SPL Joint Team SPQR
Team Description Paper 2024

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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 24 papers in RoboCup Symposia (including best paper awards in 2006, 2015 [2], 2021 [9], and 2023 [13]), in addition to other RoboCup-related publications in International Journals and Conferences in AI and Robotics (including IROS RoboCup Best Paper Award in 2016 [4]).

1.1 Joint Team Members

- **Sapienza University of Rome**: **Faculty**: Prof. Daniele Nardi (*Team Leader*), Prof. Luca Iocchi - **Members**: Vincenzo Suriani (*Team Leader*), Graziano Specchi, Francesco Petri, Daniele Affinita, Flavio Maiorana, Valerio Spagnoli, Flavio Volpi, Michele Brienza.
- **UniBas**: **Faculty**: Prof. Fabrizio Caccavale, Prof. Francesco Pierri - **Members**: Monica Sileo, Francesco Laus.
- **UNINT**: **Faculty**: Prof. Domenico D. Bloisi, Prof. Marco Romano.

Currently, Sapienza owns six NAO V6 robots and UniBas owns two NAO V6 robots. Sapienza is going to order eight additional NAO V6 robots and UNINT is going to order its first NAO V6 robot.

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 and for RoboCup 2024, 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 separated from the B-Human frameworks. To this end, since 2017, SPQR Team has been using its own Ball Perceptor, a newly developed ML approach inspired by our DL work on NAOs [1]. This allows us to play outdoor without color and camera setting calibrations [6]. We forked the B-Human 2016 repository adding our Ball Perceptor code (`github.com/SPQRTeam/SPQRBallPerceptor`). Two teams (from China and Brazil) asked us to use our Ball Perceptor and at least another team (from Holland) tested our approach. During the RoboCup Open Research Challenge 2019, we presented a supervised approach to detect also robots and gestures [8] by using the NAO V6 Hardware. A further module in our own perception tier has been tested in RoboCup 2023, which includes a pose-detection system for NAO robots and human referees.

Whistle detection For RoboCup 2024 we are developing a neural network based whistle detector, inspired by [16], 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 intend to make 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. Last year, 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. [14] 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 Coordination

To create effective modeling of the world, we developed an algorithm that has been presented at the 2016 RoboCup Symposium being awarded as IROS RoboCup Best Paper 2016 [4]. By exploiting high-level information about game-related situations, we enforce specific behaviors as responses to environmental stimuli. To this end, the approach aims to estimate a distributed world model by using the information available without sending specific packets for the purpose. The resulting world model is employed within the framework of market-based coordination. Every agent simulates locally a set of role assignments maximizing a utility measure. The combination of distributed task assignment and distributed world modeling ensures efficiency and high robustness. In addition, we consider also the contexts representing situations in which a strategy adjustment is required. A further improvement was developed in 2023 [5]. This enhancement integrates spatial information captured by the Voronoi diagram to address limited communication and improve overall robustness. The Voronoi diagram was developed using the global obstacles information as generating points. 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 the decision-making while facing the lack of communication.

3.3 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. It is possible to define different utilities, heuristics and goals, thus using the presented planning system over a heterogeneous set of agents. Since 2019, this approach has been extended to be used 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. More details about the Planning and Learning integration for RoboCup behaviors can be found in [10]. The work has been 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 are developing 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.

3.4 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[13]. 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 [9] 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 [12]. It uses a modular architecture that is easy to adapt to different teams and other purposes, including ensuting the safety of robots and human operators. In the future, it would be interesting to extend this work to create a system capable of automatically learning a domain from natural language, for example, dynamically modifying the behaviors of robots based on the RoboCup regulation of the current year.

Semantic Conditioning for Playing Everywhere In the path of having robust behaviors on robots capable to generalize when the game environment change, in [13], 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 Past History

SPQR Team joined the RoboCup competitions in 1998. The following tables contain our results in RoboCup competitions from 2019 onward.

Phase	Teams	Score
CS RR	**SPQR** - Bembelbots*	**1**:1
	MiPal - **SPQR**	0:**5**
	SPQR - SABANA H.	**4**:0
CC Play-in	**SPQR** - Naova	**3**:0
CC RR	B-Human - **SPQR**	7:**0**
	UT Austin Villa - **SPQR**	2:**0**
CC Play-in	**SPQR** - TJark	**0**:8

* **SPQR** defeated Bembelbots in a shoot out to determine the winner of the pool

Table 1: SPQR Results at **RoboCup 2019** (Main competition)

Phase	Teams	Score
RR	B-Human - **SPQR**	25.5:**0**
	Dutch Nao - **SPQR**	0:**1**
Play-in	HULKs - **SPQR**	8:**10**
Quarterf.	rUNSWift - **SPQR**	2:**6**
Semifinals	HTWK - **SPQR**	12:**9**
3rd Place	Nao Devils - **SPQR**	15:**9**

Table 2: SPQR Results at **RoboCup 2021 "1vs1" Challenge**

Phase	Teams	Score
Round 1	Bembelbots - **SPQR**	3:**0**
Round 2	**SPQR** - UPennalizers	**3**:0
Round 3	Dutch Nao - **SPQR**	0:**3**
Round 4	**SPQR** - rUNSWift	**0**:5
Round 5	**SPQR** - NomadZ	**0**:1

Table 3: SPQR Results at **RoboCup 2022**

Phase	Teams	Score
Round 1	**SPQR** - NomadZ	**1**:3
Round 2	Berlin United - **SPQR**	0:**3**
Round 3	**SPQR** - Nao Devils	**1**:1
Round 4	**SPQR** - rUNSWift	**0**:0
Round 5	HTWK - **SPQR**	4:**0**
Round 6	B-Human - **SPQR**	10:**0**
Quarterf.	HTWK - **SPQR**	10:**0**
Final rank		**7**

Table 4: SPQR Results at **RoboCup 2023**

Table 5: SPQR Results at **RoboCup 2021 (Worldwide) challenges**

Challenge	Obstacle avoidance	Passing Challenge	1vs1	Autonomous Calibration
Position	8	7	4	8

* **SPQR** got to the **7th place** in the overall ranking.

Table 6: SPQR Results at **RoboCup 2022 challenges**

	7vs7	Visual Ref.	Dyn. Ball Handling	Open Research	Sum of best 3
Points	10	-	-	25	35

* **SPQR** achieved **1st place** (with B-Human) in the Open Research Challenge and got to the **4th place** in the overall ranking.

5 Impact

Impact in SPL/RoboCup Community. The Ro.Co.Co. (Cognitive Cooperating Robots)[1] 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[11] 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[2], a Facebook page[3], and an Instagram profile[4] rich in contents about RoboCup. This effort is also pursued by participating in Italian TV shows ("I Fatti

[1] `http://www.dis.uniroma1.it/~labrococo`
[2] `https://www.youtube.com/channel/UCRboLHM75uGB4TQH7s1APUg`
[3] `https://it-it.facebook.com/SPQRTeam`
[4] `https://www.instagram.com/spqrteam/`

Vostri", "Laudato sii' ", "Tg2 insieme") and in relevant exhibitions that take place in Italy (IAB Forum, Wired Next Fest, Blue Fest, Unirete, RomeCup, MakerFaire).

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 2023, inviting teams such as HULKs, Nao Devils, and B-Human 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 30,000 views in the past year.

6 Other

SPQR published several datasets for the benefit of the community:

- The **SPQR Nao Image Dataset**[5], a set of annotated images taken in various conditions that we used to train our ball perceptor (see Section 2). [1] [8]
- The **SPQR RoboCup@Soccer Sound Dataset**[6], a set of annotated audio data gathered from RoboCup finals between 2016 and 2019. It allowed us to recognize the waveform pattern in a goal situation and use this signal as a reward for a reinforcement learning agent. [9]
- The **UNIBAS NAO Pose Dataset**[7], 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 describing the parts of the NAO's body.[15]
- The **SPQR Multi-Object Dataset**[8], released in 2023, is an annotated dataset for multiclass classification of several objects relevant to the RoboCup SPL.

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