An European Vision of Network Robot Systems in Urban Areas

Prof. Alberto Sanfeliu
Instituto de Robótica (IRI) (CSIC-UPC)
Technical University of Catalonia
June 30th, 2008
http://www-iri-upc.es

Index

- European FP6 projects related to NRS
- The URUS project
- Partners
- Experiment locations
- Global architecture
- Scientific and technological achievements
- Experiments
- Conclusions
# European FP6 Projects Related to NRS

<table>
<thead>
<tr>
<th>FP6 project Acronym</th>
<th>Urban robot</th>
<th>Safe, dependable, cooperating with humans</th>
<th>Networking</th>
<th>Title / Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA-NRS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Research Atelier on Network Robot Systems: Road Map of Network Robot Systems</td>
</tr>
<tr>
<td>AWARE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Platform for Autonomous self-deploying and operation of Wireless sensor-actuator networks cooperating with Aerial objects: Filming, and Disaster Management/Civil Security</td>
</tr>
<tr>
<td>CommRob</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Advanced Robot Behavior and High-level Multimodal Communication with and Among Robots: Consumers applications</td>
</tr>
<tr>
<td>Dusbot</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Networked and Cooperating Robotics in Urban Hygiene: Urban hygiene, vacuum clean, garbage-collect...</td>
</tr>
<tr>
<td>Guardians</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Group of Unmanned Assistant Robots Deployed In Aggregative Navigation supported by Scent detection: Search and Rescue</td>
</tr>
<tr>
<td>IRPS</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Intelligent robotic porter system: Porter guiding system for airports</td>
</tr>
<tr>
<td>IWARD</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Intelligent Robot Swarm for Attendance, Recognition, Cleaning and Delivery: Healthcare</td>
</tr>
<tr>
<td>ROBOSWARM</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Knowledge Environment for Interacting Robot Swarm: Service robot, open knowledge environment</td>
</tr>
<tr>
<td>URUS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Ubiquitous Networking Robotics for Urban Settings: Cognitive network architecture, surveillance, urban transportation</td>
</tr>
</tbody>
</table>

[http://www-iri.upc.es/groups/nrs](http://www-iri.upc.es/groups/nrs)
**Objectives:** The DustBot project is aimed at designing, developing and testing a system for improving the management of urban hygiene, based on a network of autonomous and cooperating robots, embedded in an Ambient Intelligence infrastructure.
Guardians

Group of Unmanned Assistant Robots Deployed In Aggregative Navigation supported by Scent detection

Objectives: The GUARDIANS are a swarm of autonomous robots applied to navigate and search an urban ground. The project’s central example is an industrial warehouse in smoke, as proposed by the Fire and Rescue Service. The robots warn of toxic chemicals, provide and maintain mobile communication links, infer localisation information and assist in searching. They enhance operational safety and speed and thus indirectly save lives.

http://www.shu.ac.uk/mmvl/research/guardians/
Guardians
Group of Unmanned Assistant Robots Deployed In Aggregative Navigation supported by Scent detection

AWARE
Platform for Autonomous self-deploying and operation of Wireless sensor-actuator networks cooperating with AeRial objEcts

Objectives: This project is devoted to the design, development and experimentation of a platform providing the middleware and the functionalities required for the cooperation among aerial flying vehicles and a ground sensor-actuator wireless network with mobile nodes.

http://grvc.us.es/aware/
AWARE
Platform for Autonomous self-deploying and operation of Wireless sensor-actuator networks cooperating with AeRial objEcts

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

URUS Partners

<table>
<thead>
<tr>
<th>Participant Role*</th>
<th>Country</th>
<th>Participant name</th>
<th>Participant short name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinator</td>
<td>Spain</td>
<td>Technical University of Catalonia (Institute of Robotics) Alberto Sanfeliu</td>
<td>UPC</td>
</tr>
<tr>
<td>Research Partner</td>
<td>Spain</td>
<td>Centre National de la Recherche Scientifique Rachid Alami / Raja Chatila</td>
<td>LAAS</td>
</tr>
<tr>
<td>Research Partner</td>
<td>Switzerland</td>
<td>Eidgenössische Technische Hochschule Roland Siegward</td>
<td>ETHZ</td>
</tr>
<tr>
<td>Research Partner</td>
<td>Spain</td>
<td>Asociación de Investigación y Cooperación Industrial Andalucía</td>
<td>AICA</td>
</tr>
<tr>
<td>Research Partner</td>
<td>Italy</td>
<td>Scuola Superiore di Studi Universitari e di Perfezionamento</td>
<td>SSA</td>
</tr>
<tr>
<td>Research Partner</td>
<td>Spain</td>
<td>Universidad de Zaragoza Luis Montano</td>
<td>UZar</td>
</tr>
<tr>
<td>Research Partner</td>
<td>Portugal</td>
<td>Instituto Superior Técnico do Sul / Santo Tirso</td>
<td>IST</td>
</tr>
<tr>
<td>Research Partner</td>
<td>UK</td>
<td>University of Surrey Mike Bellingworth</td>
<td>UniS</td>
</tr>
<tr>
<td>Agency Partner</td>
<td>Spain</td>
<td>Urban Ecology Agency of Barcelona Salvador Ripado</td>
<td>UEA</td>
</tr>
<tr>
<td>Industrial Partner</td>
<td>Spain</td>
<td>Telefónica I+D Xavier Kirchner</td>
<td>TID</td>
</tr>
<tr>
<td>Industrial Partner</td>
<td>Italy</td>
<td>RoboTech Nico Carenli</td>
<td>BT</td>
</tr>
</tbody>
</table>
Experiment Locations

Experiment Locations: Scenario 1
UPC

Zone Campus Nord, UPC
Experiment Location: Scenario 1
UPC
Experiment Location: Scenario 2
Gracia District

Global Architecture

[Diagram showing the global architecture with various components including robots, central station, task allocation, and communication networks]
Wireless Communication in URUS Project

Scientific and Technological Achievements in the 1rst Year
Specifications in Urban Areas

- Major urban needs:
  - Transportation of goods (urban merchandise distribution)
  - Transportation of other materials
  - Maintenance service
  - Emergency calls.
  - Security (surveillance)
  - Helping the disabled and people with mobility handicaps to overcome limitations.
  - Data gathering (noise, air pollution, temperature, wind, light conditions).
  - Access to urban information

Specifications in Urban Areas

- Urban requirements for URUS experiments
  - To inform the local authorities about the URUS experiment its main goals and features.
  - To arrange the permissions that will be necessary to carry out the tests with the help of the local authorities.
  - To gather information about regulations and laws concerning different aspects of URUS (robots, cameras, sensors)
  - To map the UPC site that has been chosen for the experiments.

- City regulations related to URUS experiment (regulation on the use of thoroughfare and public space in Barcelona approved 27th November 1998 and published the 15th January 1999)
  - Use of public space in general
  - Special Uses
  - Conditions
  - Licenses and permissions
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
- Single robot localization has been done fusing diverse sensors (GPS, laser, compass, estereovision, odometry, visual odometry)
- Cooperative localisation has been accomplished using global probabilistic model based on particle filter methods

Cooperative Navigation
- Single robot path planning has been solved by applying the E* motion planning algorithm
- There has been worked in cooperative formation maintenance, leader following and obstacle avoidance. The approach has been validated experimentally in obstacle-free environments.

Integration
- Integration has been based on YARP platform
Cooperative Localization and Navigation

Segway-robot navigation based on fusing odometry and visual odometry
Video: SANYO088.MP4 and video_SLAM_21Aug_new.avi

\[ p(x) \sim N(x; \mu, \Sigma) \sim N^{-1}(x; \eta, \Lambda) \]

[Ila et al, IROS07]

---

Smart navigation based on fusion of sensor information
Video showing Smart Ter at UPC site: SmartAndSegway.mpg

SmartTer: GPS/IMU/Odometry fusion
Safe RRT-based local planning and obstacle avoidance [Macek et al 08].
Cooperative Localization and Navigation

Robot localization using active global localisation

Video: 20080508posTrackingShort.mp4

[Corominas et al ICRA08]

Key_Note_Japan_NRF_2008

---

Cooperative Localization and Navigation

Robot formation

leader
Path planning
Obstacle avoidance
Slave robots
Specific motion control

[Mosteo et al. ICRA08]

Key_Note_Japan_NRF_2008
Cooperative Localization and Navigation

**Relative Ranging method**
- Try to eliminate effect of antenna orientation
- Suitable for static nodes approximately in the same plane
- Triangulation using a non-linear least-square method

**Experiments**
- ROMEO 4R autonomous robot with onboard WSN node
- Static WSN nodes deployed on campus
  - Average distance between consecutive nodes: 7.18 m

Cooperative Environment Perception

**Cooperative perception using:**
- embedded and own sensors
- fusion techniques and technologies
The main framework for cooperative perception has been established:

Partially Observable Markov Decision Processes (POMDPs) as a framework for active cooperative perception.

- Human activity recognition algorithms have been developed and some results have been already obtained using cameras.
- New algorithms for tracking persons have been tested in the scenario.

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
    - Colour, 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

- Homogeneous regions in scale-space: Color-blob based approach: Each blob is described by a 3d-normal distribution in RGB color space
- Without any predefined model of a person
- Initial startup: blob to track

Eliminating shadows in a sequence of images

Original image  Gradient image  Without shadows image

[Scandaliaris et al., CIARP2007]
Cooperative Map Building and Updating

Cooperative Map Building:
- Using multiple robots and sensors
- Using control techniques

- We have preliminary results on mapping the UPC North campus using 3D range data from the EHTZ’s SmartTer platform.

- The experiments conducted in July 2007 consisted in a series of runs, both inside and around the campus, gathering information from two rotating Sick laser scanners and using the platform’s global localization module.
Cooperative Map Building and Updating

3D Map construction doing by Smart Ter robot

Video: SmartData.mpg

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**

Human Robot Interaction

**Human robot interaction:**
- Combining mobile phones, voice, touch screen

Communication by voice

Communication by voice and touch screen

Communication between robots and humans through the mobile phone
**Human Robot Interaction**

- Analysis of the specifications for human-robot interaction (HRI) aspects required by the experiments considered in the project:
  - the selection of the admissible gestures that form the basic language for interaction between humans and robots
  - the selection of the adequate features for the robot head that simplify the interaction with human (e.g., the ability to generate multiple facial expressions)
  - the selection of adequate technological tools for interaction (e.g., cellphones, touchscreen, and communication media between the interaction devices and the robots).

**Gesture detection**

- Boxing detection
- Waving detection
Human Robot Interaction

Robotic Head

Hello! I'm URUS robot.
Choose one of my services!
To know how to use my services press, “PLAY”.

Emotion expressions

Neutral  Happy  Sad
Busy  Angry
Human Robot Interaction

GUI look & feel

Multi-task Allocation

Multi-task negotiation:
- Using sub-optimal techniques for multi-system task allocation
Multi-task Allocation

- Two kinds of results have been reached:
  - The first one addresses the case in which no network constraints exist.
    - Fully working infrastructure network is operative and robots are able to communicate and move without restrictions in the workspace.
    - In this case, the entire robotic workforce may be executing user tasks at full capacity.
  - The second kind of results addresses the case in which the infrastructure network is not operative or out of range.
    - Robots can only use ad-hoc, robot-to-robot communication channels to convey any necessary information to its destination.
    - In this case, some robots may be used not to execute user tasks, but to act as bridge nodes between the robots executing user tasks in out of range areas and the infrastructure network in which the central station and other robots communicate.

---

Multi-task Allocation

**Supervisor**

- Decides on the execution of the plan based on current robot state and world knowledge
- Controls sensorial task refinement
- Sends service requests to Functional modules
- Adapts to local contingencies
- Human Robot Interaction reasoning
- Sends robot information to the central station.

**Functional Modules** of the robot such as localization, navigation, perception...
Wireless communication in Network Robots

Wireless communication:
• Combining wireless techniques for robust communication

The flexibility and cost of IEEE 802.11 and Bluetooth (for robot to robot and user to robot communications respectively) has been preferred over cellular commercial solutions, keeping the latter as backup mechanism.

Creation of a software component to deal with the integration with the internal communications framework and external communications using multiple network interfaces.

Definition of a protocol to manage real-time communications in ad-hoc networks that will be used to allow communications between robots.

Development of a method to map the position of the nodes of the Wireless Sensor Network (WSN) by using the signal strength received from a mobile robot that carries one node.
Wireless communication in Network Robots

Interfaces

3G/GSM
- WLAN (Infrastructure)
- WLAN (MANET)
- Bluetooth (PAN)

Robot formation

- Leader
- Path planning
- Obstacle avoidance
- Slave robots
- Specific motion control

Network connectivity

- Executes allocated task
- Obstacle avoidance
- 3 robots collaborate to maintain connectivity
- Specific motion control

[Mosteo et al ICRA08]

Key_Note_Japan_NRF_2008
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

Guiding and Transportation

- Cameras and ubiquitous sensors
- Robots with intelligent head and mobility
- People with mobile phones and RFID
- Robots for transportation of people and goods
- Wireless and network communication