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

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Credits to the Evolution Team

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The Natural Evolution of Robotics
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

- Applications
  - Vision
  - Navigation
  - Interaction
- Evolution Robotics Software Architecture

Embedded Solutions

Prototypes
Our Challenges

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

- 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
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.
- \( m_{t,i} = \Delta(x_{t,-i}, y_{t,-i}, \theta_{t,-i}) \) Visual pose measurement relative to \( L_i \).
Relative pose measurements

Current Image

Best Database Match (80 cm off)
Example runs
Representative Images
Featureless environments
vSLAM Issues

– Training time/installation cost: 3000-4000 m² 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
(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