Cooperative Robotics in Urban Areas

Prof. Alberto Sanfeliu
Director
Institute of Robotics (IRI) (CSIC-UPC)
Technical University of Catalonia
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http://www-iri.upc.es

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- Open issues

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Network Robot Systems

Network Robots Systems (Japan)

Ubiquitous Network

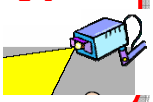
"Visible" type

Apri-alpha Robovie

Network Robots

"Virtual" type

"Unconscious" type



Network Robot Systems (EU)

Definition:

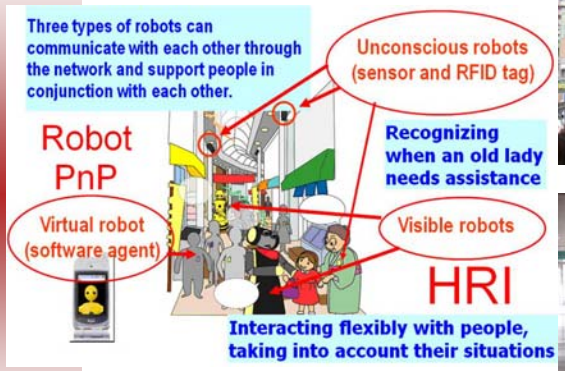
A Network Robot System is a group of artificial autonomous systems that are mobile and that makes important use of wireless communications among them or with the environment and living systems in order to fulfill their tasks.

Elements:

- Autonomous robot
- Communication network
- Environment sensors
- People

Some Examples of NRS

Japan NRS Project



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URUS: Robots in Urban Areas

Cameras and ubiquitous sensors

Robots with intelligent head and mobility

People with mobile phones and RDFI

Wireless and network communication

Robots for transportation of people and goods

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DustBot: Urban Hygiene

DustClean Robot

DustCart Robot

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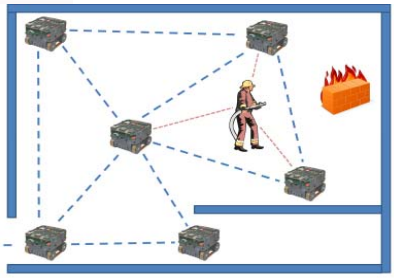
Guardians: Robot Assistant for Firemen



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URUS project

URUS project
Ubiquitous Networking Robotics in Urban Settings

http://urus.upc.es

URUS Project Objectives

- **Objectives:**
  - The main objective is to develop an adaptable network robot architecture which integrates the basic functionalities required for a network robot system to do urban tasks

- ***1. Scientific and technological objectives***
  - Specifications in Urban areas
  - Cooperative localization and navigation
  - Cooperative environment perception
  - Cooperative map building and updating
  - Human robot interaction
  - Multi-task allocation
  - Wireless communication in Network Robots

- ***2. Experiment objectives***
  - Guiding and transportation of people
  - Surveillance: Evacuation of people

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URUS Partners

Participant Role*	Country	Participant name	Participant short name
Coordinator Research Partner	Spain	Technical University of Catalonia (Institute of Robotics) Alberto Sanfeliu	UPC
Research Partner	France	Centre National de la Recherche Scientifique Rachid Alami / Raja Chatila	LAAS
Research Partner	Switzerland	Eidgenössische Technische Hochschule Roland Siegward	ETHZ
Research Partner	Spain	Asociación de Investigación y Coop. Indus. de Andalucia Anibal Ollero	AICIA
Research Partner	Italy	Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna Paolo Dario	SSSA
Research Partner	Spain	Universidad de Zaragoza Luis Montano	UniZar
Research Partner	Portugal	Instituto Superior Técnico Joao Sequeira / Jose Santos Victor	IST
Research Partner	UK	University of Surrey John_Illingworth	UniS
Agency Partner	Spain	Urban Ecology Agency of Barcelona Salvador Rueda	UbEc
Industrial Partner	Spain	Telefónica I+D Xavier_Kirchner	TID
Industrial Partner	Italy	RoboTech Nicola Canelli	RT

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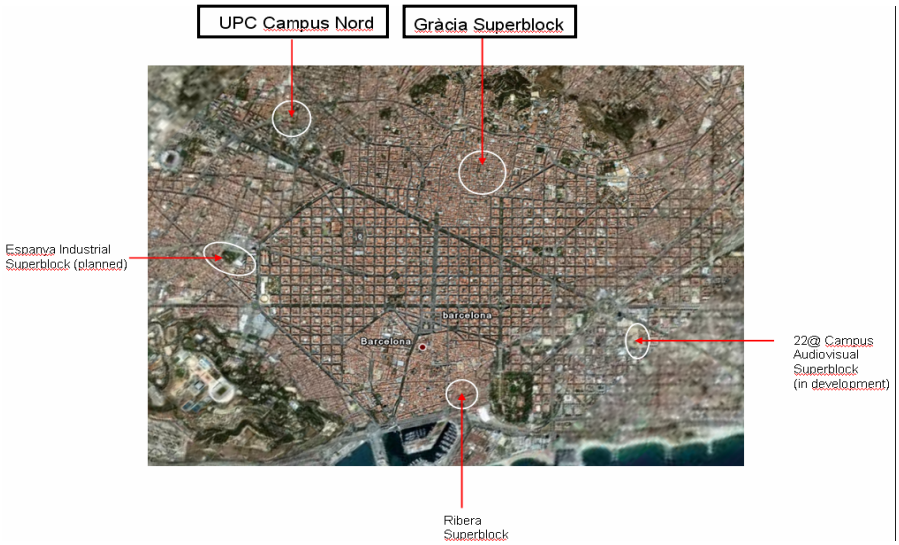
Experiment Locations



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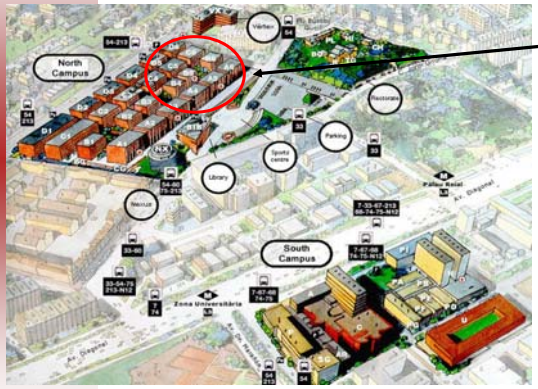
Experiment Locations: Scenario 1 UPC

Zone Campus Nord, UPC



Barcelona ROBOT Lab

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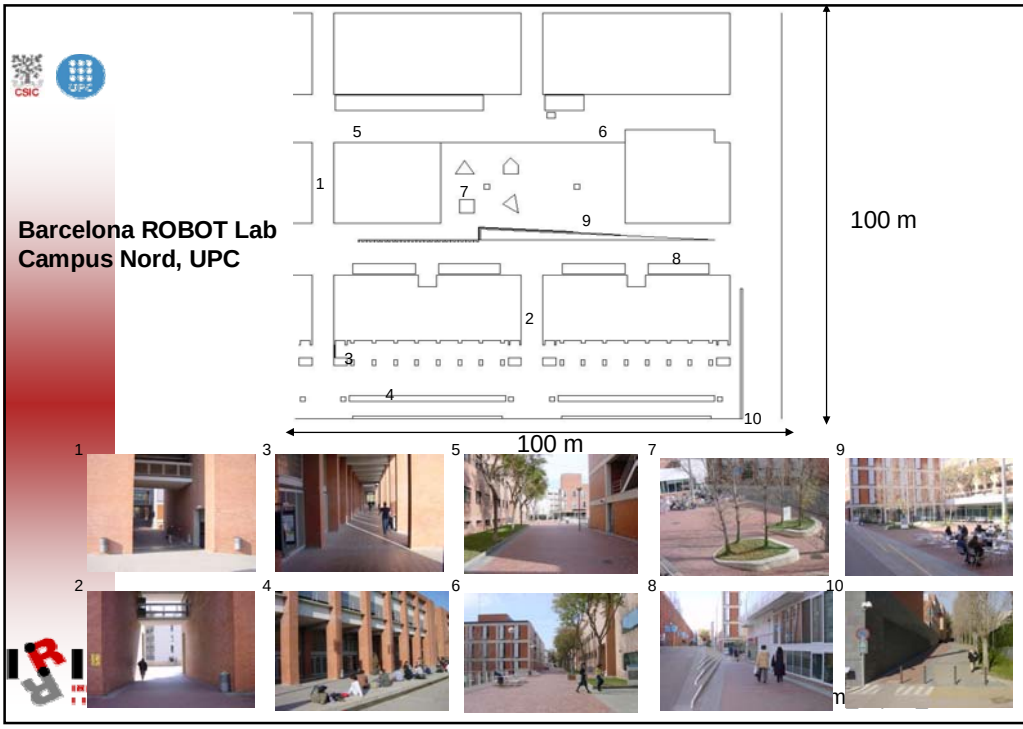
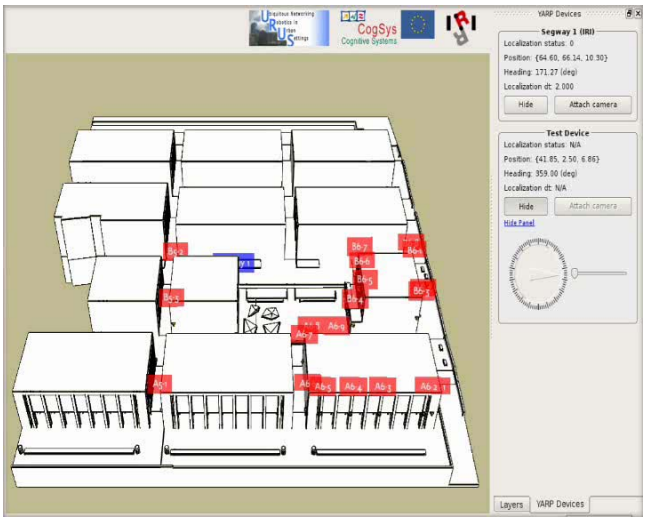
Barcelona ROBOT Lab
Campus Nord, UPC



Experiment Location: Scenario 1
UPC



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Experiment Location: Inauguration

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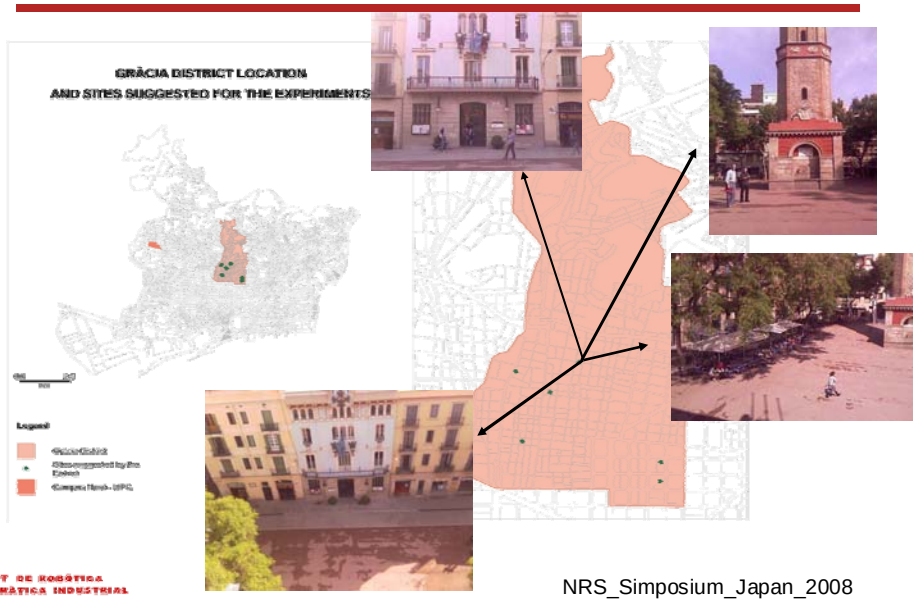
Experiment Location: Scenario 2
Gracia District



Global Architecture

URUS_rot3D.exe



Robot 1 | Robot 2 | Robot N

Functional Layer / Supervisor Task Allocation

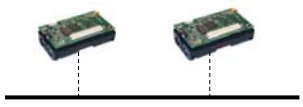
WLAN GSM/3G | WLAN GSM/3G | WLAN GSM/3G | Blue Tooth

Ethernet

Central Station: Task Allocation; Environment Perception; GSM/3G Interface; Global Supervision

GSM/3G Network

Ethernet (Gb)



Mica2/Ethernet network

Robots in Experiment Site 1

Experiments

- **Urban experiments:**
  - 1.- Transportation of people and goods
    - Transporting people and goods
      - Taxi service requested via the phone
      - User request the service directly
  - 2.- Guiding people
    - Guiding a person with one robot
  - 3.- Surveillance
    - Coordinate evacuation of a group of people
  - 4.- Map building

Concepts in Cooperative Robotics

Concepts on Cooperative Robotics: Definitions

- **Robot cooperation**
  - It is the ability of solving a task by two or more robots (with or without NRS elements)
  - Also, it is the ability of solving a task by one or more robots (or NRS element) and one or more persons
- **Robot coordination**
  - It is the functionality of executing an action using two or more robots (with or without NRS elements).
  - Synchronization is an example of robot coordination

Concepts on Cooperative Robotics: Levels

- **Cooperative robotic functions**
  - Basic robotic tools for solving tasks in a cooperative way
  - Examples:
    - Cooperative localization and navigation; cooperative environment perception; cooperative map building, etc.
- **Cooperative robotic tasks**
  - Using multiple robots (with or without NRS elements) and cooperative robotic functions for doing a specific task
  - Examples:
    - Search an rescue, soccer robots, guiding robots, etc.

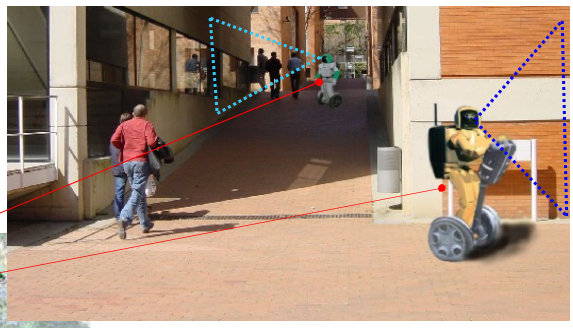
Cooperative Robotics Functions

Cooperative Localization and Navigation

Cooperative Localization and Navigation

Localization using:
- GIS, Compass, laser, estereo
- multiple robots
- ubiquitous sensors

Navigation:
- Using GIS, laser, compass
- Own and embedded sensors



Cooperative Localization: An Active Strategy for Global Localization

Question: How do we can know the global position of a robot?

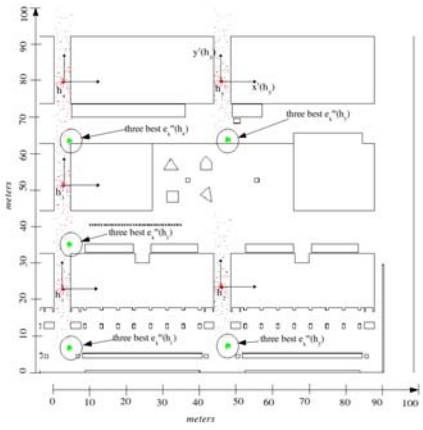
-Take measurements of the environment and make hypotheses

$$L[o_s(X_j^m), o_s(X_k^m)] \in [0,1]$$

Hypotheses

$$H = \{h_1, ..., h_i, ..., h_{N_H}\}$$

$$h_i = \{X_{h_i}^m, C_{h_i}, p_{h_i}\}; \quad \sum_{i=1}^{N_H} p_{h_i} = 1$$



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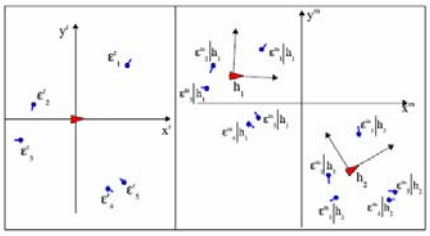
Cooperative Localization: An Active Strategy for Global Localization

Active strategy for global localization

Steps:

1.- Generating exploration particles

$$\epsilon_k^r = X_{\epsilon_k}^r = (x_{\epsilon_k}^r, y_{\epsilon_k}^r, \theta_{\epsilon_k}^r)$$



$$\epsilon_k^m|h_i = \begin{bmatrix} x_{h_i}^m \\ y_{h_i}^m \\ \theta_{h_i}^m \end{bmatrix} + \begin{bmatrix} cos(\theta_{h_i}^m) & -sin(\theta_{h_i}^m) & 0 \\ sin(\theta_{h_i}^m) & cos(\theta_{h_i}^m) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{\epsilon_k}^r \\ y_{\epsilon_k}^r \\ \theta_{\epsilon_k}^r \end{bmatrix} \quad \text{where} \quad h_i \forall \in [1..N_H]$$

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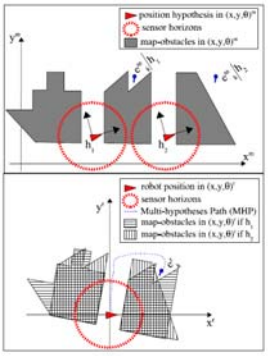
Cooperative Localization: An Active Strategy for Global Localization

2.- Multi-hypothesis path planning MHPP



$$E = \{e_1^r, .., e_k^r, ..e_{N_E}^r\}$$

N_E particles connected to a h_i

3.- Computing hypothesis reduction

$$\hat{N}_H(e_k^r)|h_i = \sum_{j=1}^{N_H} L[o_s(e_k^m|h_i), o_s(e_k^m|h_j)] \rightarrow \hat{N}_H(e_k^r) = \sum_{i=1}^{N_H} \hat{N}_H(e_k^r)|h_i \cdot p_{h_i}$$

Remaining hypotheses

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Cooperative Localization: An Active Strategy for Global Localization

Cooperative case

$$\hat{N}_H(e_k^r)|h_i = \sum_{j=1}^{N_H} L_C[o_s(e_k^m|h_i), o_s(e_k^m|h_j)]$$

$$\rightarrow \quad \hat{N}_H(e_k^r) = \sum_{i=1}^{N_H} \hat{N}_H(e_k^r)|h_i \cdot p_{h_i}$$

$$L_C[o_s(e_k^m|h_i), o_s(e_k^m|h_j)] = \begin{cases} 0 & \text{cooperative case} \\ L[o_s(e_k^m|h_i), o_s(e_k^m|h_j)] & \text{otherwise} \end{cases}$$

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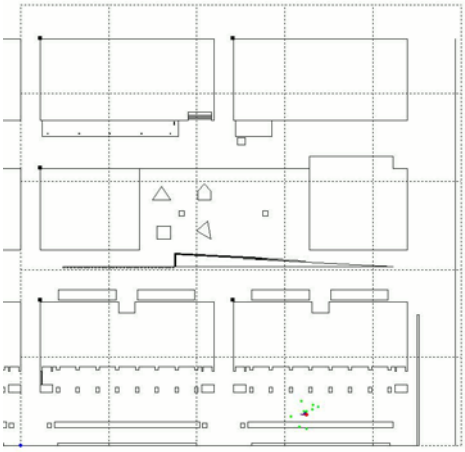
Cooperative Localization and Navigation

Robot localization using active global localisation

Video: **20080508posTrackingShort.mp4**



[Corominas, Mirats, Sanfeliu ICRA08, RAS08]

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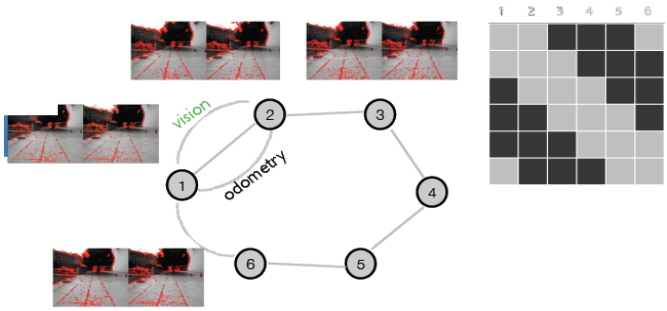
Cooperative Localization and Navigation: Fusing Odometry and Visual Odometry

Segway-robot navigation based on fusing odometry and visual odometry

Video: SANYO088.MP4 and video_SLAM_21Aug_new.avi

$$p(\mathbf{x}) \sim \mathcal{N}(\mathbf{x} : \boldsymbol{\mu}, \boldsymbol{\Sigma}) \sim \mathcal{N}^{-1}(\mathbf{x} : \boldsymbol{\eta}, \boldsymbol{\Lambda})$$

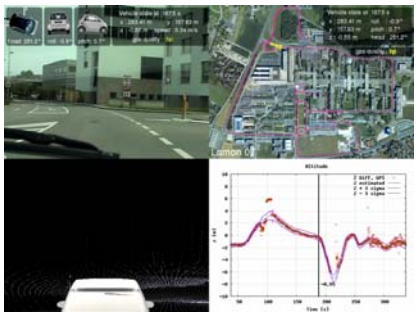


[Ila, Andrade, Sanfeliu, IROS07]

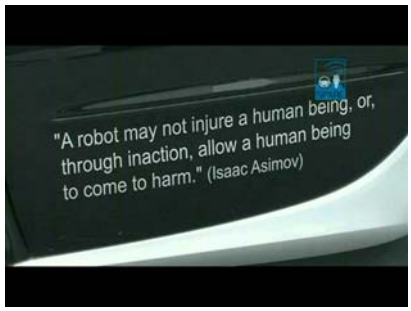
Cooperative Localization and Navigation

Smart navigation based on fusion of sensor information

Video showing Smart Ter at UPC siteVideo: SmartAndSegway.mpg



SmartTer: GPS/IMU/Odometry fusion **[Lamon et al 06].**

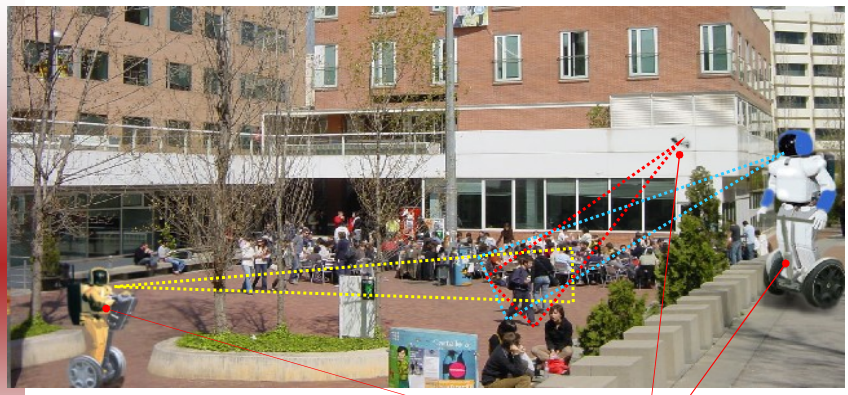


Safe RRT-based local planning and obstacle avoidance **[Macek et al 08]**.

Cooperative Robotic Functions:

Cooperative Environment Perception

Cooperative Environment Perception



Cooperative perception using:
- embedded and own sensors
- fusion techniques and technologies

Cooperative Environment Perception

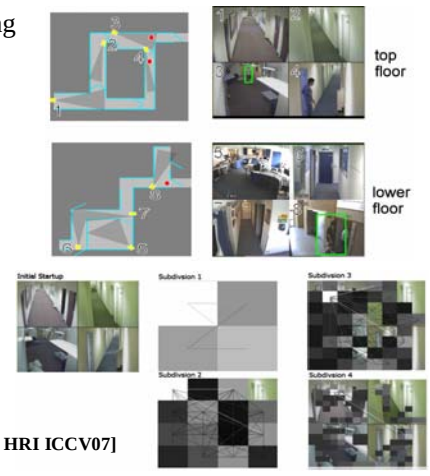
Following a person with environment cameras

video **videoUrus1.avi**

Cooperative Environment Perception

Following several persons with environment cameras

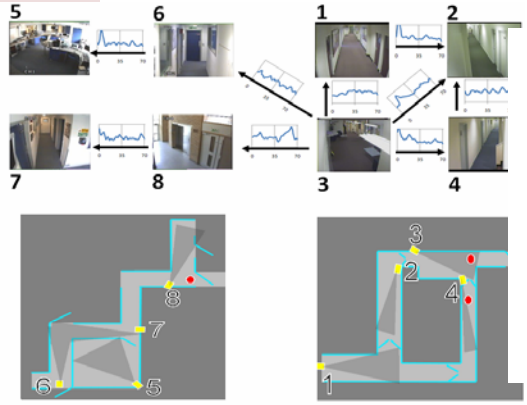
- Inter Camera – uncalibrated, non overlapping
- Learns relationships
  - Weak Cues
    - Color, Shape, Temporal
    - Learns consistent patterns
  - Learns Entry/Exit regions
- Real Time (25fps)
- Incremental design
  - work immediately
  - improves in accuracy over time

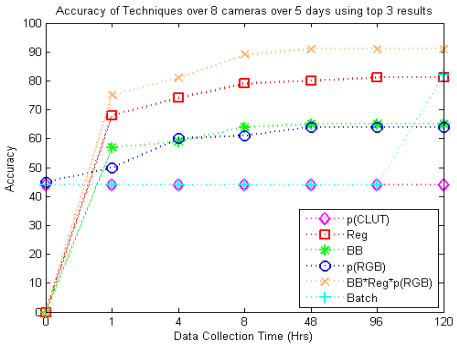


[Gilbert et al., HRI ICCV07]

Cooperative Environment Perception

Following several persons with environment cameras





Cooperative Environment Perception

The cooperation is being extended using POMPD, combining environment sensors and robot sensors

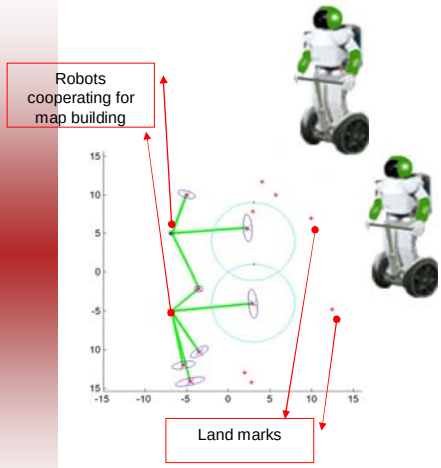
Image i

Image i+1

Cooperative Robotic Functions:

Cooperative Map Building and Updating

Cooperative Map Building and Updating



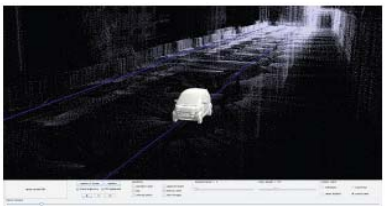
Cooperative Map Building:

- Using multiple robots and sensors
- Using control techniques

Cooperative Map Building and Updating

3D Map construction doing by Smart Ter robot

Video SmartData.mpg

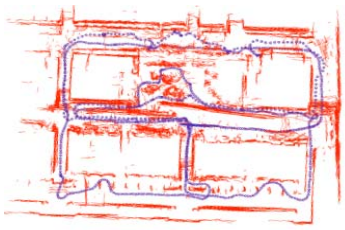


Cooperative Map Building and Updating

Video showing trasversability map building based on 3D odometry and stereovision Data robot

Video: serie04-1000-3000-dtm.mov

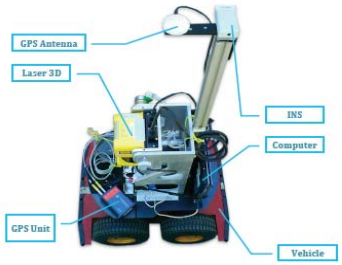
Video: serie04-1000-2260-classif.mov

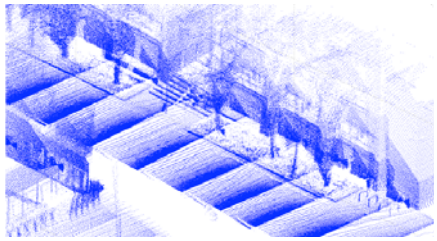


Reprojection of raw laser data on the basis of 2D odometry estimates
Final position error < 1m

Cooperative Map Building and Updating

UPC 3D ranger scan





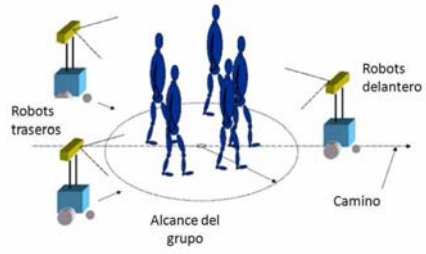
Cooperative Robotic Tasks:

Cooperative People Guiding

Cooperative People Guiding

Guiding people by robots

Cooperative People Guiding

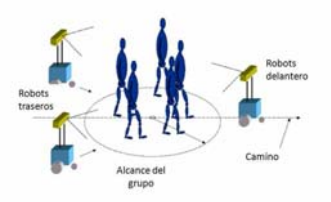


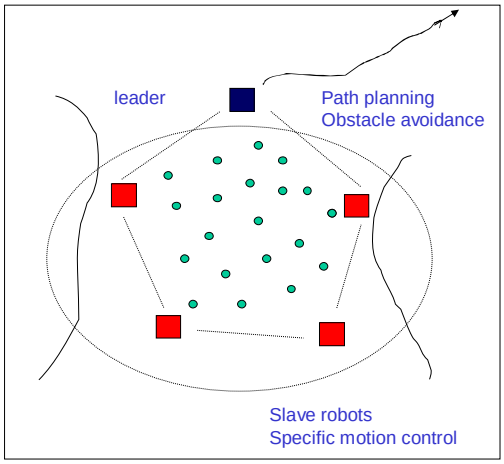
Robot formation

Dog shepherding

Cooperative People Guiding: Using Robot Formation

Robot formation





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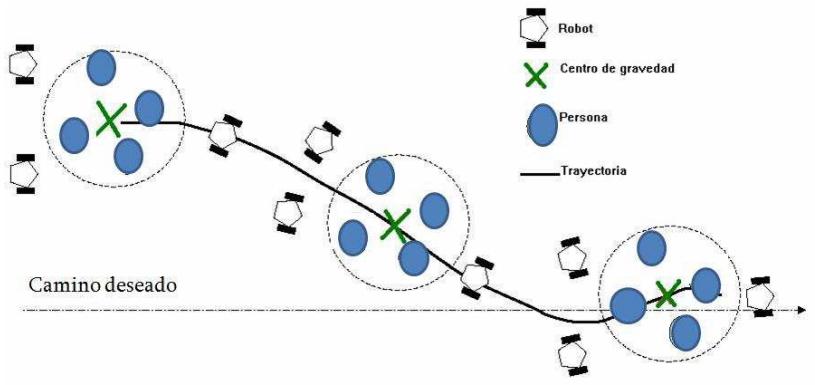
Cooperative People Guiding: Using Robot Formation



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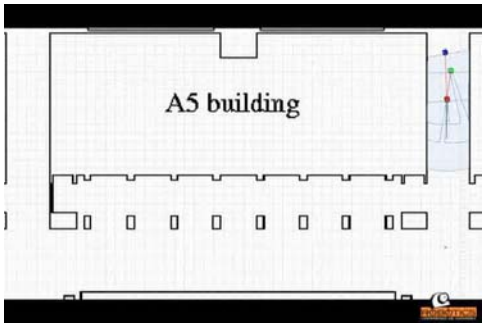
Cooperative People Guiding: Robot Formation

Robot formation



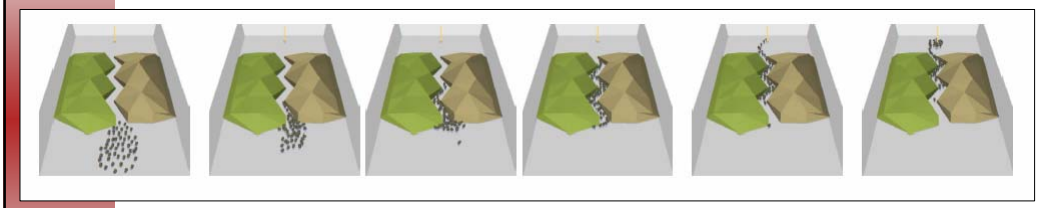
[Mosteo et al. ICRA08]

Cooperative People Guiding: Dog Shepherding

Dog shepherding

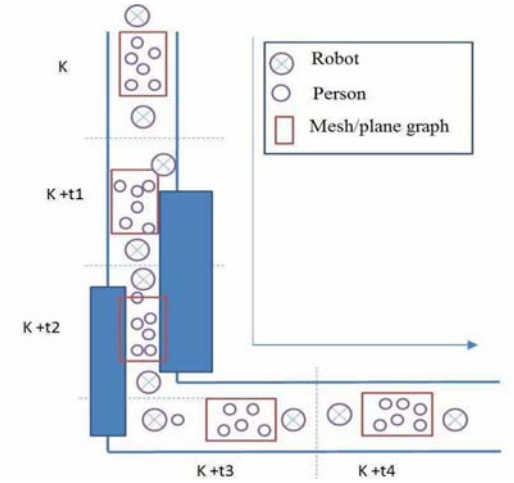
Cooperative People Guiding: Dog Shepherding

Guidance in narrow trails



Cooperative People Guiding: Dog Shepherding Method

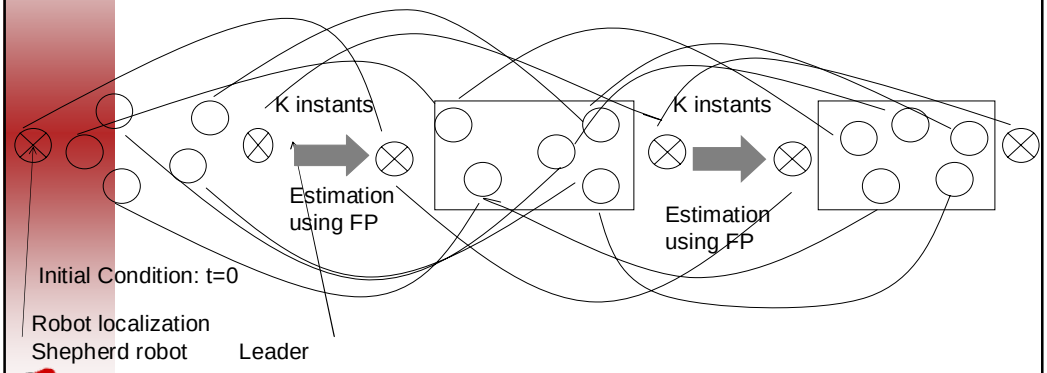
Dynamic model of Local Environment



[Garrell and Sanfeliu, 2008]

Cooperative People Guiding: Dog Shepherding Method

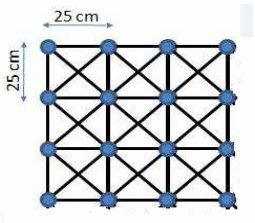
- The DLE model has a dynamic and static component
  - **Dynamic Component**

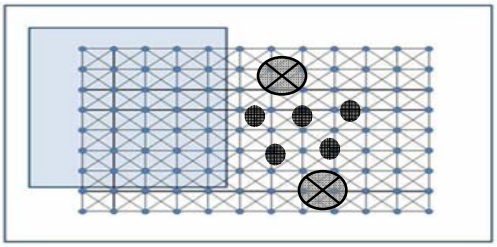


Cooperative People Guiding: Dog Shepherding

Static Component:

- Computation of the graph:
  - Mesh of 8-neighborhood.
  - The mesh is placed depending of the robot leader position and obstacles





Cooperative People Guiding: Dog Shepherding

Computation of node tension:

- Tension due to obstacles

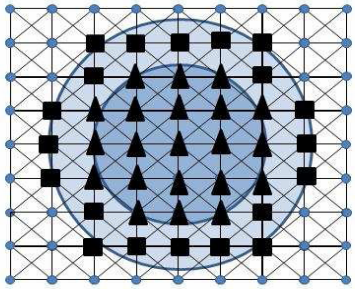
$$T_{obstacle} = \infty.$$

- Tension due to robots

$$T_{robot} = \frac{k_{robot}}{\|x_i - p\|}$$

- Tension due to people

$$T_{people} = \frac{k_{people}}{\|x_i - p\|}$$



Nodes with no tension
Nodes with infinite tension
Nodes with tension $= \frac{k_{robot}}{\|x_i - p\|}$

$$T_{total}(x_i) = T_{obst}(x_i) + T_{rob}(x_i) + T_{people}(x_i)$$

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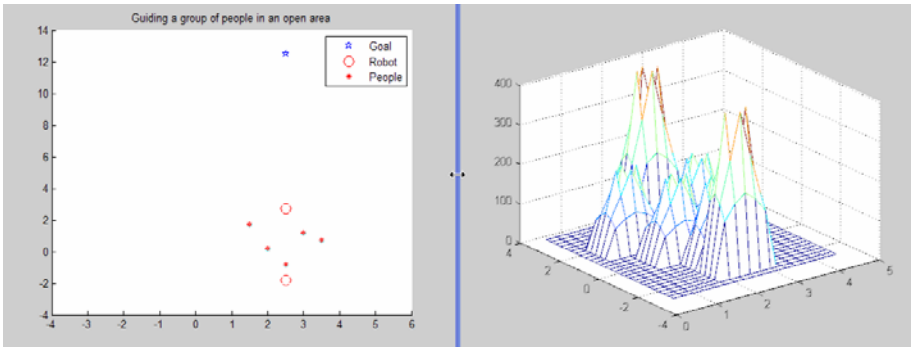
Cooperative People Guiding: Dog Shepherding

Simulation results

Guia_personas_Anais_2.avi



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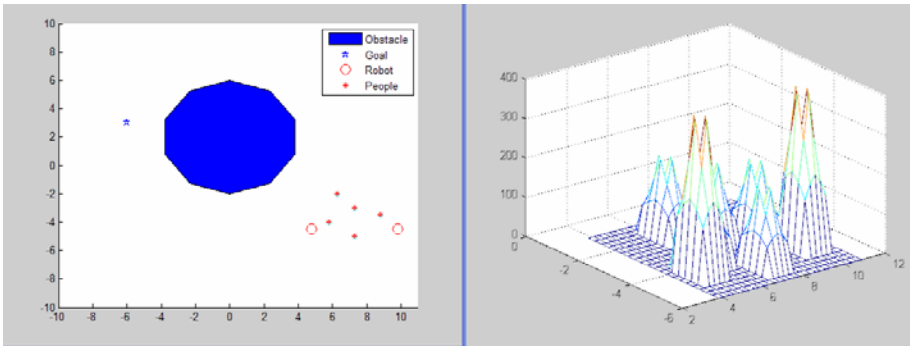
Cooperative People Guiding: Dog Shepherding

Simulation results

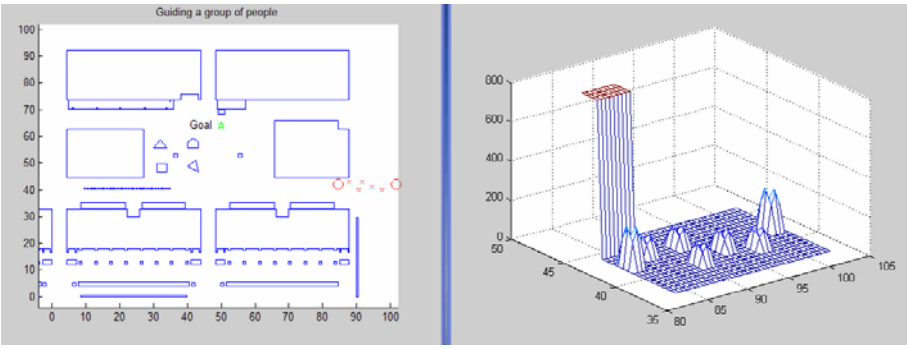
Guia_personas_Anais_1.avi



Cooperative People Guiding: Dog Shepherding

Simulation results

Guia_personas_Anais_3.avi



Open Issues

- Cooperative robotics in NRS is a field that involves not only the cooperation of robots, but also environment sensors, networks and ***human beings***.
- The cooperative robotic functionalities are yet not well known, they must be identified and analyzed.
- In order to do cooperative robotic tasks in urban areas not only requires research on engineering tools, but also to take into account the legal, social and economic issues.