vSLAM: A low-cost approach to visual localization for consumer robotics

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Credits to the Evolution Team

- In particular thanks to:

  Dr. Mario Munich,
  Dr. Luis Goncalves,
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  Dr. Enrico Di Bernardo.

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The Natural Evolution of Robotics

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Our Vision

- A Personal Robot in every Home and Workplace

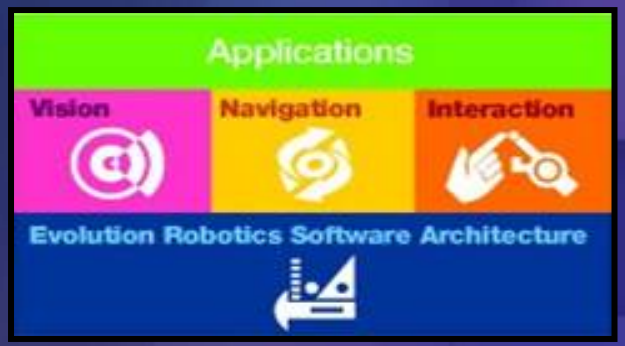
Our Mission

- To Develop the Core Technologies for Building Practical Personal Robots

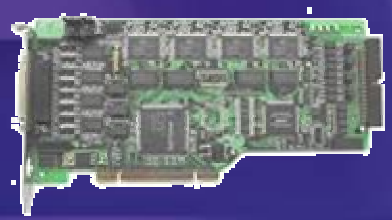
- *Help manufacturers to develop robotic products for the mass market in the next 2-4 years*

Our Strategy

Software



Embedded Solutions



Prototypes

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Our Challenges

- Challenge 1: Cost efficiency
- Challenge 2: Reliability (*Real* real-world robotics)
- Challenge 3: Power efficiency
- Challenge 4: Test and validation

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Our Challenges

- Challenge 1: Cost efficiency
- Challenge 2: Reliability (*Real* real-world robotics)
- Challenge 3: Power efficiency
- Challenge 4: Test and validation
- **Ultimate challenge: Meeting expectations of customers *and* investors.**

Focus of talk

- Breakthrough solutions **(few technical details ☹)**
  - Reliable vision for object recognition and navigation
  - Low-cost, vision-based SLAM (< $100)

Challenge 1: Cost efficiency

- Price of consumer robotic products:
  ***from* several hundred USD *to* few thousand USD**
- Production cost = 30%- 40% of retail price
  - Includes: product, manuals, manufacturing, packaging, marketing, …
  - Example:
    - Retail price: $500
    - Landed cost: $150-$175
    - HW cost: $100-$125
      Includes CPU board, connectors, sensors, actuators, gears, batteries, charger, chassis, appliance related components (e.g., vacuum),…
- *How much hardware can you get for a couple of hundred USD?*

Challenge 2: Reliability

- Consumer robotic products must operate in unknown environments; home, office, stores, factories, …
  - E.g., how does odometry behave on plush carpet?
  - How does vision work with lighting changes, reflections, moving objects, etc?
- Work for hours, days, weeks, months without (too much) human intervention
- *Imagine an autonomous robot in a home or office:*
  - *Reliable vision with such huge variation in lighting*
  - *Obstacle avoidance dealing with table tops, chair/table legs, glass, stairs, …*
  - *SLAM in cluttered environments*
  - *Voice recognition across the room*
  - *…*

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Challenge 3: Power efficiency

- Low-power actuators
- Low-power sensors
- Power management including self-charging
- Low-power computing, e.g., going from Pentium-grade computing to embedded
- …

Challenge 4: Test and validation

- How do you characterize and verify a system?
- Can we learn from the automotive industry?
- Can we automate testing?

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What are we left with?

- Imagine solving SLAM, Avoidance, Speech, Vision, reliably.
- ***Now imagine solving all these with low-cost sensors, low-cost computing, and in unknown, unstructured environments.***
- *What can we do?*

One thing we *can* do is …

to use vision!

- Low cost ($10 camera compared to $1000 LRF or $100-200 sonars)
- Images contain rich information
- But extracting the info requires reliable algorithms
- And more computation, i.e., need more computing which could add cost unless we optimize code and hardware

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What do we have?

- Object Recognition
  - Reliable to lighting, scaling, rotation, occlusions
  - Useful for many applications
- Vision-based SLAM (vSLAM)
  - Low-cost solution
  - Reliable in realistic settings
  - Adaptive to short-term and long-term changes

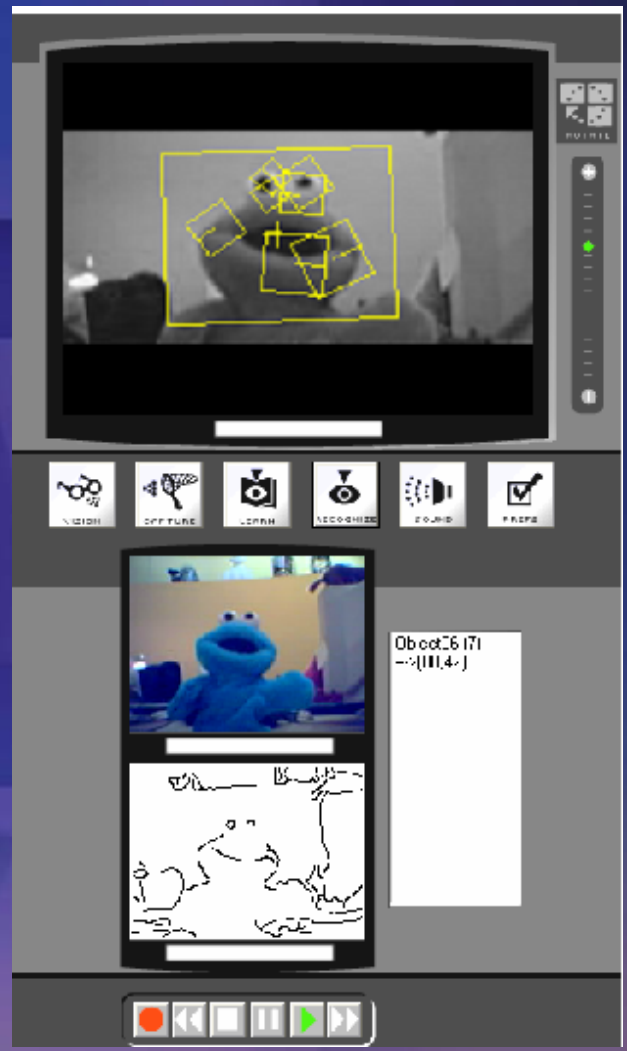
What else do we need? (for another time)

- Reliable, low-cost obstacle detection
  - Avoidance is considered done
- Reliable, low-cost voice recognition
  - From 3 meters distance and background noise
- Other human-robot interaction
  - Follow me, come here, pick that up, face recognition, …
- Reliable, low-cost manipulation
  - Pick and place, fetch, play chess, etc.
- Low-cost, low-power computation boards
  - GHz computing at < $50

Object Recognition

Approach:

- Extracts 1000 SIFT features of each object. A very small subset of those features with the right configuration is required for identification of the object.
- Estimation: Identification can provide the name of the object and the full pose of the camera with respect to the object.



Example applications

- Visual servoing, navigation, docking
- Edutainment: Reading book, visual programming
- Manipulation
- SLAM

Sony Aibo uses ER Vision

Visual Simultaneous Localization & Mapping

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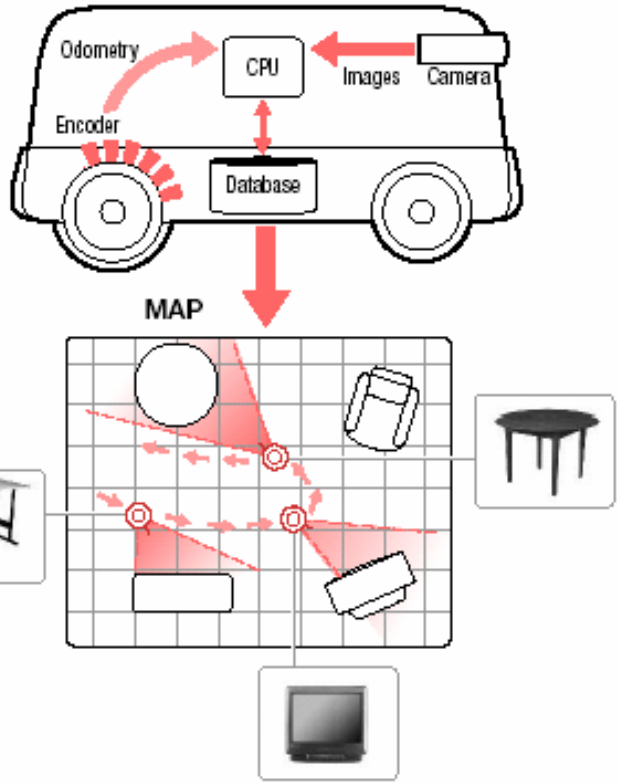
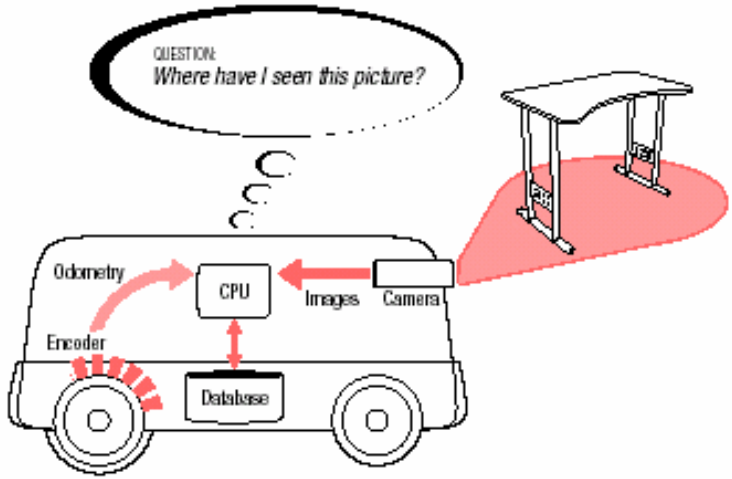
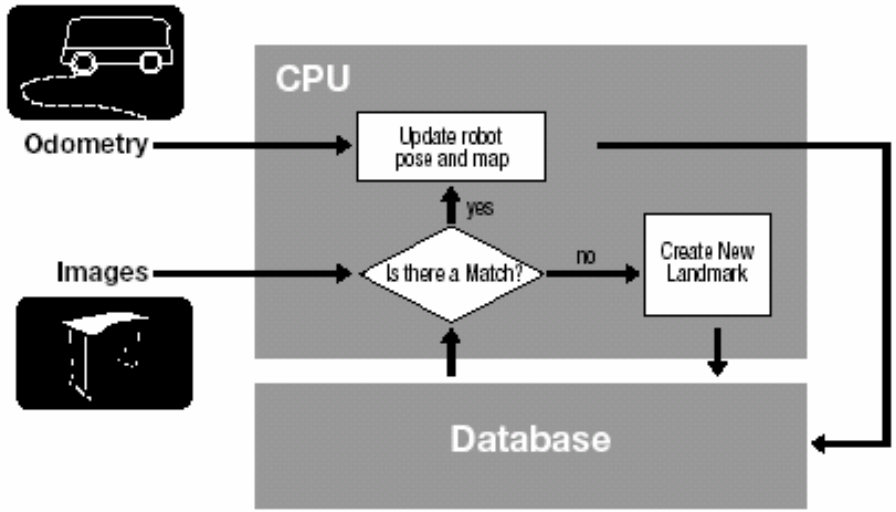
- Fuses data from single USB camera and odom
- Use sparse range of unique features. Dense range is not necessary.
- Builds map from scratch and adaptively updates map with new landmarks as required.
- Creates very unique landmarks which solve the data association problem
- Very robust handling of robot “kidnapping”
- Robust to transient and permanent changes in dynamic environments
- Accuracy of about +/- 25cm in x,y, and about 5 degrees in heading

INITIALIZATION

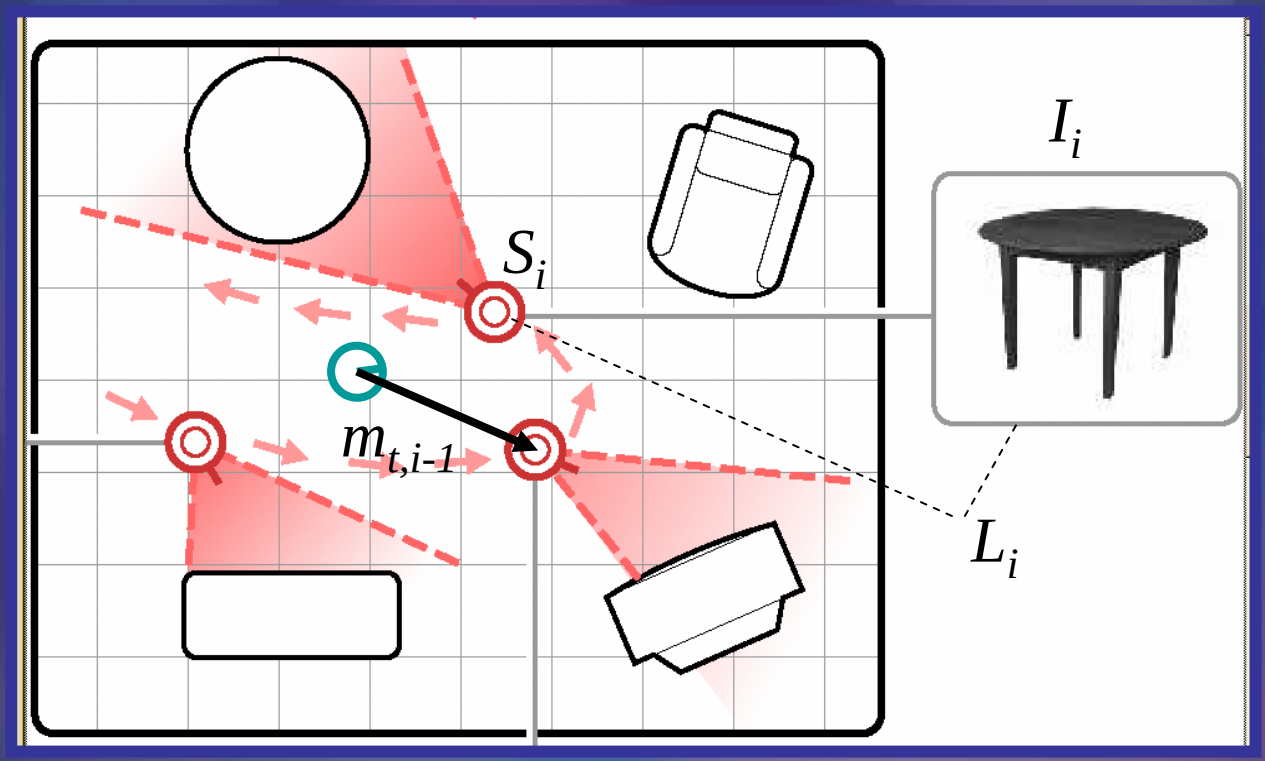






Definitions

- $L_i = \langle I_i, S_i \rangle$ — Landmark i.
- I_i — Image corresponding to L_i
- $S_i = (x_i, y_i, \theta_i)$ — Pose of robot when image I_i was acquired
- $M = \langle L_1, L_2, \ldots, L_k \rangle$ — Map of k unique landmarks
- $m_{t,l} = \Delta(x_{t,-l}, y_{t,-l}, \theta_{t,-l})$ — Visual pose measurement relative to L_i



Relative pose measurements

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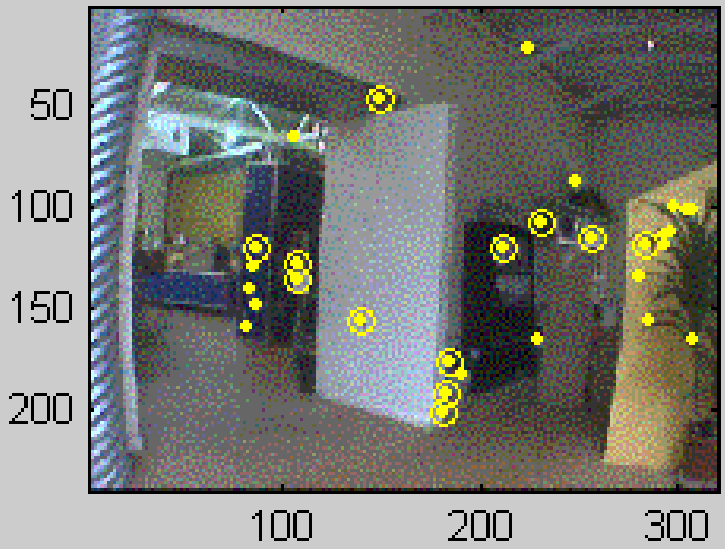
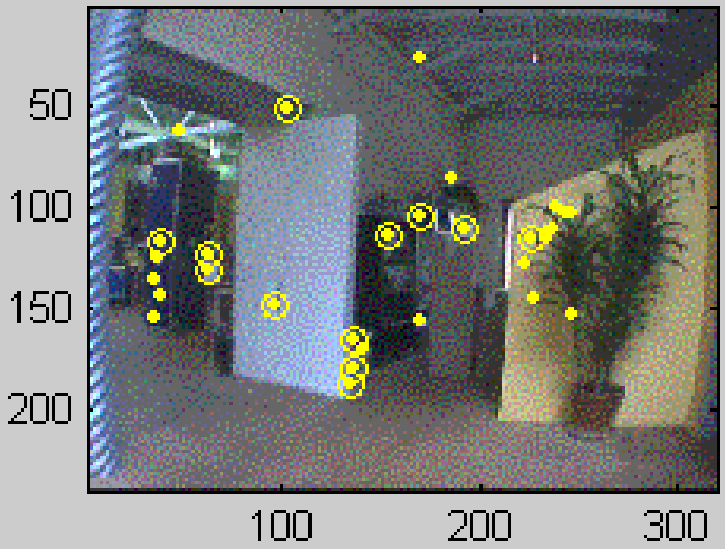
Current Image



Best Database Match (80 cm off)



Example runs

Representative Images

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Featureless environments

vSLAM Issues

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- Training time/installation cost: 3000-4000 m^2 facility. Ideally want to use an existing map of the facility
- No metric/occupancy map
  - User interface: Topological map with visual thumbnails? Metric map? Hybrid map?
  - Path-planning: Topological path
- Navigation in the dark
  - Headlights?
  - Use of IR cameras?

ER Software Platform (ERSP)

- Architecture that runs on many platforms
- Has been embedded
- Cross OS (3 OSs)
- Highly independent of robot

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(Near) Future work

- Develop < $100 navigation system
  - SLAM
  - Path planning/execution
  - Obstacle detection/avoidance
  - Hazard detection/avoidance
  - Self-docking and charging

Contact information

- www.evolution.com
  - Whitepapers, videos, press releases
  - Job descriptions
  - Sales
- paolo@evolution.com
  - Interested in collaboration
  - Licensing of technologies
- IROS Exhibition, Oct 2003 in Las Vegas
  - Demo of vSLAM and other navigation