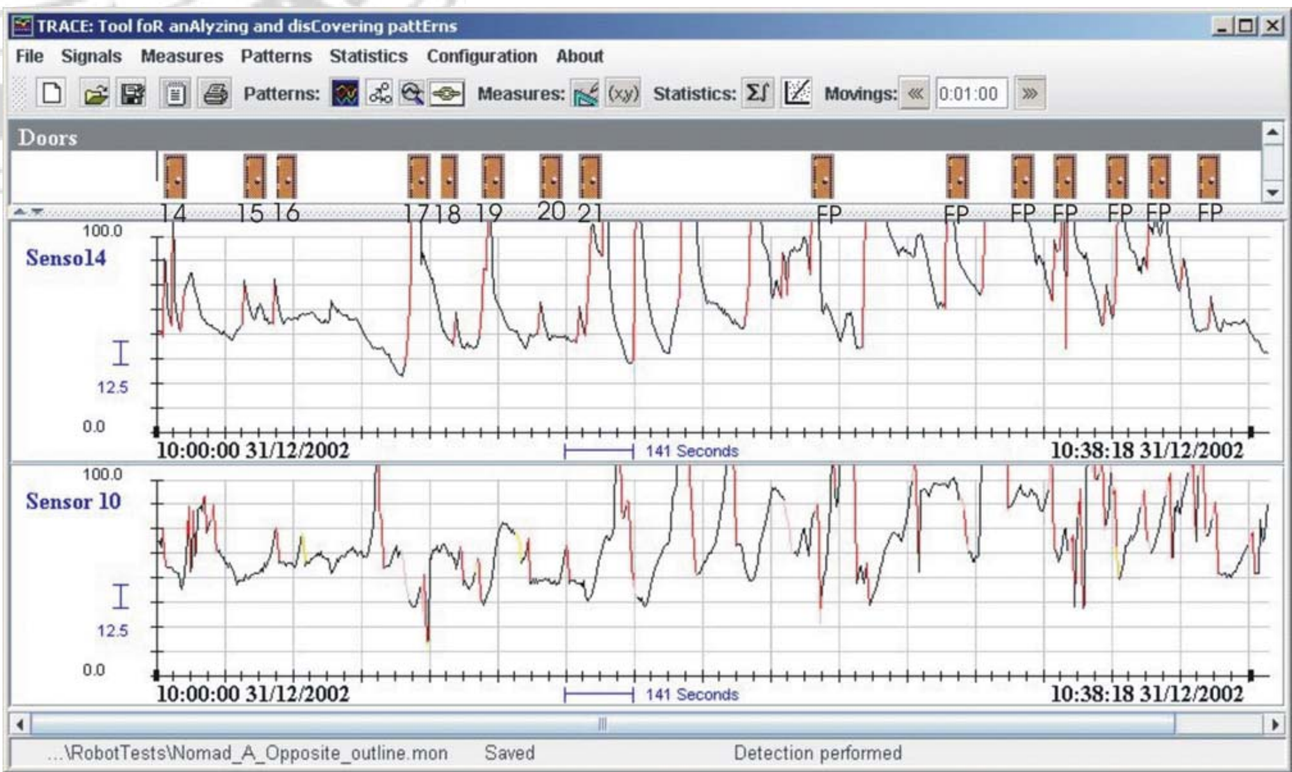
- Opposite outline:





Sample trajectory II

The problem

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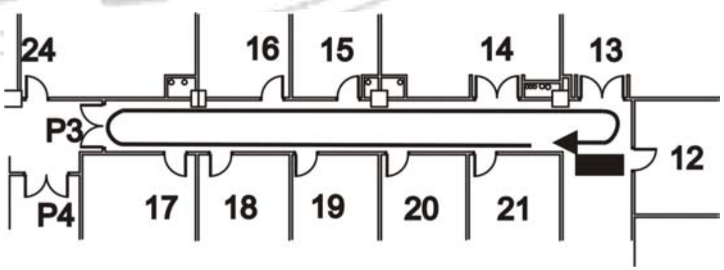
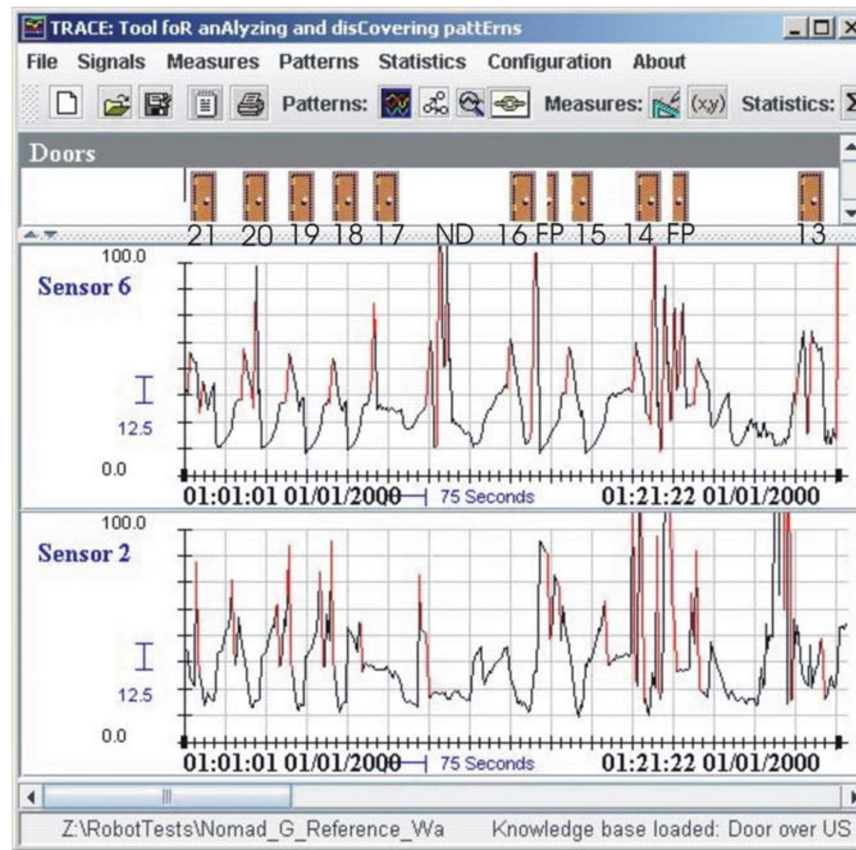
- Alignment of base and tower is not forced.





Global results

- Global results:
  - 93% correct detections with 15% FP.
  - 81% correct detections with 27% FP in the opposite outline.
- In the trajectories F and G the alignment of the base and the tower is not forced.

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Reference wall

Test	TD	DD	CD	FP	%CD	%FP
A	16	15	15	0	94	0
B	17	19	17	2	100	11
C	17	20	17	3	100	15
D	22	24	20	4	91	16
E	11	12	10	2	91	17
F	11	12	9	3	82	25
G	10	11	9	2	90	18
H	10	11	9	2	90	18
Total	114	124	106	18	93	15

TD: Total Doors; DD: Detected Doors; CD: Correct Detections; FP: False Positives

Opposite wall

Test	TD	DD	CD	FP	%CD	%FP
A	8	15	8	7	100	47
B	18	17	15	2	83	12
C	18	20	16	4	89	20
D	18	17	14	3	78	18
E	11	11	8	3	73	27
F	11	10	8	2	73	20
G	9	12	6	6	67	50
H	9	12	8	4	89	33
Total	103	114	85	31	81	27

TD: Total Doors; DD: Detected Doors; CD: Correct Detections; FP: False Positives

Detection's performance

- A note on computational requirements:
  - 30 minutes of robot's trajectory can be processed in a Pentium III 800 MHz in less than 5 seconds (both sides).
    - Thus it can be applied to real time tasks.
  - The algorithm only requires the storage of a few trapezoidal possibility distributions and of a fragment of sensor signals whose temporal extension is equal to the maximum length of the pattern.

Conclusions

- This work presents a landmark detection method that can be applied to any robot that has a belt of US sensors.
  - It can be applied to robots with small computing power.
- The method is very robust inside corridors
  - Turns (corners, end of corridors…) are the main cause of fails in the detection.
- The integration of information arising from more than one sensor has been the key to obtain a reliable detection despite signal's noise and uncertainty.
- Even though we have applied the method to US sensors, it may be applied to any sensor that produces a one dimensional signal.

Future Work

- To build a fuzzy representation of the environment which:
  - Exploits the landmarks obtained through MFTP model and their fuzzy spatial relations.
  - Represents the environment in a hierarchical way, allowing several levels of detail depending on each specific task.
- To tackle rout planning and navigation tasks in the aforementioned representation.