Robust Vision Algorithms for Quadruped Soccer Robots

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Presentation Outline

- Introduction
- RoboCup Initiative and Leagues
- AIBO Platform and Legged League
- Agent Architecture and Team Strategy
- Vision Module Algorithms
- Localization and World State
- Results
- Conclusions
Introduction - Motivation

How to develop a robust vision system to be able to cope with variable lightning conditions in a multi-agent, inaccessible, non-deterministic, dynamic environment?

Autonomous Agents - Definition

Traditional Definition:
“Computational System, situated in a given environment, that has the ability to perceive that environment using sensors and act, in an autonomous way, in that environment using its actuators to fulfill a given function.”
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RoboCup
Objectives of the RoboCup Initiative

- Joint International Project:
  - (Distributed) Artificial Intelligence
  - Intelligent Robotics

- Soccer – Central Research Topic:
  - Very complex collective game
  - Huge amount of technologies involved:
    - Autonomous Agents, Multi-Agent Systems, Computer Vision, Cooperation, Communication, Robotics, Sensor Fusion, Real-Time Reasoning, Machine Learning, etc
RoboCup

Objectives of the RoboCup Initiative

Main Goal of the RoboCup Initiative:

“By 2050, develop a team of fully autonomous humanoid robots that may win against the human world champion team in soccer!”

RoboCup

RoboSoccer – Major Leagues

- Soccer Leagues
  - Simulation – SoccerServer (2D, 3D, Coach)
  - Robots Small-Size
  - Robots Medium-Size
  - Legged Robots (Aibo Dogs -Sony)
  - Humanoid Robots
- RoboCup Rescue
  - Simulation, Virtual, Robotic
- RoboCup Júnior
- RoboCup @ Home
### RoboCup

**The Complexity of RoboSoccer**

<table>
<thead>
<tr>
<th>Comparison with Chess</th>
<th>Chess</th>
<th>RoboSoccer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>Static</td>
<td>Dynamic</td>
</tr>
<tr>
<td>State Change</td>
<td>In Turns / Deterministic</td>
<td>Real-Time / Non-Deterministic</td>
</tr>
<tr>
<td>World State Accessibility</td>
<td>Complete</td>
<td>Incomplete</td>
</tr>
<tr>
<td>Sensor Reading</td>
<td>Symbolic</td>
<td>Non Symbolic</td>
</tr>
<tr>
<td>Control</td>
<td>Centralized / Single-Agent</td>
<td>Distributed / Multi-Agent</td>
</tr>
</tbody>
</table>

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AIBO Platform ERS110, ERS210 and ERS7

- Stereo Microphone
- Infrared Sensors
- Processor MIPS
- CCD Color Camera
- Legs with 3 degrees of freedom
- Acceleration and vibration sensors
- Lithium ion battery pack

Actuators

- 20 Motors: 3 on the Head
- 6 Leds (Face): 4 Red, 2 Green
- Mode Led, Tail Led (2 colors)
- Speaker: 8/16 KHz
Sensors – Head, Body and Sound

- Touch Sensor
- Distance (10 - 90 cm)
- Back and Chin, 4 Touch - Legs
- Stereo Microphone
  - Sampling Freq: 16KHz
  - 16 bits linear PCM
  - 2 channels (stereo)
  - Omni directional or Directional
- Acceleration (ax, ay e az), 2.0G ±2.0G, Vibration and Temperature
- Slots:
  - PC Card (Wireless)
  - Memory Stick: Only Open-R!
  - Battery: Lithium (7.4V / 2300mAh)

Sensors – Color Camera

- Color (YUV)
- 352(H)x288(V) pixels
- 25 FPS
- Lens
  - F 2.0, f=2.18mm
- Vision angle:
  - (H:57.6 x V: 47.8 graus)
- Shutter Speed, White Balance e Ganho
Robot Mechanics

OPEN-R SDK - Introduction

- OPEN-R:  
  - Standard interface
- OPEN-R SDK (OPEN-R Software Development Kit)  
  - gcc (C++) - Open source  
  - Hardware and Software modular architecture  
  - Wireless
- Aperios OS
- Memory Sticks (wireless?)
- OPEN-R Objects:  
  - .BIN  
  - Message communication
RoboCup Leagues
4Legged Sony League

- Teams of 4 Robots – Sony AIBO dogs (30cm)
- Field of 5*4m
- Autonomous Robots
- Emphasis on Computer Vision and Legged Motion
RoboCup Leagues
4Legged Sony League

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FC Portugal Legged Team
Agent’s Architecture

Formalization of the Team Strategy
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Vision Algorithms

- Construction of color calibration lookup tables
  - Automatic? Dynamic?
- Image capture (25 fps)
- Noise Filtering: Spatial, Temporal
- Pixel classification into pre-defined color classes
- Conversion to RLE – Run Length Encoding
- Image segmentation:
  - Finding blocks of the same color (blobs)
  - Characteristics: center, size and shape
- Object recognition:
  - Image high-level description (world coordinates)
- Textual image description
Calibration Verification

- Re-Check Image Classification:
  - Check all images are classified correctly by the semi-automatic process (wrong positives)

- Examine the Colour Cube:
  - RGB colour cube, compare color areas with “normal” areas

- Examine the Images Gathered in Real Movement
  Gather and classify manually new images?

Sony Legged League - Vision

- Color Segmentation

![Color Segmentation Images]
Sony Legged League - Vision

Blob Formation

Image Analysis:
- Distance
- Direction

3d -> World

Image Analysis – Object Recognition
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World State Update

- High-level visual information:
  - Vision module
- Sensorial information:
  - Proximity and touch sensors
- Communicated information:
  - Sent by other members of the team
- Action prediction:
  - Prediction of the effects of robot actions in the environment

Sensor fusion, world-state update, input to high-level decision module
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Results – Controlled Experiments

Experiments:
- Six games (5 minutes)
- CMU and UNSW (simple vision calibration)
- FC Portugal:
  - Semi-automatic/normal-calibration (using CMVision)
  - Same localization, locomotion, decision and cooperation configuration.
  - Lightening variable environment
## Results – Controlled Experiments

**Results:**
- RES - global result (number of goals for each team)
- ATT - Percentage of attack
- BFP - Ball false positives detections
- OGFP - Opponent goal false positive detections

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<th></th>
<th>RES</th>
<th>ATT (%)</th>
<th>BFP</th>
<th>OGFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto vs CMU</td>
<td>8-0</td>
<td>90.3%</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>Auto vs UNSW</td>
<td>5-1</td>
<td>68.3%</td>
<td>38</td>
<td>3</td>
</tr>
<tr>
<td>Manual vs CMU</td>
<td>10-0</td>
<td>86.9%</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Manual vs UNSW</td>
<td>6-1</td>
<td>67.2%</td>
<td>36</td>
<td>1</td>
</tr>
</tbody>
</table>

Performance of both teams is similar

Automatic calibration (slightly worse):
- False positives on goal detection, leading to shoots in the wrong direction
- Problem: Objects around the field with color similar to yellow
Results - RoboCup Competitions

- Small-Size – 3rd World Championship – 1998 in Paris!
- Sim2D - European Champions - 2000 in Amsterdam (86-0)!
- Sim2D - World Champions – 2000 in Melbourne (94-0)!
- Sim2D - European Champions - 2001 in Paderborn (56-4)!
- Small-Size - European Champions - 2001 in Paderborn!
- Sim2D - 3rd World Championship - 2001 in Seattle! (150-5)!
- Coach - Champions – 2002 in Fukuoka, Japan
- Coach - 2nd Place – Padova, Italy and Lisbon, Portugal (2003,2004)
- Sim3D - European Champions - 2006 in Eindhoven! (17-0)!
- Small-Size - European Champions - 2006 in Eindhoven!
- Rescue - European Champions - 2006 in Eindhoven!
- Small-Size - 2nd World Championship – 2006 in Bremen!
- Sim3D – World Champions - 2006 in Bremen! (78-0)!

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Conclusions and Future Work

Semi-automatic calibration process enables playing without significant performance loss

In these applications, with limited time for setup and tuning, time is scarce resource

Semi-automatic calibration process:
- Major advantage
- RoboCup 2003-2005 with only two partial-time team members achieving very good results (40 goals, 5th place in Padua, Italy)

Different fields and lightning conditions without deteriorating team performance

Future Work:
- Dynamic calibration algorithms
- General image description language for multi-robot applications