Intelligent Autonomous System Laboratory (IAS-Lab)
University of Padua, Italy

Breakthroughs and new applications:

A Distributed Sensing and Cooperative Planning based approach for using robots in ordinary life

by
Enrico Pagello
President of the International IAS-Society

Presentation Outline

- New application area:
  - Introducing robots in people's ordinary life
- Our Laboratory in Italy - our Japanese partners:
  - IAS-Laboratory (School of Engineering)
    Dr. Emanuele Menegatti, Assistant Professor
    & IT+Robotics Srl, a Spin-off of Padua University
  - Tokyo University (prof. Tamio Arai)
  - Osaka University (prof. Hiroshi Hishiguro)
  - Keio University (prof. KazuoYoshida)
- Scientific and technical challenges:
  - Distributed Sensing
    - Developing a Omnidirectional Distributed Vision System
  - Cooperative Task Planning
    - Using Collective Emergent-Behaviors Engineering

Motivation of our research work -1

- If we consider as a New application area:
  Introducing robots in people's ordinary life
  we need to deal with Multi-robot Systems (MRS)
- Why MRS are being so successful ?
  - In challenging application domains, MRS can often deal with tasks that are difficult, if not impossible, to be accomplished by an individual robot
- IEEE/RAS recognized the relevance of this new field with a Transactions' Special Issue on MRS by [Arai, Pagello, & Parker, 2002], where several primary research areas were identified for the first time

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Motivation of our research work -2

- Early research on MRS goes to
  - Cellular Robotics by [Fukuda, IECON 1987] and Cyclic Swarm by [Beni, Intelligent Control 1988]
  - Multi-Robot Motion Planning by [Arai, IROS 1989]
  - ACTRESS Architecture by [Asama, IROS 1989]
- We developed our research work in cooperation with some Japanese Universities
  - Since 1994, with prof. Tamio Arai of University of Tokyo on motion planning strategies for MRS
  - Since 2001, with prof. Hiroshi Hishiguro, now at Osaka University, on distributed omnidirectional vision sensing
  - Since 2005, with prof. Kazuo Yoshida of Keio University on Task and Role assignment for soccer-robot teams

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Early MRS Motion Planning Methods

- At the beginning of our cooperation with the University of Tokyo, we turned our attention to Motion Planning (MP) problems involving time, dynamic constraints, moving obstacles, multiple robot coordination, etc.
- *Robots execute robot algorithms ...* but in the case of MRS a MP Solver needs a Distributed or a Centralized Planner as a component inside its algorithmic structure.
- A Global Method for MRS MP in Time-Space [IROS-1995, and IROS-1996], with Tamio Arai, and Jun Ota was definined

C. Ferrari, E. Pagello, J. Ota, T. Arai. *Multirobot Motion Coordination in Space and Time.* Robotics and Autonomous Systems, Vol 25, 1998

Motivation of our research work -2

- But moving from a single-robot theory_and_practice to a multi-robot science_and_technology requires also more sophisticated techniques:
  - Developing a distributed vision system
  - Relying on efficient localization algorithms
  - Balancing social deliberation and reactivity in control architectures
  - Using emergent behaviors to better understand what collective behaviors are
  - Experimenting with teams of robots:
    - Going from RoboCup environment towards real service robotics application environment

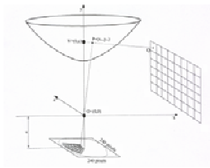
Distributed Vision Systems (DVS)

- What is a DVS?
  - a set of vision systems embedded in the environment and connected by a network
- Which are the DVS tasks?
  - Real time wide area safety surveillance
  - Home assistance for young and old people

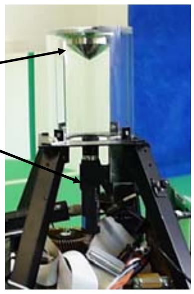
From prof. Matsuyama

The DVS structure as a set of OVAs

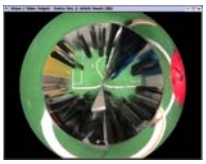
- Each Vision Sensor of the Distributed Vision System (DVS) relies on a specialized omnidirectional mirror plus a camera
- Vision Sensors must be able to acquire the images, process them, and transmit the information over a LAN.
- We call these vision systems, Omnidirectional Vision Agents (OVA)



Omnidirectional Vision Sensors



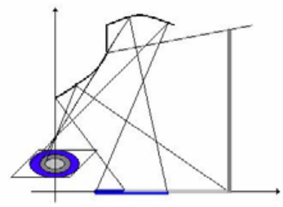
- Convex Mirror
- Perspective camera
- Perspex Cylinder (support)



Our robot mirrors

Mirror's three parts:
- Measurement Mirror
- Marker Mirror
- Proximity Mirror

The task determines the mirror profile



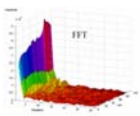
Mirror Profile

Integrating OVA on a Robot

- We stressed why we need:
  - Developing powerful omnidirectional specialized sensors
  - Introducing the concept of an Omnidirectional Vision Agent
- Going from Single-robot simple task-solving to MRS cooperative task-solving requires:
  - Enhancing localization (by integrating Image-based metods with Monte Carlo methods)
  - Using range finders for localization purposes (through omnidirectional vision sensors)
  - Making calibration easier (by introducing learning methods)
  - Sharing and distributing sensor knowledge through the net

Ishiguro & Menegatti's Fourier Signature

a)



c)

"unwarping" ↓ FFT ↑

b)

a) One Omnidirectional Image 7.3 MBit
640x480 pixels colour image, 24 bit

b) One Panoramic cylinder 983 KBit
512x80 pixels grey scale image, 24 bit

c) Each Fourier signature 19 KBit
two 80_rows x 15_coeficients arrays, one for magnitude, one for phase, 8 bit

only the first 15 components of the Fourier transform of each line of the panoramic cylinder are considered

The Rotational Invariance

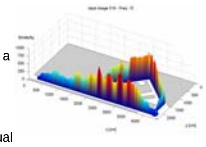
To make the robot able to match the current view with the corresponding reference image regardless of the current heading, a rotational invariance in the calculation of the similarity between two images is considered.

Two panoramic cylinder acquired at the same location before and after a rotation on the spot. The dashed box indicates the spatial shift a between the two images.

E. Menegatti, T. Maeda H. Ishiguro *Image-based memory for robot navigation using properties of the omnidirectional images* Robotics and Autonomous Systems, Vol. 47, No. 4 , July 2004

Using the Fast Fourier Transform in Omnidirectional Distributed Vision Systems

In an image-based approach, the robot tries to match the current view of the environment with the reference views stored in its the visual memory to calculate its position.

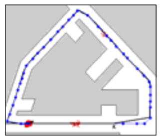


In Monte Carlo Localization method, the posterior probability density of the robot's pose is represented with a set of weighted samples.

Our method combines the advantages of both

To work in environments with spatial periodicity (perceptual aliasing), we avoid to use a metrical map.

We exploits the properties of the Fourier Transform of the omnidirectional images, and uses the similarity between images to weights the samples used by MCL.



E. Menegatti, M. Zoccarato, E. Pagello and H. Ishiguro. *Image-Based Monte-Carlo Localisation with Omnidirectional Images.*

Robotics and Autonomous Systems, Vol. 48, No. 1 , 2004

An Application: Using the Image-Based Localization in a higly dynamic environment

- Traditional image-based localization methods do not work when the robot is moving in an highly dynamic environment whose appearance is changing in time.
- Several cameras are installed in the environment and one camera mounted on a mobile robot.
- Robot localization is achieved by comparing the current image grabbed by the robot with the images grabbed at the same time by the DVS.

A person is seen as occluding the right part of OVA's background, and the left part of robot's background. Nevertheless, the Fourier Signatures of the two images do not differ greatly.

What is important is the occlusion existence, not its horizontal position!

FTT in a DVS as a key-tool to localise humanoid robots

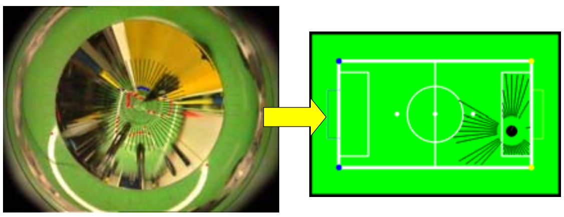
- H. Ishiguro's Eveliee robot at Intelligent System Laboratory at Osaka University, where some tests were done
- The network's camera can be used also for other duties, like surveillance, people tracking, activity monotoring in cooperation with floor sensors, etc.

E. Menegatti, G. Gatto, and E. Pagello, T. Minato and H. Ishiguro *Distributed vision system for robot localisation in indoor environment.* ECMR'05 Proceedings, Ancona Sept. 2005

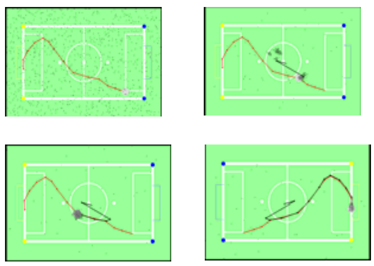
An Omnidirectional-Vision based Range Finder

Use an omnidirectional vision sensor as a range finder (like a laser or a sonar) sensitive to colors transitions to detect the nearest obstacles.

E. Menegatti, A. Pretto, and E. Pagello *Testing omnidirectional vision-based Monte-Carlo Localization under occlusion.* Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS-2004), Sendai, (Japan), Sept. 2004

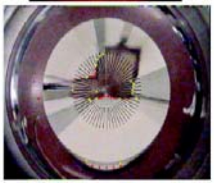


Applying Monte-Carlo Localization to the sensor for Position Tracking



The current location of the robot is modelled as a posterior distribution on the sensor data represented by a set of weighted particles.
grey circle represents the actual robot pose, red line represents the ground-truth path, black line represents the estimated path of the robot, black dots represent the particles

Experiments at Padua University Building

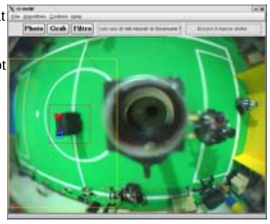


- Red floor, white walls, and gray furnitures
- Color transitions:
  Red - White, Red - Gray

Sensoring the environment with an Omnidirectional Distributed Vision System

To distribute the Knowledge through an Omnidirectional DVS (Distributed Vision System), we developed two experiments.

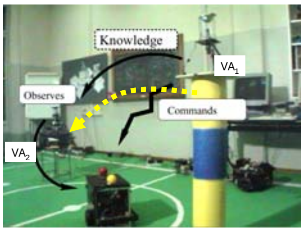
The first deals with an Omnidirectional DVS that learns how to navigate a service-robot in an office-like environment without any knowledge about the calibration of the cameras or the robot control law.



One Vision Agent (VA) learns to control the robot with a SARSA(lambda) reinforcement learning technique, using Asada's LEM strategy to speed-up learning. Once the Agent learnt the correct policy, it transfers its knowledge to another Agents.

Implicit Communication

- VA_1 learnt its own mapping
- VA_1 moves the robot in the field of view of VA_2
- VA_2 observes the robot
- VA_2 receives from VA1 the motor commands sent to the robot
- VA_2 is guided in its learning from VA1



E. Menegatti, C. Simionato, S. Tonello, G. Cicirelli, A.Distante, H. Ishiguro, E. Pagello Knowledge *Propagation in a Distributed Omnidirectional Vision System.* Submitted to a Special Issue in Memory of Marco Somalvico, Int. Jour. of Intelligent and Fuzzy Systems

A DVS used for Surveillance

Static VA (SVA) detects intruders

SVA sends robot to intercept intruders

The robot recognises the intruders in the omnidirectional image and sends a picture of the intruder to SVA

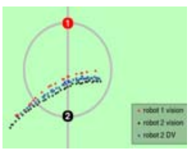
Sharing the Distributed Knowledge in an Omnidirectional Distributed Vision System

The second experiment deals with sensor fusion.

Cooperatively track and share the information about moving objects using a multi-robot team

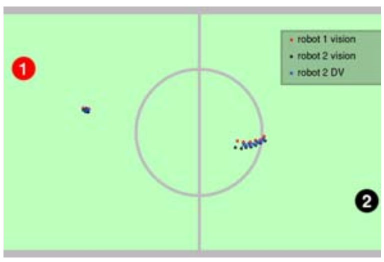
The information gathered from every robot is broadcast to all the other robots.

Each robot fuses its own sensor measurements with the information received from the teammates, building its own "vision of the world".



E. Menegatti, A. Scarpa, D. Massarin, E. Ros, E. Pagello *Omnidirectional Distributed Vision System for a Team of Heterogeneous Robots.* Proc. of IEEE Workshop on Omnidirectional Vision (Omnivis'03), Madison (USA) 2003

Experiment



Kidnapped ball

RoboCup Soccer: From simple moves towards complex actions

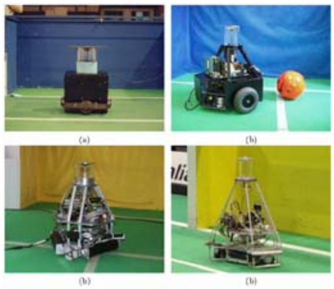
- Middle-size League: progresses from 1997 to now

USC (USA) - Osaka Univ. (Japan) Nagoya 1997 — Isfahan Univ (Iran) - AIS (Germany) Padua 2003

QuickTime™ and a decompressor are needed to see this picture.

Evolving the Artisti Veneti Team: An heterogeneous soccer robot team

- (a) Early platform for MSL was designed on 1998 over a Pioneeer1 base
- First and second platforms in figure evolved from a Pioneer1 to a Pioneer2 base, with omnivision
- Third platform is a Golem robot: we shifted from 2-wheeled robot, towards omnidrive and omnivision
- Fourth platform ehnanced the circular movement of original goalkeeper



Hybrid Architectures

- Traditional AI failed for real-time systems, but offers explanation and allows control.
- Pure reactivity systems allows using real-robots in real-world, but only for simple tasks.
- Hybrid systems are needed
  - M. Hannebauer, E. Pagello, and J. Wendler (Eds): *Balancing Reactivity and Social Deliberation in Multi-Agent Systems*, LNAI, No. 2103, Springer 2001

- In Hybrid Architectures The critical point is the choice of the degree of balancing:
  - How much is left to reactivity and how much is left to deliberation?

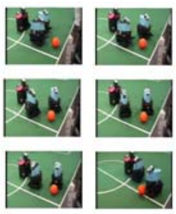
    S. Carpin, C. Ferrari, E. Pagello. *Map Focus: a way to reconcile reactivity and deliberation in multi-robot systes.* Robotics and Autonomous Systems. 2002, Vol. 41, pp. 245-255

Dynamic Role Assignment

- What role is played by the team membership in the development of this architecture?
- A Dynamic Role Assignment schema is the basic mechanism to make emerging a collective behavior inside a MRS
- Dynamic role assignments among attacker, supporter and defender, were managed by considering collision avoidance issues and arbitration among competitive behaviors

Ball exchange through emergent behaviors

Ball passing by role exchange
Quarter-finals: ART against Ulm University (Stockolm, August 1999)



Passing the ball to defend from opponents' attack
Preliminary round robin game: Artisti Veneti against Friburg University (Seattle, August 2001)

The ***Artisti Veneti*** RoboCup Team

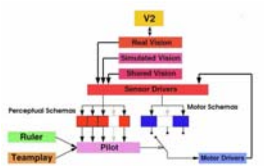
Cooperation with Keio's EIGEN Team

- We are studying the benefits of a balance between the social benefit and the individual benefit on which EIGEN Team's Dynamic Role Assignement policy is based.

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.

A Robot Architecture used for Coordination: Artisti Veneti's Challenge Game at RoboCup-2003

An hybrid architecture can take advantages from the interaction between the deliberative part and the reactive one and viceversa, to make a MRS to exhibit the assigned cooperative task.



QuickTime™ and a
Motion JPEG OpenDML decompressor
are needed to see this picture.

- Conditions are defined as fuzzy functions. Team coordination is obtained by incorporating some conditions depending on messages coming from other robots, when the condition is evaluated

Cooperation Issues for Multi-Agent Systems

Task Allocation Problem is a key issue in the MRS domain. Applying it to a team of robots means to switch to a dynamic role allocation approach. Gerkey and Mataric showed it is similar to task allocation problem for MRS in order to cooperatively achieve the goal, where a time-extended role concept replace that of a transient task.

A. D'angelo, E. Menegatti, E. Pagello *How a cooperative behaviour can emerge from a robot team.* R. Alami, H. Asama, R. Chatila Eds., Proceedings of Int. Conf. on Distributed Autonomous Systems (DARS-2004), Toulouse (Fr), 23-25 June, pp. 71-80

Before the conclusions ...

IAS-Lab organized the following meeting with Japanese partners in the last 5 years:

- IAS-6, The Sixth Int. Conference on Intelligent Autonomous Systems, held at Giudecca Island, in the city of Venice, and at Padua University, on July 2000 - 108 paper + 32 posters, 200 participants
- RoboCup-2003, The VII Int. RoboCup Competitions and Symposium, held at Padova Fiere and at Padua University, on July 2000 - 1243 participant, 42 Teams

We realized the need of starting the IT+Robotics Srl Spin-off to move the cooperation with our Japanese partners towards a more industrial application oriented approach in the field of advanced robotics (see Nedo's robot week in Aichi)

Conclusions

- Moving from single-robot theory_and_practice to a multi-robot science_and_technology requires:
  - Sofisticated sensors
  - Better understanding of collective behaviors
- Future perspectives:
  - Introducing humanoids

Thanks for Your Attention!

Artisti Veneti RoboCup-MSL Team

www.dei.unipd.it/~robocup

welcomes You at IAS-9

the Ninth Int. Conference on Intelligent Autonomous Systems to be held at Kashiwa Campus of the University of Tokyo, on March 2006