Real-Time Vision in the RoboCup - Robotic Soccer International Competitions

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ABSTRACT: In many robotic applications, autonomous robots must be capable of locating the objects that they have to manipulate. In the case of autonomous soccer robots, they must, at least, be able to locate the ball, the opponent robots and the team robots, and also to collect field information essential for self-localization. In this paper, we present a survey on the vision systems developed for four RoboCup leagues: Small Size, Middle Size, Standard Platform and Mixed Reality Leagues. In the Small size and Mixed Reality leagues, we typically have a global vision using an overhead camera and off-field PC. In the case of the Middle Size and the Standard Platform Leagues, the robots have their own vision system and the image processing is performed in each agent. In the Standard Platform and Mixed Reality Leagues, teams use exactly the same robots. The Standard Platform League used the quadruped Sony Aibo robots but recently moved to the Nao humanoid robots. Mixed Reality League uses the very small EcoBe robots from Citizen. Contrarily, in the Small-Size and Middle-Size leagues teams develop their own robots and use camera systems of their choice. The computer vision challenges are quite different in the four leagues. From very fast robots and ball in the small-size, to very unstable camera due to the robot's locomotion in the standard platform league. This paper presents some of the problems faced by distinct RoboCup teams and the vision solutions in our teams that participated in these four leagues (5DPO, Cambada and FC Portugal).

1 INTRODUCTION

After Garry Kasparov was defeated by IBM's Deep Blue Supercomputer in May 1997, forty years of challenge in the artificial intelligence (AI) community came to a successful conclusion. But it also was clear that a new challenge had to be found.

"By mid-21st century, a team of fully autonomous humanoid robot soccer players shall win the soccer game, complying with the official rules of the FIFA, against the winner of the most recent World Cup." This is how the ultimate goal was stated by the RoboCup Initiative, founded in 1997, with the aim to foster the development of artificial intelligence and related field by providing a standard problem: robots that play soccer. RoboCup chose soccer as the main problem aiming at innovations to be applied for socially relevant problems. It includes several competition leagues, each one with a specific emphasis, some only at software level, others at both hardware and software, with single or multiple agents, cooperative and competitive.

It will take decades of efforts, if not centuries, to accomplish this goal. It is not feasible, with the current technologies, to reach this goal in any near term. However, this goal can easily create a series of well directed subgoals. The first subgoal to be accomplished in RoboCup is to build real and simulated robot soccer teams which play reasonably well with modified rules (Lau & Reis, 2007). Even to accomplish this goal will undoubtedly generate technologies with impact on broad range of industries.

One problem domain in RoboCup is the field of Computer Vision. Vision is an extremely important sense for both humans and robots, providing detailed information about the environment. A robust vision system should be able to detect objects reliably and provide an accurate representation of the world to higher level processes. The vision system must also be highly efficient, allowing a resource-limited agent to respond quickly to a changing environment. Each frame acquired by a digital camera must be processed in a small, usually fixed, amount of time. Algorithmic complexity is therefore constrained, introducing a trade-off between processing time and the quality of the information acquired.

In this paper, we present a survey on the problems posed and the vision systems developed for four RoboCup leagues: Small Size, Middle Size League, Standard Platform League and Mixed Reality League.

The rest of the paper is as follows. Section 2 presents the Small-Size league and the main challenges in this league. Section 3 presents the middle-size league. Section 4 presents the two versions of the standard platform league: Sony Aibo and Nao humanoid robots. Section 5 describes the Mixed reality league. Section 6 concludes the paper with some conclusions and future work.

2 SMALL SIZE LEAGUE

A Small Size robot soccer game takes place between two teams of five robots each. Each robot must conform to the dimensions as specified in the F180 rules. The robot must fit within a 180mm diameter circle and must be no higher than 15cm unless they use on-board vision. The robots play soccer on a green carpeted field that is 4.9m long by 3.4m wide with an orange golf ball.

Robots come in two flavours, those with local onboard vision sensors and those with global vision. Global vision robots, by far the most common variety, use an overhead camera and off-field PC to identify and track the robots as they move around the field.

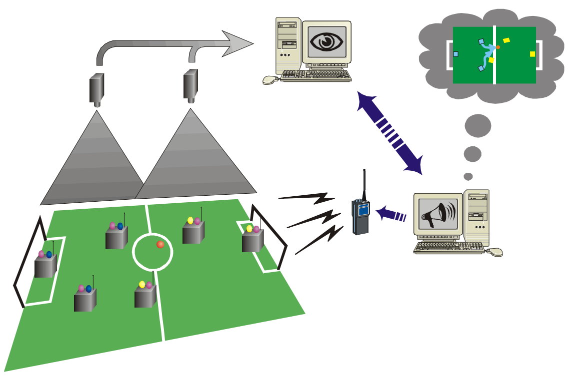

Figure 1 – Small-Size League 5DPO Team Setup.

The overhead camera is attached to a camera bar located 4m above the playing surface (figure 1). Local vision robots have their sensing on the robot itself. The vision information is either processed onboard the robot or is transmitted back to the off-field PC for processing (figure 2). Some teams use two cameras, as is the case of the 5DPO team since it enables a more accurate and free of occlusions vision of the field.

Figure 2 – Small-Size League Field.

An off-field PC is used to communicate referee commands and, in the case of overhead vision, position information to the robots. Typically the off-field PC also performs most, if not all, of the processing required for coordination and control of the robots. Communication is wireless and typically uses dedicated commercial FM transmitter/receiver units.

Figure 3 – Small-Size League Robots

To cope with high speed tracking of team members and opponents, some teams use structured colored hoods both in radial bar code manner as well as in several spots (figure 3). In all cases player number and direction is readable with high accuracy. The accuracy of all measurements is very important due to reduced ball size and high ball speed.

3 MIDDLE SIZE LEAGUE

Two teams of mid-sized robots with all sensors on-board play soccer on a field (figure 4). Relevant objects are distinguished by colors. Communication among robots (if any) is supported on wireless communications. No external intervention by humans is allowed, except to insert or remove robots in/from the field.

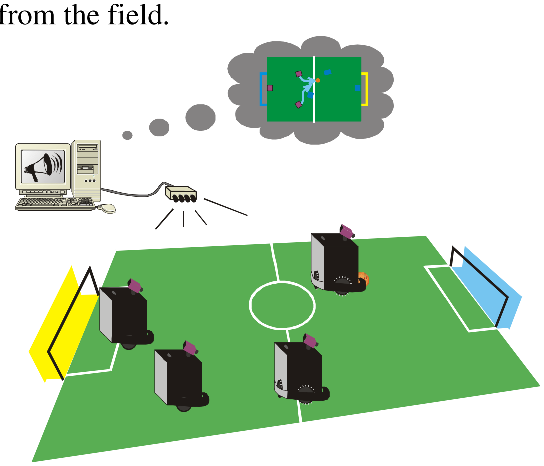

Figure 4 – Middle-Size League Team Setup.

In the context of RoboCup, the Middle Size League (MSL) is one of the most challenging. In this league, each team is composed of up to 6 robots with a maximum size of 50cm x 50cm width, 80cm height and a maximum weight of 40Kg, playing in a field of 18m x 12m. The rules of the game are similar to the official FIFA rules, with minor changes required to adapt them for the playing robots.

The MSL competition of RoboCup is a standard real-world test for autonomous multi-robot systems.

Yet being a color-coded environment, despite the recent changes introduced (such as the goals without color), recognizing colored objects, such as the orange ball, the black obstacles, the green field and the white lines, is one of the basic abilities that these robots must possess. In fact, the computer vision field is of the upmost importance for the robotic players, because it responsible for providing fundamental information that is needed for calculating and controlling the behavior of the robots.

The color codes tend to disappear as the competition evolves, increasing the difficulty posed to the vision algorithms. The color of the ball, currently orange, is the next color scheduled to become arbitrary (figure 5).

Figure 5 – Middle-Size League Robot

In this league, omnidirectional vision systems have become interesting in the last years, allowing a robot to see in all directions at the same time without moving itself or its camera (Lima et. al., 2001), (Sousa et al. 2005), (Lu, et al., 2008), (Hafner et al., 2008), (Zweigle et al., 2007), (Azevedo et al., 2008); (Neves et al., 2007). Omnidirectional vision is the method used by most teams in the Middle Size League.

Many teams are currently taking their first steps in 3D ball information (Hafner et al., 2008), (Zweigle et al., 2007) while others are developing vision systems capable of detecting balls without a specific color (Kimiyaghalam et al., 2008). There are also some teams moving their vision systems algorithms to VHDL based algorithms taking advantage of the FPGA's versatility (Hafner et al., 2008) (Jahshan, 2008). Even so, for now, the great majority of the teams base their image analysis in color search using radial sensors (Bouchard et al., 2008), (Chen et al., 2008), (Kimiyaghalam et al., 2008).

4 STANDARD PLATFORM LEAGUE

RoboCup legged league used for several years teams of four AIBO (ERS210A or ERS7) robots (figure 6) that play a soccer match in a green carpeted field (figure 7).

Figure 6: ERS210A (left) and ERS7 (right) AIBO Sony quadruped robotic platforms.

The robots have a huge amount of sensors, including a CCD Color Camera (352x288 pixels), Stereo Microphone (16 kHz), one or three Infrared Distance Sensors (10-90 cm) depending on the model, Touch Sensors spread throughout the body, Acceleration, Temperature and Vibration sensors.

The robots have 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.

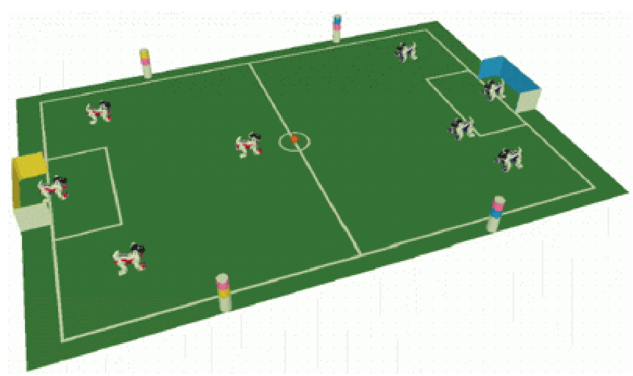

Figure 7: Legged League field.

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.

Our 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.

Most of the teams in the legged league use a vision system 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 (Reis, 2007):

- 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.

Figure 8: Standard Platform League Nao Robot.

In the league all teams use identical robots. Therefore the teams concentrate on software development only, while still using state-of-the-art robots.

The robots operate fully autonomously, i.e. there is no external control, neither by humans nor by computers. In 2008 the league went through a transition from the four-legged Sony AIBO to the humanoid Aldebaran Nao (figure 8). Recently the league moved completely to humanoid robots using the Nao robotic platform. However, the challenges faced by the teams are still similar to the ones faced using the Sony AIBO robot.

5 MIXED REALITY LEAGUE

The Mixed Reality Soccer League is a recent RoboCup league that started in 2007, where small real robots, called Eco-Bes, play soccer on top of a virtual field with a virtual ball, thus using the concept of augmented reality (Mackay and Gold, 1993). Augmented Reality is an environment that includes both virtual reality and real-world elements (Milgram and Kishino, 1994). Most augmented reality research uses a processed video which is augmented with virtual elements. The Augmented Reality at Physical Visualization League can improve the simulation, adding virtual elements that surround the real player. An example applied in that soccer league is a virtual leg with the ability to kick and to dribble the virtual ball and vision to perceive the world state (Azuma, 1997).

The Mixed Reality League offers a very interesting challenge for teams since several research challenges are included in this setup (Vision Based Self Localization, Data Fusion, Real-Time Control; Decision and Cooperation). The simplicity of this setup compared with the small-size league, makes it very interesting for educational and demonstration purposes (Lau and Reis, 2007). The vision problem, although similar to the Small-Size league problem is simplified and thus the league is a simpler setup than small-size.

The Eco-Be is a very small vehicle remotely controlled by infrared commands, currently handmade. As presented in Fig. 10, it is composed by two step motors (1), a li-ion polymer battery (2), a control board (using an 8bit PIC18 family processor) (3), an Infrared Sensor (4) to receive its movement commands and an aluminium body (5). The robot can not send any kind of messages and its position is determined by an external camera (Yanagimachi and-Guerra, 2007). Each robot has a configurable ID, which can be freely changed. The robot can use each motor individually and each motor has three different speeds available. While using the fastest speed, all resources are drained from the controller, disabling the reception of new commands during this fast movement. The kit furnished by Citizen contains a set of 20 robots with one charger, two AC/DC adapters and one infrared transmitter.

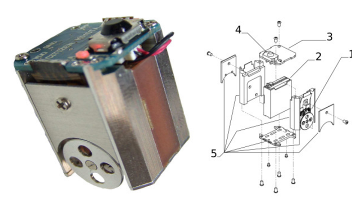

Fig. 9. Eco-Be Robot (Yanagimachi, S. & Guerra, R. 2007)

The Eco-Be has a simple protocol of communication to control its movement. The robot's IR sensor recognizes a command through the modulation of the flash light as a square wave at 40 kHz with an on-to-off ratio of 50%. The period of Signal/Space allows the translation into valid logical states.

The LIRC software (Linux Infrared Remote Control) encodes the correct sequence of flash lights to compose a valid string to the robot. LIRC is an open source software capable to decode and send infrared signals from and to the common serial port. It receives commands via socket and sends them to the infrared device driver. A specific communication protocol is followed in order to send commands to the robot. The transmitter uses a public circuit which receives a signal from the serial port and polarizes the infrared LED accordingly. The robot's Infrared Protocol accepts a string of 12 bits as a valid word. The first 5 bits identify the destination robot. The next three bits command the left motor and the following three command the right motor. The last bit is used for parity.

The Physical Visualization Sub-League started in 2007 focused on augmented reality, on its practical simple environment and on demonstrating that the possibilities of the ECoBes are not limited to robot soccer. The league format has several competitions: demonstrations, technical developments and soccer tournament. Rules of the tournament disallow communication between the teammates in such a way that it is solely up to the server to provide players' with sensory data.

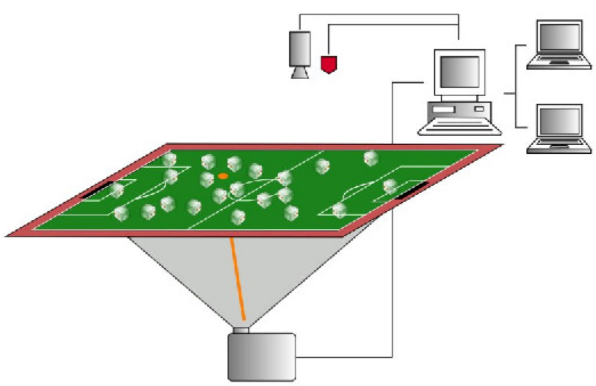

Fig. 10. Mixed Reality League Schematic Setup.

Prior to any game the camera is calibrated to recognize the field and the robots' markers. Each robot is identified by an individual marker that is recognized by the vision system. Each robot then receives an ID that corresponds to its marker and thus may be controlled by an autonomous agent running on a separate PC. Figure 10 presents the field Schematic Setup.

A server application is responsible to control the socket connections with the clients, the monitor, the camera and the communication with the infrared USB transmitter. It has a file that defines the field size and the positions of each goal and each flag pole. For each instant, the server just has to identify the robots using their color markers. For the other elements, the server uses the positions in the configuration file. The server, then, compiles all information and, for each robot, it sends the relative positions (polar coordinates) of all elements in the field, including the ball and the other robots.

An associated monitor application uses the same information to draw the field and project it at the display where the robots play. The server sends the robot's absolute position to the monitor that projects them in the screen with a considerable precision. The monitor also shows the virtual ball.

Figure 11 depicts a match with all the necessary elements. The field's background, lines, goals and poles are the passive elements drawn by the monitor. The marks below the robots and the ball is repeatedly updated, this way when the robots are over the screen monitor, the setup transmits the sensation the robots are really controlling the virtual ball with their physical movements.

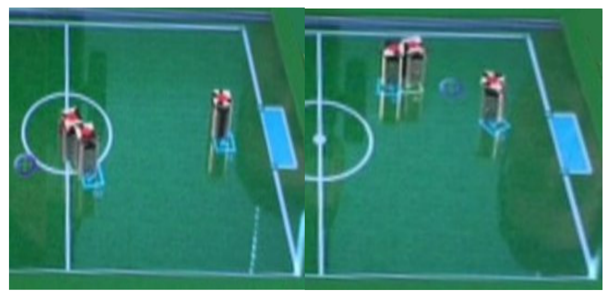

Fig. 11. Snapshot from an official Mixed Reality League match

Developing new low level skills for physical robots in virtual environments is a very challenging task as it was clear in RoboCup 2007 and 2008, the first two editions of the MR-League. Methods for navigation, ball dribbling, passing, shooting and for goalie positioning were the basis for having a successful team.

6 CONCLUSIONS

Throughout this article, the autonomous Competitions of the RoboCup Robotic Soccer competitions were reviewed with enphasis on the challenges faced by the computer vision systems.

The small size and mixed reality leagues have a global off field vision. The challenge is higher in the small-size league due to the large number of high speed vision items to track on a filed with natural lighting conditions.

The medium size league is a distributed vision system where the light weight Real Time processing of the field lines and other robots is hard to tackle due to the natural light environment on the competition. This competition frequently uses catadioptric vision system that require complex vision mapping to the world.

The Standard Platform has different ruleset that addresses specific problems of intelligent actuators, that is, systems where the camera is mounted on a neck actuator that can turn to face a given play. The specific problems of this leagues's vision problems were also addressed concluding the difficulty of the vision system with legged locomotion.

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