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# SPQR

## Team Description Paper

RoboCup 2008 Standard Platform League - Nao Division

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## 1 Introduction

SPQR<sup>1</sup> is the group of the Faculty of Engineering at Sapienza University of Rome in Italy, that is involved in RoboCup competitions since 1998 in different leagues (Middle-size 1998-2002, Four-legged since 2000, Real-rescue-robots 2003-2006, Virtual-rescue since 2006 and @Home in 2006). In RoboCup 2008, SPQR team will participate in the Standard Platform League with Nao humanoid robots and in the Virtual Rescue League.

The team for 2008 is composed by two groups from the Computer and System Science Department of Sapienza University: the *Artificial Intelligence* group and the *Robotics* group. The main research motivation for participation in RoboCup 2008 Nao division is *to study the integration of complex control systems for humanoid locomotion with artificial intelligence techniques that have been typically developed on other mobile robotic platforms*.

The members of the SPQR team that have developed the Nao soccer team are: Andrea Cherubini, Luca Marchetti, Matteo Leonetti, Simone Elviretti, Federico Faina, Francesca Giannone, Marcello Lombardo, Marco Manganelli, Pier Francesco Palamara, Diana Nobili, Mauro Sbarigia.

The development for RoboCup 2008 has been mainly divided in three parts: 1) implementation of a robotic software architecture for the Nao robots; 2) humanoid control and locomotion for realizing basic movements that are necessary for a soccer application; 3) artificial intelligence techniques for perception, localization, behavior control, behaviors learning and multi-robot coordination. In this report, we will first present our development framework for RoboCup 2008 and then we describe in more details the AI and humanoid control techniques that have been used on the Nao robots.

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<sup>1</sup>[spqr.dis.uniroma1.it](http://spqr.dis.uniroma1.it)

## 2 Development Framework

During the development of many RoboCup applications (ranging from middle-size, to legged, rescue and @home robots) we have gained a lot of experience and developed a set of reusable modules. Except for the AIBOs, that have a specific platform and operating system, all the other robots and robotic applications have been realized by using a common middleware. In particular, we have developed a Robot Development Kit (RDK), OpenRDK<sup>2</sup> (formerly named SPQR-RDK [4]), that is now released as open source.

OpenRDK allows for fast implementation of robotic applications on different platforms and for reuse of software components. It provides middleware tools for managing a set of modular components that interact with each other via a shared repository. Each component is responsible for a basic functionality of the robotic platform (e.g., perception, localization, plan execution, motion control, etc.) and the OpenRDK framework provides all the routines needed for effective interaction among these components: synchronization, information sharing with memory lock mechanisms, remote inspection for debugging, etc.

Modules are loosely connected to each other and can be scheduled independently and with different priorities. The modules interact and communicate with each other using a blackboard-type data repository. Based on an abstraction of the information shared by the modules, OpenRDK allows for an easy interchange among modules with similar functionalities, without modifying or recompiling the code. This is very useful, for example, to evaluate alternative modules or to switch from simulated to real robots and sensors. Moreover, information can be shared among different processes/computers and thus visualized and modified by a remote console at run-time. This is extremely useful for tuning and debugging purposes.

Overall, the use of OpenRDK has notably increased productivity of our research group in the development of Nao soccer application. The porting of OpenRDK on the Nao platforms required only a few modifications and it is completely available for use to other teams as well (see SPQR and OpenRDK web sites for more details).

## 3 AI techniques for a Standard Platform Team

The RDK allows for an effective interaction among modules that compose a robotic application. In this section we will briefly present some of the components that are included in Nao 2008 development: color segmentation based on a dynamic and adaptative color space transformation that increases robustness to light variations [8]; image processing using a limited number of perceptual pixels that activate object recognition; localization implemented with a particle filter based method [11]; behavior control using Petri Net Plan representation language [13]; learning techniques for improving robot performance [1, 2]; coordination based on a distributed task assignment [10, 6].

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<sup>2</sup>[openrdk.sf.net](http://openrdk.sf.net)

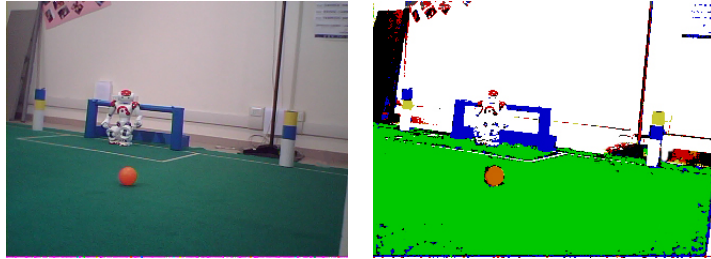


Figure 1: Color segmentation on Nao robots

### 3.1 Dynamic color segmentation and image processing

In order to improve robustness of color segmentation and to avoid long and tedious calibration processes, we have developed a dynamic color segmentation method [8] that is able to provide robust and efficient color segmentation with very few calibration effort (Figure 1).

The method is mainly based on fast analysis of a mono dimensional color space: the H component of the HSV. By analyzing color distribution of the current image, we are able to compute a transformation function that transforms such distribution in another distribution. The resulting distribution provides for efficient color segmentation based on static threshold, but being computed according to the current image is also very robust to illumination changes. Evaluation of the approach shows that the method achieves performance that are comparable with those obtained by manual calibration, being at the same time robust to illumination changes.

Image processing on legged robots usually has to take into consideration limitations in CPU power. For AIBO robots we have developed a hierarchical approach for examining the image pixels: first a set of *sentinel pixels* that are non-uniformly spread on the image are analyzed; then, for those pixels that activate some condition, a region growing approach is used to analyze adjacent pixels and then these regions are grouped in blobs that are then analyzed for object recognition. This approach provides for similar results with respect to complete scanning of the image, but it significantly reduces the computational time.

### 3.2 Localization

Our approach to localization uses a probabilistic technique based on particle filters. In [11] we have compared different solutions based on particle filters, investigating the use of two different strategies: the well known Sample Importance Resampling (SIR) filter, and the Auxiliary Variable Particle filter (APF). As a result of the experiments performed, we have detected situations where one strategy is better than the other as well as hints about the use of sensor resetting, that is common in this kind of implementations.

For the Nao robots, we have integrated in the localization technique information about the game state (or in general about the task state), aiming at choosing the localization strategy and parameter setting that are more suitable for the current situation.

Localization is based on perception of known landmarks: beacons, goal poles, lines and corners, for which different sensor models are used in the particle filter implementation. Moreover we are developing more sophisticated mechanism in proposal selection of Particle Filter algorithm that use the result from a Kalman Filter. The aim of this is to use a more informative distribution rather than approaches from previous years.

### 3.3 Petri Net based behavior control

The behaviors of a complex soccer robot require to be represented by plans with high representation power, in order to express all the capabilities of the robot. In particular, it is important to model the following features: 1) sensing actions implementing `if-then-else` or `while` constructs able to determine the robot behavior according to the current situation at run-time; 2) concurrency of actions (e.g., moving the head while going to a position); 3) interrupts (e.g., aborting a `go-to-ball` action if the robot can not see the ball anymore); 4) action synchronization between two parts of the robot (e.g., head and legs); 5) action synchronization between two or more robots.

In order to represent the above mentioned features, transition graphs are not adequate, since, for example, concurrency and interrupts can not easily be modeled. Therefore, we adopted a formalism, called Petri Nets Plans (PNP), which is enough expressive to describe plans with all the above mentioned features (see [13] for further details).

As a difference with other approaches based on extensions of transition graphs, such as XABSL [12], we clearly distinguish action specification from action implementation, obtaining a framework which permits easier debugging: first, the semantic is well defined and easily verifiable by automated verification programs; second, we have a high granularity of actions which are grouped by functional properties and physical resources used.

The plan execution module based on PNP formalism has been successfully used in all our robotic applications (Four-Legged soccer, Rescue and @Home), providing a high flexibility and being easy to use, thanks to graphical tools for writing, verifying and debugging plans.

### 3.4 Behavior Learning

Soccer robots, and in particular legged ones, require a fine tune of the parameters specially in the implementation of behaviors and basic control actions and in the strategic decisional processes.

In [1] we have performed experiments on layered learning approaches for learning optimal parameters of basic control routines, behaviors and strategy selection. We compared three different methods in the different layers: genetic

algorithm, Nelder-Mead, and policy gradient. Moreover, we studied how to use a 3D simulator for speeding up robot learning. The results of this experimental work on AIBO robots have been not only the realization of improved behaviors, but also a more effective learning methodology that makes use of a simulator. Some preliminary results on learning approaches for humanoid robots are described later in Section 4.3.

### 3.5 Multi-robot coordination

In previous multi-robot applications we have implemented a distributed coordination protocol that allows the robots to assign themselves tasks according to the current situation of the environment. During the last years we have experimented many coordination protocols for dynamic task assignment, using both full broadcast communication [10], and token passing based approaches [3]. These systems have been demonstrated to work effectively in soccer applications (both in middle-size and in the four-legged leagues).

Moreover, we have addressed another important problem for multi-robot coordination that arises in presence of dynamic and noisy perception. The works in [5, 6, 7] show different ways to distributed coordination in presence of dynamic perception of tasks to be accomplished and on noisy and erroneous perception. The main advantage of the proposed solutions with respect to others is in the achievement of optimal results with limited bandwidth communication requirements. This makes the approaches effective also in presence of noisy communication with limited bandwidth.

## 4 Humanoid locomotion and control

Research on biped locomotion has steadily increased over the last years. Advances in hardware technologies and software architectures allowed the realization of impressive humanoid robots, such as the Honda ASIMO or the Sony SDR-3X, as well as many prototype robots developed in university labs. Biped locomotion is classified in *static*, *dynamic* or *purely dynamic* methods. In our recent research work, we have developed both static and dynamic locomotion approaches. In both cases, the biped locomotion developed is composed by two main phases: the single support phase and the double support phase.

### 4.1 Biped Locomotion based on static walking

For the NAO robot, we have developed a parameterized static walk control scheme. Our scheme consists of planning the trajectories of the feet and barycenter in the robot workspace. The swing and stance feet (during the single support phase) respectively track a semi-elliptical and a linear trajectory. These trajectories are generated by solving the inverse kinematics problem for the 6 pitch joints (which are not actuated during double stance), see Figure 2, left. The robot barycenter (during both single support and double stance), is moved along

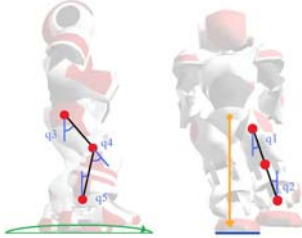


Figure 2: NAO walking: pitch joints (left), roll joints (right).

a trajectory designed so that its projection on the ground stays within the support foot. This trajectory is parallel to the ground plane and is generated by solving the inverse kinematics problem for the 4 roll leg joints (see Figure 2, right). In order to improve the gait stability, reduce noise in the FSR readings, and guarantee a 'human-like' gait, the foot soles are kept parallel to the ground throughout the gait. This constraint reduces from 10 to 6 the number of degrees of freedom utilized for gait generation. Curvilinear gaits are generated by exploiting the ankle yaw joint. This joint tracks a sinusoidal trajectory with amplitude proportional to the desired curvature.

## 4.2 Biped Locomotion based on dynamic walking

A Biped Locomotion Strategy for the AIBO ERS-210 Quadruped Robot has been developed and presented in [14] (see Figure 3). Although AIBO has several limitations which make biped locomotion a challenging task, such as passive feet, a high baricenter in the erect posture, and relatively weak actuators, we showed that it is possible to realize a biped gait by properly designing the single and double support phases. This approach is in contrast with most previous works, in which a biped mechanism is built having already in mind a certain control strategy.



Figure 3: AIBO biped walking.

During the double support phase the robot is controllable, while it is not in the single support phase. This is due to the lack of an actuated foot. In the double support phase there is the transition of the support leg, from right to left or viceversa. Many authors have proposed a control strategy in which the double support phase is assumed to be instantaneous, and the actual biped locomotion is achieved by the single support phase, while we have chosen to fully exploit the double support phase. The main idea on which we rely for the control of the system is to reduce the dynamic of the system, in the single support phase, as that of a passive inverse pendulum, in order to explicitly control the boundary conditions of the pendulum to obtain a desired dynamic evolution. The double support phase is thus exploited in order to achieve the correct take-off conditions for performing the single support phase. During the latter, the mechanism motion is essentially uncontrolled but can be predicted and planned using a simple equivalent mechanical system. Both simulation and experimental results described in [14] show the positive outcome of our study.

### 4.3 Learning Techniques for Biped Locomotion

Another approach for humanoid locomotion has been experimented using learning techniques<sup>3</sup> In particular, we have devised and applied a learning method for biped locomotion using genetic algorithms and a new strategy for interleaving learning steps in simulation with learning steps on the real robot. In particular, we use genetic algorithms to explore the parameter space of a fuzzy controller guided by an oscillator that implements a walking behavior for the robot. Preliminary results of our approach show that most of the learning can be done in simulation and the steps on the real robot are used to adjust the learnt fitness function. In contrast with other approaches that use simulated results to refine the model of the virtual robot, we use simulated results only to modify the fitness evaluation function. Such a learning approach has been experimented on the humanoid robot Robovie-M and its virtual model in USARSim [9].

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<sup>3</sup>Demo movies with simulated robot are available at [www.dis.uniroma1.it/~spqr/download/hwalk-video/](http://www.dis.uniroma1.it/~spqr/download/hwalk-video/)



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