# S.P.Q.R. Legged Team

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**Abstract.** The SPQR (Soccer Player Quadruped Robots, but also *Senatus PopolusQue Romanus*) team participates for the fourth time to RoboCup Four-Legged League. This paper presents the main development efforts of the team in 2003: the realization of an efficient and robust color segmentation algorithm for the AIBO robots, the development of a localization technique, and the realization of a coordination mechanism based on dynamic role assignment.

## 1 Introduction

S.P.Q.R. is the group of the Faculty of Engineering at University of Rome "La Sapienza" in Italy, that is involved in developing RoboCup teams within the Four-Legged League [9], the Middle Size League [6], and recently also within the Rescue Robots League.

In this paper we present the main achievements and research objectives of the **S.P.Q.R. Legged** team for RoboCup 2003. In order to improve our robotic system, we have specifically addressed the following issues: 1) color segmentation by means of an implementation of a dynamic thresholding method which is both efficient on the AIBO robots and robust to light conditions; 2) robot self-localization, by applying a probabilistic method based on feature extraction and Kalman Filtering [8]; 3) multi-robot coordination, based on dynamic role assignment [2].

Before addressing the specific issues that have been developed during this year, we will briefly describe in the next section the main features of the system architecture.

## 2 Software Architecture

The main focus of our research group is the realization of a team of cognitive soccer robots and to this end we have defined and implemented a hybrid architecture that allows for an effective integration of reasoning and reactive capabilities, a high level representation of the plans executed by the players, a formal account of the system for generating and verifying plans (see also [5, 3] for a detailed description).

Specifically, there are four main functional modules: *Perception*, *Deliberation*, *Control*, *Coordination*. The communication among these modules is done by sharing a common memory that contains the internal model of the world evolving during the game.

This world model has two different representations: i) numerical data, representing object coordinates in the world (i.e. position of the robot in the field, position of the ball, etc.); ii) symbolic predicates, representing facts that holds during the game (e.g. the ball is close to the robot, the robot cannot see the ball, etc.). The first representation is used in the Control module to execute the actions (e.g. going to the ball); while the symbolic representation is used within the Deliberation module to take decisions about which primitive actions should be activated in the current situation of the world.

Thus, the Perception module analyzes the sensor data (which are mainly obtained by the camera) and stores and updates the internal world model. The Deliberation module is in charge of executing a plan and activating/deactivating the primitive actions according to the current situation of the world. The Control module is responsible for actual execution of primitive actions. Finally, the Coordination module is responsible for selecting the plan to be executed according to a distributed coordination protocol that has already successfully implemented in the Middle Size league [2] (see Section 5).

## 3 Color segmentation by dynamic thresholding

In order to improve color segmentation for the AIBO robots we have devised and implemented a method based on dynamic thresholding, that is both efficient and robust to different light conditions. This improvement has allowed for a better recognition of the objects in the field in terms of both precision and reliability and a localization technique (which is described in the next section) has been implemented by making use of features extracted by the color segmentation module.

The dynamic color segmentation technique we have implemented is based on the following steps: 1) image filtering for the U and V components based on a SUSAN operator; 2) creation of the color histograms for the U and V components of the image and detection of its modes; 3) color segmentation by using the modes of the histograms detected before. 4) edge detection for the Y components

The first step is important in order to reduce noise in the image and to have smoother histograms for the components U and V. We have designed a modification of the SUSAN filter [10] that can be efficiently implemented on the AIBO robots (we have called it *Real-Time SUSAN Filter*). With respect to the standard SUSAN filter, the Real-Time version has the two specific features: 1) the correlation function is rectangular instead of Gaussian; 2) it makes use of a 3x3 kernel in which only the 4-connected pixels are considered (i.e. only north, south, east and west positions). The Real-Time version of the SUSAN filter has a lower (but still significant in our application) noise reduction ability, and it has been implemented on the AIBO robots ERS-210 with 200 MHz CPU and for high resolution images (176x144) at a frame rate of 14 fps. The second step is the application of a dynamic thresholding method, in which the color histograms of the U and V components are created, the corresponding modes are detected and the color thresholds are computed. The third step is a color segmentation procedure that is based on the color thresholds computed in the previous step. Finally, in order to properly detect also the lines in the field, that are white and thus not well characterized by the U and V components, we have also applied an edge detection process for the Y component of the image. We have implemented a SUSAN Edge Operator, that has been shown to be more precise and effective than other methods [10]. An efficient implementation of such operator has been obtained by defining a *Lite SUSAN Edge Operator*, that uses a pre-computed correlation function with a 3x3 kernel, that does not determine the direction of the edge and that does not perform the non-maxima suppression phase. This Lite version of the SUSAN Edge Operator can process more that 20 fps (for the AIBO robots ERS-210A with 400 MHz CPU and high resolution images 176x144).

The method proposed above has been implemented with several kinds of code optimizations and it currently allows for processing almost 10 fps (for the AIBO ERS-210A robots with 400 MHz CPU and high resolution images 176x144), during the normal operations of the robots (i.e. in parallel with other modules). The overall results of the technique in terms of quality of color segmentation is shown in Figure 1.

Color segmentation is followed by three additional phases: blob extraction, object recognition and 3D reconstruction. Blob extraction has been implemented following the work in [1]. The segmented image is decomposed in runs, where every run is made up by horizontally contiguous pixels of the same color, and then vertically contiguous runs are merged by making use of a union-find algorithm, thus forming the blobs. Once the blobs are obtained, an object recognition routine classifies them on the basis of their color, while trying to recover from possibly wrong decisions through the use of some heuristics, depending on the Four-Legged League operational setting. During this process every blob is marked with a label corresponding to the object it represents and additional information about the resulting objects is used to adjust classification according to known constraints. Finally, a method based on the robot kinematic model is adopted for calculating the position of the robot camera with respect to the ground and thus obtaining the position of the objects relative to the robot.

## 4 Vision-based Localization

Building on the capabilities of the vision system, a localization procedure was written, based on the estimation of the landmarks in the field and on the use of a probabilistic model defined by an Extended Kalman Filter (see [8] for a similar approach in the Middle Size League). This technique is based on the position of the landmarks with respect to the robot, and since the object classification

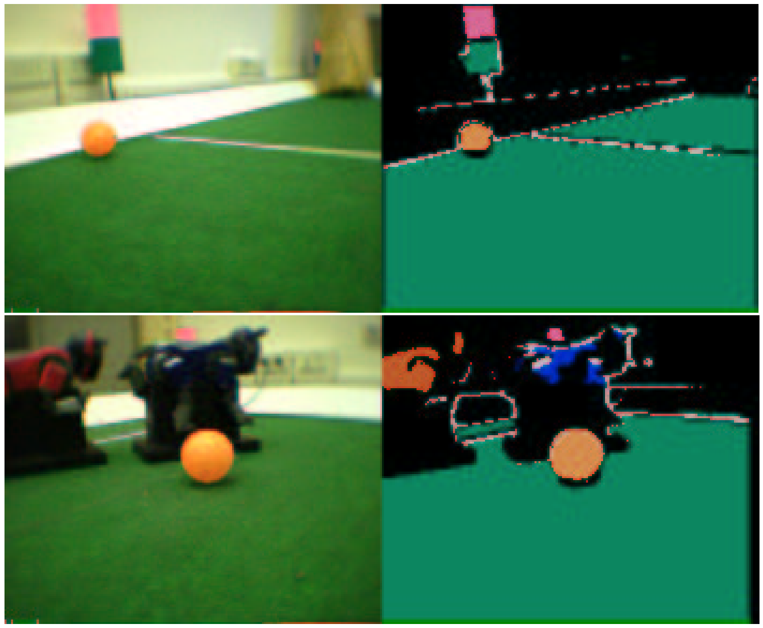

**Fig. 1.** Image color segmentation

reported in the previous section allows for discriminating among those landmarks (thus solving the data association problem), the localization technique has been implemented in such a way that a correct localization is achieved also in the case of "kidnapped" robots. We are currently performing extensive experiments for evaluating precision and accuracy of our localization method.

## 5 Coordination through dynamic role assignment

The Coordination module is responsible for implementing a distributed coordination protocol that allows the robot to assign themselves tasks according to the current situation of the environment [2]. The possibility of using wireless communication has allowed us to port the implementation realized for our Middle Size team. The approach relies on the definition of a set of roles, that are ordered with respect to importance in the domain, and a set of utility functions, one for each role, expressing the capability of a robot to play this role. The values of the utility functions are computed by all the robots in the team for all the roles and these data are exchanged broadcast through the wireless network. A coordination algorithm is then executed by each robot in order to determine robot-role assignment. This algorithm ensures that every role is assigned to one robot and that the robots assigned to the most important roles are those that are in the best situation (according to the values of the utility functions).

The roles played by the robots are implemented as *plans* to be executed by the Deliberation module. Such plans are represented as graphs, in which nodes denote states in the world while edges represent primitive actions that will be performed and cause state transitions. The plans that are executed by the robot may be generated off-line by an automatic planner [7], or written by the user with a graphical tool. The Deliberation Module implements an algorithm that visits the graph activating and deactivating actions according to the current state of the robot.

Moreover, in the Legged League the distributed task assignment was not the only requirement for coordination, since in several cases also the problem of resource conflict must be addressed (e.g. two defender rule). Therefore, we have added a mechanism of action synchronization based on explicit communication that has been used for example in the coordination challenge in RoboCup 2002. In particular, action synchronization is implemented by a sensing action and by a while loop in the plan that has the meaning of waiting until a specific condition is true. In this way, one robot can wait until the other robot sends a signal indicating that it is ready to perform a coordinated action (see [4] for details).

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