

Robust Vision Algorithms for Quadruped Soccer Robots

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ABSTRACT: This paper presents a robust vision system based on semi-automatic color calibration, color segmentation and image high-level analysis for quadruped soccer playing robots. The algorithms presented were used in the context of FC Portugal legged league team that participated since 2003 in RoboCup – Robotic Soccer World Championship. Controlled experiments with variable lightning conditions are analyzed in order to conclude the robustness of our vision system.

1 INTRODUCTION

RoboCup legged league uses teams of four AIBO (ERS210A or ERS7) robots (figure 1) that play a soccer match in a green carpeted field.



Figure 1: ERS210A (left) and ERS7 (right) AIBO Sony quadruped robotic platforms.

Figure 2 depict an ERS210A robot and its main sensors and actuators. The robots have a huge amount of sensors, including a CCD Color Camera (352x288 pixels), Stereo Microphone (16 kHz), Infrared Distance Sensors (10-90 cm), Touch Sensors spread throughout the body, Acceleration, Temperature and Vibration sensors.

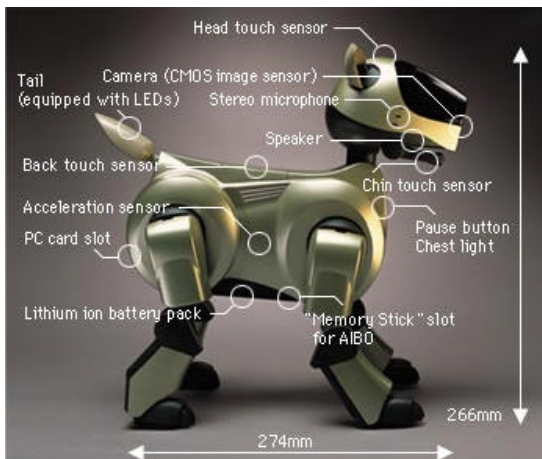


Figure 2: ERS210A sensors and actuators.

The robot has 20 degrees of freedom, including three motors on each leg and three motors on the head (pan, tilt and roll). The robots also include a speaker and, depending on the model, several leds are also included, mainly with debugging purposes.

A legged league game has two halves of 10 minutes each, and is played in a 5,4m x 3,6m field, as depicted in Figure 3. The robots must be completely autonomous and play without any human intervention. Most of the interesting objects in the field are colored in order to enable the robots to use as main sensorial source a real time vision system based on fast color segmentation.

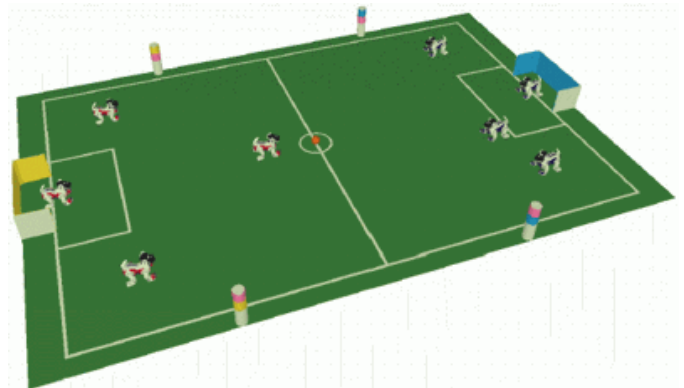


Figure 3: Legged League field showing colored goals and landmarks.

FC Portugal legged league team research focus is mainly on coordination methodologies applied to the legged league and on developing a common approach to all RoboCup soccer leagues. In the context of our legged team we also perform research on high-level vision and automatic calibration, sensor fusion, multi-agent communication, navigation, localization and learning applied to teams of mobile robots.

The team started performing experiments with the German Team [21] simulator [5, 20, 21] and using our ex-

expertise in RoboCup simulation league and on developing complex simulators [16, 17], we have built a very simple legged league simulator (with very simple models of the robots) enabling us to test different positioning strategies. Afterwards we have bought Sony ERS210A robots and moved our code from the simulator to the real robots. For that, we have used over the years, CMPack02 [23] and UNSW03 [7, 8, 22] codes as the base. We have applied over the base code, several previously researched methodologies developed and tested in our teams in other RoboCup leagues (Simulation, Small-Size, Middle-Size and Coach Leagues). From FC Portugal [10] (champion of RoboCup simulation league in 2000, European champion in 2000 and German Open Winner in 2001) we introduced simple versions of SBSP – Situation Based Strategic Positioning [17, 18], ADVCOM – Advanced Communications [11, 17] and DPRE – Dynamic Positioning and Role Exchange [17, 18]. From our FC Portugal Coach (Coach Competition champion in 2002), we have taken our tactical structure and coaching language [19]. From 5DPO teams [1] (small-size 3rd in RoboCup 1998, German Open Winners in 2001 and 2nd in 2002) we have taken the base vision system and most of our navigation algorithms [9, 15]. Our vision algorithms were then extended in order to enable robust color segmentation, automatic calibration and high-level image analysis. This paper describes briefly these extensions and the results achieved by our vision system in variable lightening conditions.

The paper is organized as follows. Section 2 presents our vision module. Section 3 describes the localization module and the world state information used for high-level decisions. Section 4 presents some results and section 5 the paper conclusions.

2 VISION MODULE

Based on the publicly available code from RoboCup 2002 legged league champions (CMPack) [23], namely on its CMVision image processing library [3, 4] and on our experience and own code for small-size and middle-size leagues vision [9], we have developed a robust vision system including capabilities for color image segmentation, automatic calibration and object recognition. The approach is based on the use of thresholds for performing color segmentation on a given color space. A color space is an abstract mathematical model describing the way colors can be represented as tuples of numbers, typically as three or four values or color components (e.g. RGB and CMYK are color models). Several

color spaces are in wide use, including Red Green Blue (RGB), Hue Saturation Value (HSV) and YUV (YCbCr). The choice of color space for classification depends on several factors including the type of hardware used and the particular application.

RGB is one of the most used color spaces in image processing. It suffers from an important drawback regarding robotic vision applications based on color segmentation. In robotic soccer, for instance, features of the environment are identified by colors (e.g. the ball is orange, goals cyan and yellow). Color segmentation should be robust in the face of variations in the brightness of illumination. HSV and YUV systems have the advantage that chrominance is coded in two of the dimensions (H and S for HSV)

or U and V for YUV) while intensity value is coded in the third. Thus a particular color can be identified as a column that uses all available intensities. These color spaces are therefore often used in simple robotic applications. However, using regions of arbitrary shape in RGB color space, enable us to identify exactly the same colors with a completely free region in the color space. Thus, that was our approach with only the special concern of achieving the possibility to perform color segmentation using arbitrary shapes in the RGB color space.

2.1 General Description

This system is also capable of performing the generation of a high-level description of the image contents, including the identification of each object, its direction, distance, size, elevation and confidence. The steps performed by the vision module are the following:

- Construction of color calibration lookup tables by a semi-automatic process;
- Capturing an image and classifying pixels into the pre-defined color classes (basically by looking up into the previously defined table);
- Conversion of the image to RLE – Run Length Encoding (although in practice because of performance reasons this step is performed together with the previous step);
- Image segmentation, finding blocks of the same color (blobs) and their characteristics (center, size and shape). This step is performed using hierarchical, multi-resolution algorithm;
- Object recognition and generation of an image high-level description: identifying objects based on color blobs and converting its own coordinates to world coordinates (relative distance and direction);

- Textual image description: changing the high level image description into a text description easily understandable by humans.

We use the eight typical colors of the legged league: pink (for the beacons), yellow and sky blue (for beacons and goals), dark red and dark blue (for the robots' uniforms), orange (for the ball), green (for the field carpet) and white (for the field lines and detection of ERS7 bodies). Our robots need to detect and discriminate these colors in order to recognize the appropriate objects. Figure 4 shows the result of the color segmentation process for completely different lightening conditions.

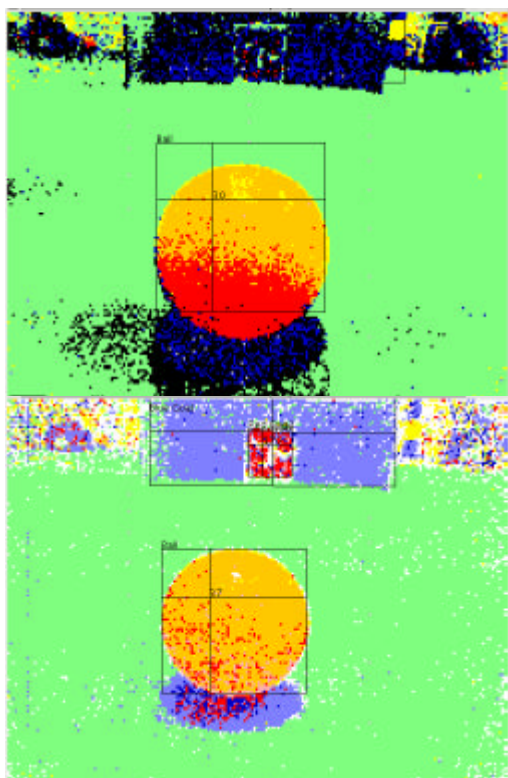


Figure 4 – Color Segmentation result for different lightning conditions.

Image segmentation is performed based on the pre-processed image resulting from our color calibration module using the fast blob formation algorithm.

2.2 Automatic Calibration

One of the main innovations of our team's vision system resides on the method developed for the construction of the color calibration tables. We have used our previous experience in designing vision systems for the small and middle-size leagues [1, 9] and designed a very simple automatic color calibration module. Using this module, we construct the color table, based on a set of significant images autonomously collected by the robot that walks around the field looking for colors similar to the ones available in its previous calibration. With the pictures autonomously gathered by the robot we assemble in a

semi-automatic manner the color segmentation table. This system was demonstrated in RoboCup 2004 challenge (Lisbon) achieving 8th place in Challenge 1.

The system gathers in semi-automatic process 44 images for the final calibration process by using a moving robot on the field. The robot starts using a color table, previously constructed and that contains very large color areas. While collecting images, the robot also adjusts its initial color table in order to be able to cope with the lightening variations.

The robot starts on the middle of the field. Several balls are located on the field including a ball in each of the goals. Three robots of each team are located on the field, including one in each goal. The process steps are the following:

- Take pictures 1-4 of the field, one in each direction.
- Adjust global lightening of the color cube.
- Rotate to find the yellow/pink beacon and the pink/yellow beacon. Pink is the simplest color to identify on the field.
- Rotate to find the yellow goal.
- Adjust pink and yellow on the color table.
- Rotate to find the cyan/pink and the pink/cyan beacons.
- Rotate to find the cyan goal.
- Adjust pink and cyan on the color table.
- Take pictures (5-8, 9-12, 13-16, 17-20) from each beacon at different distances.
- Find the orange balls in both goals.
- Adjust orange on the color table.
- Find each of the four balls and take pictures at four different distances (21-24, 25-28, 29-32, 33-36).
- Find the red robot in the yellow goal.
- Adjust red.
- Find the blue robot on the cyan goal.
- Adjust blue.
- Take pictures (37-40, 41-44) from robots of each team at different distance.
- Use all images gathered to create the final color cube.

After this initial color calibration, steps are taken to verify that the calibration has been performed properly and, in addition, to further improving the accuracy of the color calibration process. The following steps are performed:

- Re-Check Image Classification: This is a quick check that all the images have been classified correctly by the semi-automatic process. All the images are reviewed and checked to see that the

ball has not been accidentally classified as a red dog for example. Also it is important that that the area outside the object has not been classified as this would result in the blob generated to expand into incorrect regions. Also the outside area of the field is checked for wrong positives that could mean objects detected outside of the field during the game.

- Examine the Colour Cube: The RGB colour cube is depicted graphically and checked analysing the eight color areas and comparing them with the “normal” areas for this application.
- Examine the Images Gathered in Real Movement: This check is performed to determine whether the robot has classified objects correctly. The robot analysis of the field in real movement is visualized on the screen and correct object detection is checked. Vital information is the capability to detect the ball, goals and localize using the beacons. Objects appear with a slightly different colour when the robot is moving fast (the images are more blurred and elongated as well). This is an important consideration. Although training images were collected with the robot also moving, since during the games the robots move in a faster way, this check enables to predict the real vision behaviour during real games.

If the calibration process is not sufficiently robust, new images may be gathered and classified manually to increase the robustness of the calibration process.

3 LOCALIZATION AND WORLD STATE

In the legged league the objects that must be tracked include: the four unique markers, the ball, the two goals and the other seven robots. Objects in the image are identified based on its color, shape and position. Color is the main feature used for object identification, an approach similar to that used by most other teams so far. Since our Image Segmentation module also gives some information about the shape and size of the blobs, we use this information to recognize objects and to estimate its distances, directions, elevations and headings relatively to the neck of the viewing robot.

Several localization algorithms have been proposed and tested in the context of RoboCup [12]. We started by using a localization method that works using high-level vision information with a Fuzzy Landmark-Based Localization algorithm similar to several RoboCup teams, in-

spired in [6] and moved to a sensor resetting localization [13] whose source code was available on the web [14]. FC Portugal agent’s internal representation of the world, results on the processing of various sensorial information sources fused with communicated information. The information contained in the world state includes:

- Self Position (Cartesian coordinates);
- Ball Position and Velocity (Cartesian coordinates);
- Teammates’ Position and Velocities (Cartesian coordinates);
- Teammates’ Behavior and State;
- Opponents’ Position and Velocities (Cartesian coordinates);
- Opponents’ Behavior and State.

All the above measures have an associated certainty factor, expressing the probability of the measure being accurate.

Our world state update method is somewhat different from other teams because since 2004 competition we use a trigonometric world state fusion method. Figure 5 shows a graphical description of this method. The area defined between the interceptions of two of the agents quantifies the uncertainty of the calculated ball position (the bigger the area the bigger the uncertainty). This area is the limiting area for the presence of the ball according to the sensorial information of the two involved robots (see details in [2]).

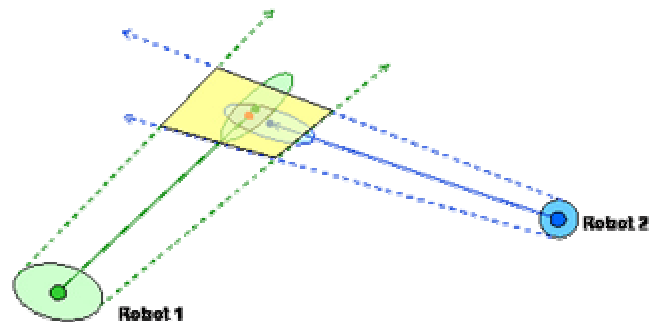


Figure 5 – Limiting area for the presence of the ball, in conjunction with the extreme vectors.

Our global World state update is similar to our simulation league team FC Portugal [10, 17]. It uses:

- High-level visual information: resulting from our vision module;
- Sensorial information: achieved using proximity and touch sensors’ preprocessing;
- Communicated information: sent by other members of the team; and
- Action prediction: prediction of the effects of robot actions in the environment.

These four types of information are fused together to assemble our world-state used as an input in the high-level decision module.

The communication between the robots complements the internal world state from all the robots, with additional information concerning team coordination, such as, position swap between team members or the existence of a ball pass to another team member.

4 RESULTS

To validate our approach six games, with 5 minutes duration, were performed against each of CMU 2003 and UNSW 2003 teams (configured with simple vision calibration). Our team used semi-automatic calibration in three games against each opponent and normal calibration (with the aid of CMVision) in the other three. The same localization, locomotion, decision and cooperation configuration was used in all experiences. The experiences were performed in a quite lightening variable environment in order to test the robustness of both vision systems.

Figure 6 show the results attained by our automatic calibration process compared with the results obtained using the completely manual calibration process. The results gathered, besides the global result (measured in the number of goals for each team), include, for each set of three experiences: the percentage of attack, ball false positives and opponent goal false positive detections.

Experience/Values	RES	ATT	BFP	OGFP
Auto vs CMU	8-0	90.3%	25	6
Auto vs UNSW	5-1	68.3%	38	3
Manual vs CMU	10-0	86.9%	24	2
Manual vs UNSW	6-1	67.2%	36	1

Figure 6—Results achieved in laboratory tests.

From the results displayed it is clear that the performance of both teams is similar. With automatic calibration the performance is slightly worse, mainly in terms of the number of goals achieved, even with some improvement in the percentage of attack against both opponents. This performance loss in the number of goals scored seems to be explained by the number of false positives in the detection of the opponent goal, leading to shoots in the wrong direction. These false positives were mainly due to other objects around the field with color similar to yellow that were filtered in the manual calibration process but the automatic calibration process was not able to filter completely.

5 CONCLUSIONS

The results achieved showed that for normal play, the semi-automatic calibration process enables the robots to play without significant performance loss. Since in these robotic applications, involving competitions, with limited time for setup and tuning, time is scarce resource, the semi-automatic calibration process is a major advantage. It enabled our team to participate in RoboCup 2003, 2004 and 2005 with only two partial-time team members and compete against teams with more than twenty full-time team members achieving very good results.

Our legged team in its three participations in RoboCup scored 40 goals and conceded also 40, achieving 5th place in Padua, Italy, and 9th place in Lisbon, Portugal. In all three competitions our vision system needed only one semi-automatic calibration in the beginning of the competition and was able to cope with different fields and lightning conditions without deteriorating significantly the team performance.

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