Vision-Servoed Localization and Behavior-Based Planning for an Autonomous Quadruped Robot

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AIPS-2000

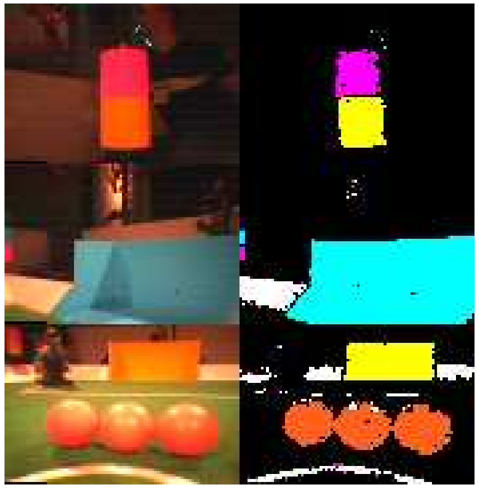
Complete Robotic Agents - The Challenge

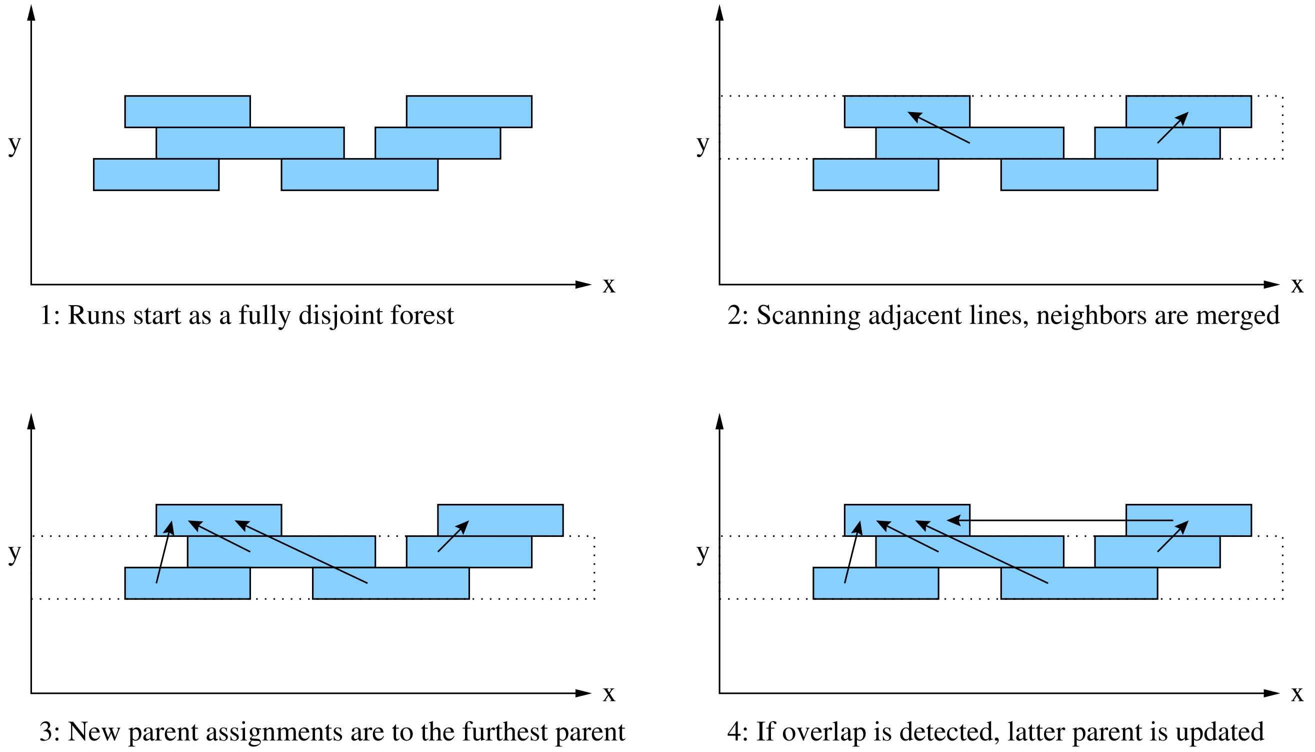
- Robotic soccer as a concrete environment for research in planning and execution.
- CM-Trio'99: team of 3 SONY robots participated in RoboCup-99, 3rd place.
- Robots gather state information, select actions, and accomplish real execution.
- Technical contributions include:
  - ▷ An algorithm for learning color segmentation thresholds and real-time object recognition.
  - ▷ A probabilistic localization algorithm robust to errors and poorly modeled movement.
  - ▷ A multi-fidelity behavior approach to address cost of perception and goal accomplishment.

Vision System Overview

- **Image capture/classification:** images in YUV color space; each pixel is classified in hardware by constant thresholds for up to 8 colors.
- **Connected regions:** pixels of each color are grouped together into connected regions using union-find.
- **Region merging:** similarly, colored regions are merged based on a preset minimum density for the merged region for each color.
- **Object filtering:** false positives are filtered out via specific geometric object filters for each type of object; a confidence value is calculated for each detected object.
- **Distance and transformation:** the angle and distance to detected objects are calculated relative to the image plane, and then mapped into ego-centric coordinates.

Vision Implementation





Sensor Resetting Localization

- $P(l)$ - locale probability density
- $P(l' \mid m, l)$ - movement probability density
- Movement update - each sample independently

  $P(l^{j+1} \mid m, l^j) = P(l^j)$ convolved with $P(l' \mid m, l)$

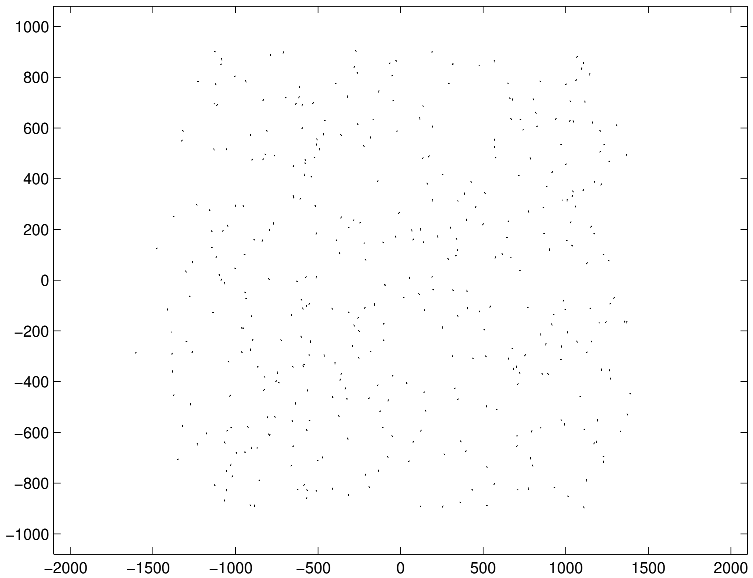
- Sensor update - Bayes rule using the sensor probability distribution $P(l \mid s)$

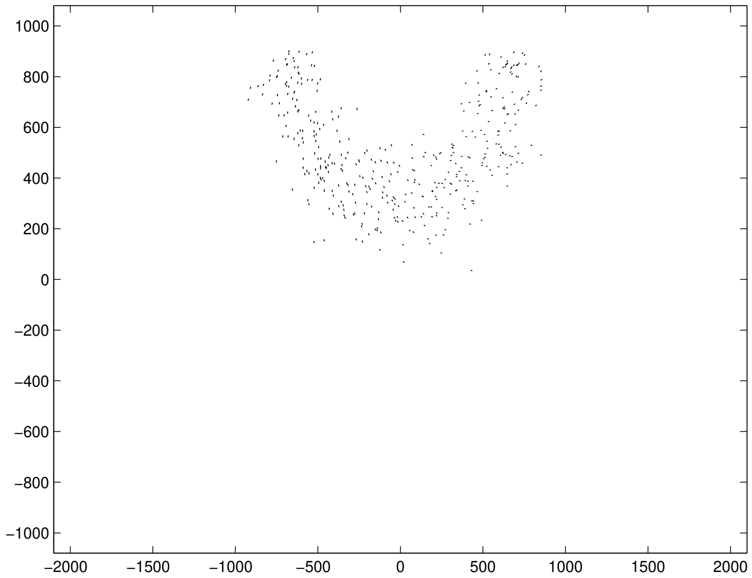
$$P(l^{j+1} \mid s, l^j) = P(l^j) \times P(l \mid s)/\alpha$$

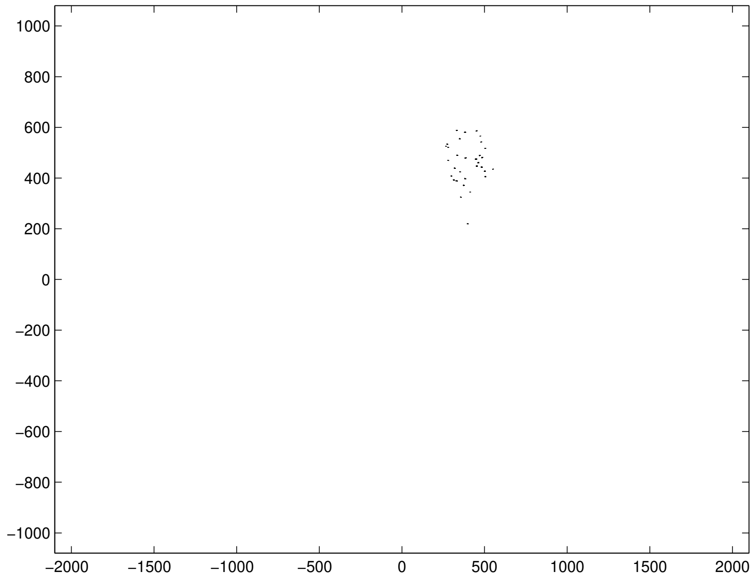
- If $P(l)$ is low given the sensor data $P(l \mid s)$,
- Then replace some samples with samples drawn from the probability density $P(l \mid s)$.

Further details in Lenser & Veloso, ICRA-2000

Sensor Resetting Localization





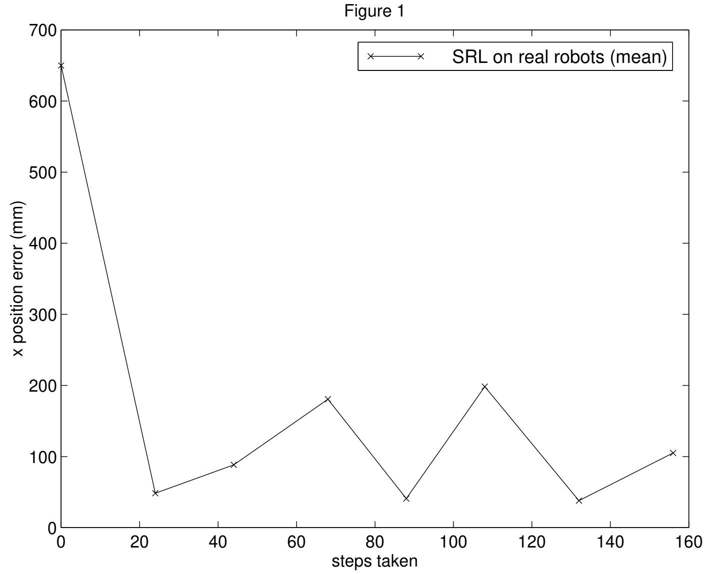


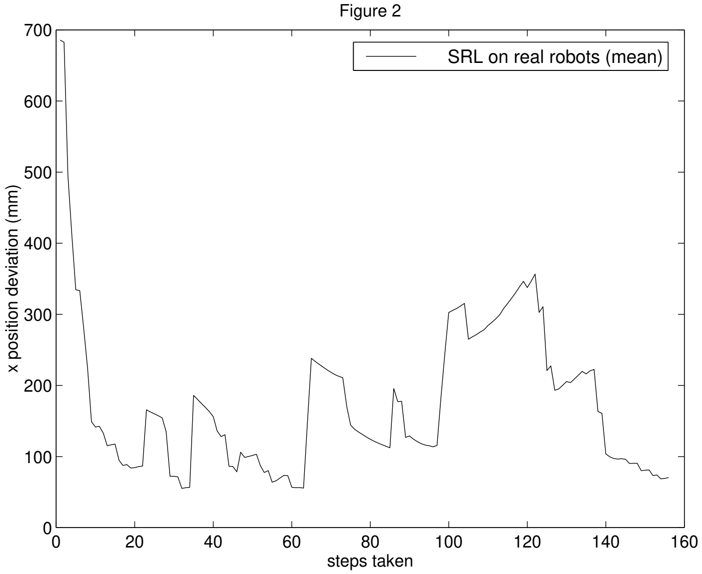
SRL on Real Robots

Output of localization:

- mean and standard deviation of probability density in x, y, θ (Gaussian approximation);
- real valued, with approximate reliability.

Typical results of localization





x position error x position deviation

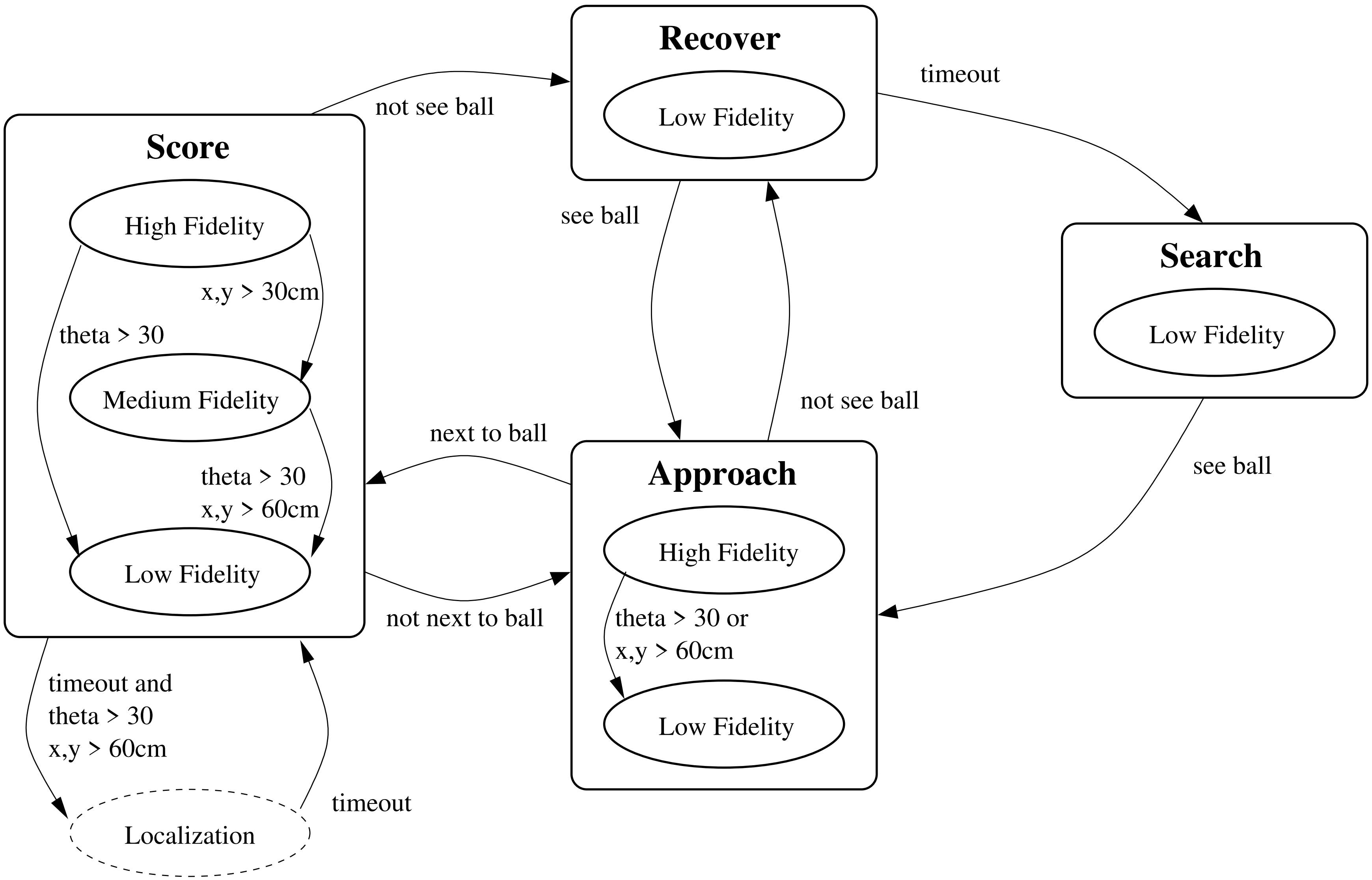
versus number of steps taken

Multi-Fidelity Behaviors

- General modes of behavior
- Different levels of behaviors as a function of the accuracy of the processed sensory data: visual, localization
- Recover ball - low fidelity
- Search for ball - low fidelity
- Approach ball - low, high fidelity
- Score - low, medium, high fidelity

Further details in Winner & Veloso, AAAI-2000

Multi-Fidelity Behaviors



Low-Fidelity Behaviors

No accurate localization information

Recover:

```
Walk backwards for some preset time.
  If does not see ball,
    then Turn in the direction last seen.
         If still does not see the ball,
           then Random search.
```

Search:

```
(Random search)
 Until the robot sees the ball,
   Walk forward a random distance.
   Turn a random angle.
```

Multi-Fidelity Behaviors

Approach:

Low:

```
Run straight towards the ball.
```

High:

```
Skew approach to ball to get behind it,
when closer to its goal position.
```

Score:

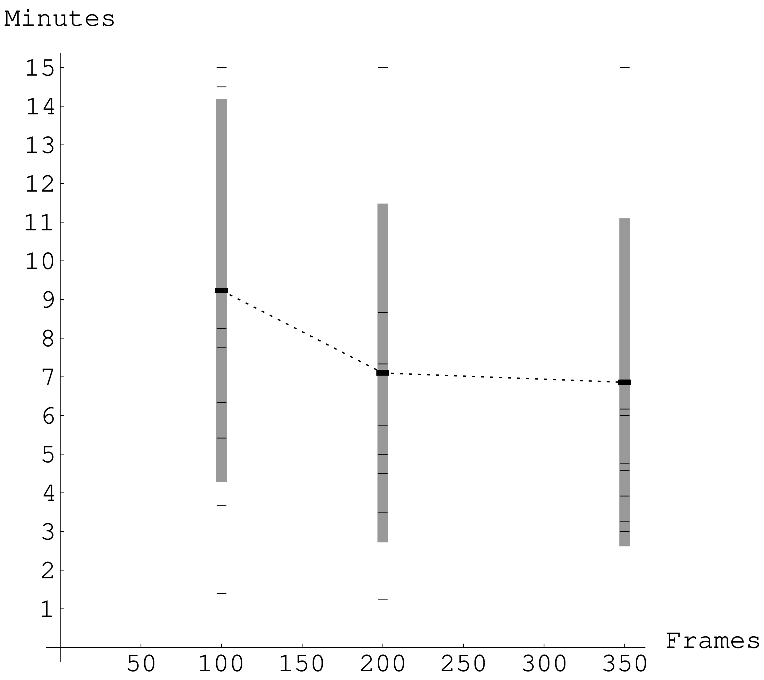
Low:

```
Until the robot sees the goal,
  Walk sideways around the ball.
Walk forward pushing the ball.
```

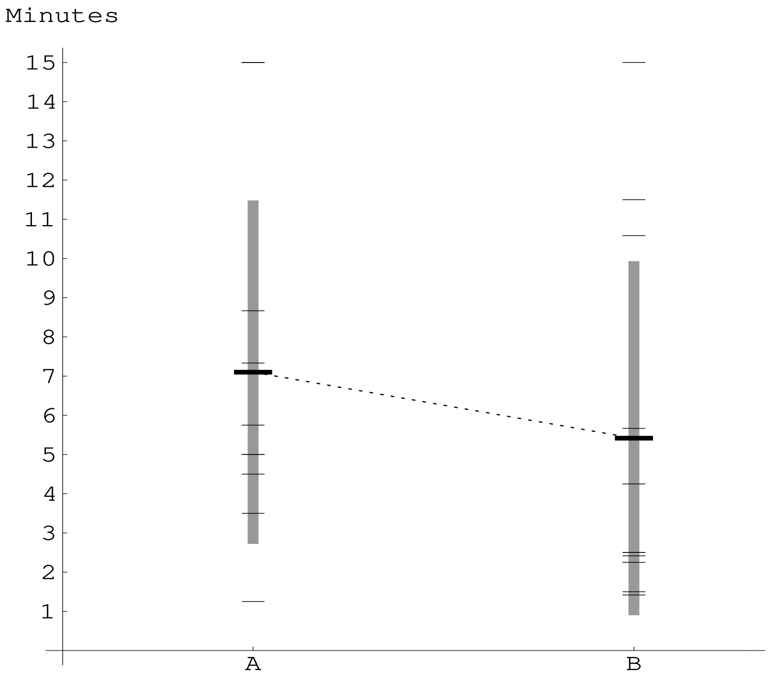
Medium-High:

```
Circle ball using shortest distance
If facing goal, push ball forwards.
```

Empirical Setting of Fidelity Thresholds



Scoring time versus time without localizing.



Scoring time in two setups for transitioning.