SPL Joint Team SPQR
Team Description Paper 2025

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1 Team Information

- **Team name:** SPQR Team
  A joint team composed by Sapienza University of Rome, University of Basilicata, and International University of Rome - UNINT
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SPQR is a growing research team based at the Department of Computer, Control, and Management Engineering "Antonio Ruberti" at Sapienza University of Rome (Italy). SPQR Team has been involved in RoboCup competitions since 1998 in different leagues: Middle-size 1998-2002, Four-legged 2000-2007, Real rescue robots 2003-2006, @Home in 2006, Virtual-rescue since 2006 and Standard Platform League (SPL) since 2008. SPQR hosts other two robocup teams based in Italy, namely UninBas Team and UNINTeam. SPQR team members have served the RoboCup organization in several ways:

- Prof. Daniele Nardi served as Exec, Trustee, and President of RoboCup Federation from 2012 to 2014 and was RoboCup Symposium co-chair in 2004.
- Prof. Luca Iocchi is Exec member of RoboCup@Home, Vice-president and was RoboCup Symposium co-chair in 2008.
- Prof. Domenico D. Bloisi is the Italian Regional Committee spokesperson.

SPQR team members published a total of 25 papers in RoboCup Symposia (including best paper awards in 2006, 2015 [2], 2021 [6], and 2023 [10]), in addition to other RoboCup-related publications in International Journals and Conferences in AI and Robotics (including IROS RoboCup Best Paper Award in 2016 [3]).

1.1 Joint Team Members

- **Sapienza University of Rome**: **Faculty**: Prof. Daniele Nardi (*Team Leader*), Prof. Luca Iocchi - **Members**: Vincenzo Suriani (*Team Leader*), Francesco Petri, Daniele Affinita, Flavio Maiorana, Valerio Spagnoli, Flavio Volpi, Michele Brienza, Filippo Ansalone, Eugenio Bugli, Can Lin, Damiano Imola, Jacopo Tedeschi.
- **UniBas**: **Faculty**: Prof. Fabrizio Caccavale, Prof. Francesco Pierri - **Members**: Monica Sileo, Francesco Laus.
- **UNINT**: **Faculty**: Prof. Domenico D. Bloisi, Prof. Marco Romano.

Currently, SPQR Team owns a total of nine NAO V6 robots viable for competition: seven from Sapienza, one from UniBas, and one from UNINT.

2 Code Usage

Before 2013, SPQR used its own framework, called *OpenRDK*. From 2013 onward, SPQR Team has chosen the *B-Human Team* framework as base for developing its code. We acknowledge the B-Human team members for their great contribution and work in the SPL league. From RoboCup 2019 up to RoboCup 2022, SPQR Team adopted the B-Human 2018 framework, widely modified to be adapted for the V6 NAO robot hardware and low-level software. Since RoboCup 2023, SPQR has adopted the B-Human 2021 framework, modified in the following areas: *perception, coordination, and decision making* (see the section below).

3 Own Contributions

We provide our own contributions related to the following critical areas:

3.1 Contributions in Perception

Our goal is to create a perception tier independent of the B-Human frameworks. To this end, since 2017, the SPQR Team has been using its own Ball Perceptor, a newly developed machine learning approach inspired by our deep learning work on NAOs [1]. In RoboCup 2024, we switched back to a deep learning-based approach. The current Ball Perceptor is designed to be highly efficient in terms of inference time, leveraging separable depth-wise convolution to reduce the number of operations performed. The model was trained using self-supervised learning techniques with the **SPQR Multi-Object Dataset**[1], followed by a subsequent supervised learning phase. This approach

[1] https://sites.google.com/diag.uniroma1.it/spqr-multi-object-ssd-pruning.

reduces the need for labeled examples, enabling the model to achieve better generalization capabilities.

During the RoboCup Open Research Challenge 2019, we presented a supervised approach for detecting both robots and gestures [5], using the NAO V6 hardware.

An additional module in our perception tier was tested in RoboCup 2023, featuring a pose-detection system for NAO robots and human referees. To train the model, we set up a pipeline based on automatic synthetic data generation, given a high-level description of the target pose [21]. This provides an effortless approach to seamlessly adapt the model as new gestures are introduced in the league.

Whistle detection For RoboCup 2024 we developed a neural network based whistle detector, inspired by [13], where the main goal is to exploit model-based approaches and make the detection robust to noise, fusing prior knowledge with a convolutional neural network. Beyond that, we made the overall architecture more versatile, modular and decoupled by adopting continuous convolutional kernels, which allow to lift the neural network architecture from the constraints due to input data length, dimension and resolution, namely sampling frequency in case of audio detection. Moreover, the intrinsic adaptability of continuous kernels allows to optimize the size of the network itself, tailoring it for the task at hand, leading to better computational performance, which is of utmost importance in a real-time scenario.

Unified Yolo-Based Vision Recognition System The images taken from the cameras are the main source of information for computing the world's state. The frames are processed to detect field lines, opponents, teammates, generic obstacles, and the ball. In 2023, we proposed a real-time multi-class detection system for the NAO V6 robot using state-of-the-art structural pruning techniques on neural networks derived from YOLOv7-tiny. [11] The system is capable of detecting various objects, including the ball, goalposts, and other robots, in a single forward pass through the network from the robot's camera images. The goal has been to guarantee high speed and accuracy trade-offs while keeping the computational complexity suitable for the limited processing resources of the NAO robot. We release our annotated dataset, which consists of over 4000 images of various objects in the RoboCup SPL soccer field that can be found here `https://sites.google.com/diag.uniroma1.it/spqr-multi-object-ssd-pruning`.

3.2 Contributions in Motion

Gait Generation As SPL games become increasingly dynamic, the ability to adapt the robot's walking patterns efficiently is crucial for maintaining competitive performance. To address this challenge, SPQR is actively developing a gait generation system based on Model Predictive Control (MPC). This approach allows for real-time optimization of the robot's walking trajectory by predicting future states and adjusting control inputs accordingly. The robot is modeled as a linear inverted pendulum, thus we may identify the center of mass (CoM) and the zero-moment point (ZMP) as its main components. The latter, which captures the point where reaction forces at the contacts between the feet and the ground do not produce any moment in the horizontal direction, must always lie inside a stability region, called support polygon. By using MPC, we are able to enforce this constraint while tracking a desired trajectory. Practically speaking, the MPC controller generates a trajectory for the ZMP, based on the desired velocity and the planned footsteps, which then needs to be tracked by the CoM. To ensure the ZMP trajectory never diverges, we enforce the so-called **stability constraint** [19], which basically enforces a terminal constraint on the MPC horizon in order to stabilize the unstable component of the LIP dynamics. We formulate all MPC problems (footstep planner and controller) as QP problems, using PROXQP [20] to solve them. This development marks a significant step in further differentiating the SPQR framework from its starting point, the BHuman 2021 codebase.

Genetic Algorithm for Keyframes Motion learning From the Keyframe Motion engine already available in BHuman 2021, motions are represented as predefined interpolation points that can be configured as parameters; usually they are used for some special motion behaviors. SPQR is actively developing a continuous genetic system to find the parameters values to execute some custom movement. In particular, we are focusing on kicks executed through Keyframe motions, exploiting the capacity of evolutionary algorithms to generate multiple individuals and to combine the most promising (according to a fitness function) together, evolving toward better solutions.

3.3 Contributions in Coordination

We use an approach that aims to estimate a distributed world model by using the information available without sending specific packets for the purpose, which is then employed within the framework of market-based coordination. This system was recently improved in 2023 [4]. This enhancement integrates spatial information captured by the Voronoi diagram to address limited communication and improve overall robustness. This ensures that the vertices and edges of the diagram maximize the distance to obstacles identifying uncrowded areas. The vertices of the graph represent a desirable position for the robots, and this information is exploited within the coordination to enhance decision-making while facing the lack of communication.

3.4 Contributions in Decision Making

Since 2017, we decided to adapt our framework also to allow the possibility of having some behaviors completely based on a planning system. In 2019, this approach has been extended as a base for efficient Reinforcement Learning procedures for soccer robots. The Monitor Replanning algorithm has been used to lead the exploration during the training of Deep Neural Networks for RL. This method has been used for several behavior applications such as soccer contrasts or shooting decisions, as in [7] , publicly released at `https://sites.google.com/diag.uniroma1.it/robocupcoach`.

Network Our current network management approach is a mix of a role-based event-driven system that immediately notifies the team specific circumstances, such as seeing the ball after it had been lost, and a slow periodic update to maintain coordination in calmer situations. For RoboCup 2024, we developed an approach to automatically balance the update period, not only based on player roles and on specific playing circumstances but also on overall game situations.

3.5 Research Roadmap

SPQR Team is interested in detaching the robot perception system from the RoboCup field peculiarities and in increasing the world representation of the robots. To this end, we started with a ball preceptor that does not rely on ball and field colors and we recently detached the perception from the action of the robot creating a semantic layer capable of inferring the inner capabilities of the perceived elements[10]. To increase the state representation of the robot, we included crowd noise and indication from a human coach as a means to extend the inner representation of the agents.

Robot Behavior Conditioning With Crowd Noise In [6] we exploit the collective intelligence of the audience of a robot soccer match to improve the performance of the robot players. In particular, audio features extracted from the crowd noise are used in a Reinforcement Learning process to modify the game strategy. The effectiveness of the proposed approach is demonstrated by experiments on recorded crowd noise samples from several past RoboCup SPL matches.

Team Behavior Conditioning from Human Coach Although it has not been used in competition yet, in the RoboCup Symposium 2022, we laid the foundation for working on a higher level of abstraction in the decision-making process that can condition the strategies of a robot team through the use of intelligible commands [9]. It uses a modular architecture that is easy to adapt to different teams and other purposes, including ensuring the safety of robots and human operators.

Semantic Conditioning for Playing Everywhere In the path of having robust behaviors on robots capable to generalize when the game environment change, in [10], we propose a temporal logic based approach that allows robots' behaviors and goals to adapt to the semantics of the environment. The proposed approach enables the robot to operate in unstructured environments, just as it happens when humans go from soccer played on an official field to soccer played on a street.

4 Unpublished Results

SPQR Team joined the RoboCup competitions in 1998. The results of all recent competitions we attended are published on the SPL website, specifically:

- RoboCup 2021: all four challenges [14]
- GORE 2022 [15]
- RoboCup 2022: main competition and open research challenge [16]
- RoboCup 2023: main competition and technical challenges [17]

- RoboCup 2024: main competition and shared autonomy challenge [18]

In addition to RoboCup 2025, SPQR Team will participate in German Open 2025.

5 Impact

Impact in SPL/RoboCup Community. The Ro.Co.Co. (Cognitive Cooperating Robots)[2] laboratory has been participating in the RoboCup since the beginning of the SPL. The aim is to transfer our research in machine learning, behavior formalization and coordination in the RoboCup competition and to contribute to the development of a more reliable soccer team in the pursuing of the goals of the league. In 2017, we proposed a supervised method for detecting the realistic black and white ball in images captured by a NAO robot. In 2019, with the adoption of the new robotic platform, i.e. the V6 NAO robot, Starkit team from Russia has been involved in the competition by using the Code Base released by SPQR. In 2021 we introduced the concept of audio exploitation for capturing the crowd sentiment. Our work has been awarded as Best Paper at 2021 RoboCup Symposium.
In 2022, we presented MARIO[8] a fully-automatic system specifically designed for analyzing NAO soccer robot matches. MARIO ranked first, ex-aequo with the B-Human Team's system, in the Open Research Challenge at RoboCup 2022. Robot and ball tracking in MARIO are done automatically. Game analysis can extract trajectories, passes made, and heatmaps through graphs and tables containing both traditional statistics and more advanced statistics within the field, such as falls and foul actions made by the robots. We recently updated the capabilities of *MARIO*. The latest version is publicly released at `https://github.com/michelebri/MARIO2.0`.

Impact in University/Community. Our University strongly supports our work in RoboCup competitions, which are an excellent testbed for validating our research results. The Petri Net Plans (PNP) framework has become, in our laboratory, the standard tool for robot behavior design and formalization, after the work done in RoboCup experience. In the last years, we started exploiting our knowledge of vision and dynamic walking engine to better govern the NAO platform and deploy NAO robots in other applications.

We are promoting research in AI and Robotics through several types of media channels to disseminate our research results. In order to pursue this goal, we have a YouTube Channel[3], a Facebook page[4], a LinkedIn page[5], and an Instagram profile[6] rich in contents about RoboCup. This effort is also pursued by participating in Italian TV shows ("I Fatti Vostri", "Laudato sii' ", "Tg2 insieme", "Quante storie") and in relevant exhibitions that take place in Italy (IAB Forum, Wired Next Fest, Blue Fest, Unirete, RomeCup, MakerFaire).

[2] `http://www.dis.uniroma1.it/~labrococo`
[3] `https://www.youtube.com/channel/UCRboLHM75uGB4TQH7s1APUg`
[4] `https://it-it.facebook.com/SPQRTeam`
[5] `https://www.linkedin.com/company/spqr-team/`
[6] `https://www.instagram.com/spqrteam/`

We are committed to promoting scientific knowledge through the dissemination of technology culture, using RoboCup to show progress. Demonstrating practical applications of artificial intelligence and robotics becomes pivotal in bridging the gap and engaging people in these fields. We achieve this mainly through events like the Maker Faire. This European event connects businesses, academia, and tech enthusiasts, facilitating discussions on technological advancements and practical demonstrations. This gives us the opportunity to share the latest RoboCup SPL advancements with thousands of people by organizing friendly matches with other SPL Teams. We started this tradition back in 2019 when we invited for the first time two SPL teams (i.e., HTWK and NomadZ). We continued this trend in editions from 2021 to 2024, inviting teams such as HULKs, Nao Devils, B-Human and HTWK Robots to play in person or remotely depending on their availability. Recognizing the event's appeal on social media, we actively share updates to amplify the reach of RoboCup SPL videos. Notably, a video we posted on our Instagram page garnered an impressive 100,000 views in 2024.

6 Other

SPQR published several datasets for the benefit of the community:

- The **SPQR Nao Image Dataset**[7], a set of annotated images taken in various conditions that we used to train our ball perceptor (see Section 2). [1] [5]
- The **SPQR RoboCup@Soccer Sound Dataset**[8], a set of annotated audio data gathered from RoboCup finals between 2016 and 2019. It enabled us to identify the waveform pattern in a goal situation and use it as a RL reward. [6]
- The **UNIBAS NAO Pose Dataset**[9], released in 2022 and consisting of 451 frames containing about 3,000 NAO robot instances in the well-known COCO format. In the annotations, the pose is represented by up to 18 key points.[12]
- The **SPQR Multi-Object Dataset**[10], released in 2023, is an annotated dataset for multiclass classification of several objects relevant to the RoboCup SPL.

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