UnBeatables Team Description

Team UnBeatables
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Abstract

UnBeatables is a Brazilian Standard Platform League (SPL) team based at the University of Brasília. This paper offers a comprehensive overview of the team's formation, the current state of its competition code, and its previous contributions to the field of robotics research. Additionally, the team's social initiatives, which have garnered recognition for their positive impact on the community, are discussed.

The team has demonstrated strong performance in regional competitions and special categories, with local authorities acknowledging the social value of its educational initiatives. As a result of these efforts, UnBeatables has gained widespread recognition for its contributions to both robotics and the community.

In its ongoing development, the team is focused on refining its competition code post-pandemic, with the goal of resuming participation in national and international tournaments. While the team continues to primarily develop and maintain its own code, it has also integrated the B-Human code sporadically to further advance its research and knowledge. This hybrid approach allows UnBeatables to expand its technical capabilities while still staying committed to its own innovative contributions to the field.

Keywords: Humanoid robotics, computer vision, robot soccer.

1. Introduction

UnBeatables is a technological and social project affiliated with the University of Brasília (UnB), specifically with the Automation and Robotics Laboratories (LARA) and the Robotics and Control Systems Lab (LaRSis). These labs specialize in research and development in areas such as computer vision, localization and mapping, locomotion, robot cooperation, and human-robot interaction.

In 2013, the NAO robot emerged as a platform that brought together the laboratory's core research areas. This development, coupled with the opportunity to apply and test ongoing research in real-world conditions at RoboCup 2014, held in Brazil, led to the creation of an SPL team. The team participated in the SPL Drop-In category, winning first place in the MVP (Drop-in Only) category. Since then, UnBeatables has continued to enhance its research, with a particular focus on upcoming competitions.

However, for RoboCup 2018, the team faced a new challenge: the discontinuation of the Drop-In category. With most Brazilian teams, including UnBeatables, lacking the number of robots required to compete, the solution was to form a strategic partnership with the Brazilian team RinoBot. The two teams participated as a cooperative unit under the name AstroNAOtas, a collaboration that proved extremely valuable, as both teams were composed of undergraduate students.

At the end of 2018, the University of Brasília and LARA acquired three NAO v6 robots, significantly improving the team's strategic capabilities for SPL games. Then, with the onset of the COVID-19 pandemic, UnBeatables, like many other teams, faced the challenge of adapting to online simulation competitions in place of in-person events. In this new environment, the team performed exceptionally well, securing first place in both the LARC and RoboCup 2021 SPL categories.

Despite these successes, the pandemic posed further challenges. Many team members completed their undergraduate degrees during this time, and due to the lack of new recruits, UnBeatables was unable to participate in RoboCup 2022.

In 2023, UnBeatables made a strong return to competitions by participating in LARC 2023. While there were no other teams in the SPL category, the team competed in a mixed category, facing humanoid teams against SPL teams, and achieved second place. Additionally, in the Brazilian Robotics Competition (CBR) of 2024, UnBeatables secured second place in the SPL category and third place overall in the humanoid category, demonstrating the team's resilience and expertise. The team also aims to strengthen its presence and performance in future international competitions, including RoboCup 2025.

2. The Team

Team: UnBeatables

Leaders: Fernanda Diniz

Members as show from left to right in the Figure 1:

- Rodrigo Torreão Fonseca (Undergraduate Student)
- Guilherme Barbosa de Sousa (Undergraduate Student)
- Isabela Nunes Daltro (Undergraduate Student)
- Rodrigo Martins (Undergraduate Student)
- Gabriela Campos de Oliveira (Undergraduate Student)
- Fernanda Faria Diniz (Undergraduate Student)

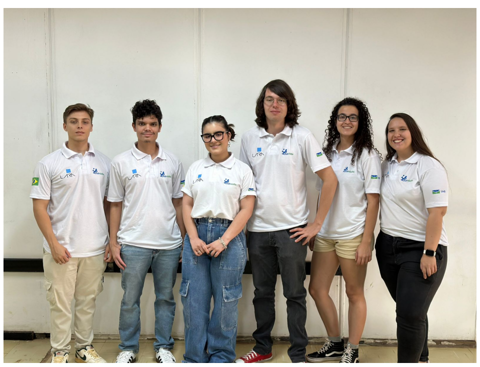

Figure 1. UnBeatables Team Members.

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3. Code Description

3.1. Architecture

The development of the UnBeatables software architecture began with an initial reliance on ROS [1], a powerful but resource-intensive framework. Although ROS provided a solid foundation, its high computational demands made it unsuitable for long-term use in competition environments. The team then transitioned to a more lightweight solution, based on the B-Human 2014 code, which demonstrated good results and laid the groundwork for the creation of a fully custom software architecture.

In 2015, the UnBeatables team adopted a new software architecture for the NAO V4 robots, inspired by the blackboard system used by the rUNSWift team. This architecture leverages a shared memory model, enabling seamless communication between threads. By utilizing the Boost library, the code became more modular, efficient, and maintainable. This approach significantly improved performance and reliability, providing a stable framework for continuous development.

For the NAO V6 robots, the team undertook a complete redesign of the software, moving away from the previous C++-based implementation in favor of a Python-centric architecture. This new design retains the foundational principles of the earlier systems but has been thoroughly optimized and restructured to take advantage of Python's flexibility and ease of use. The Python-based architecture enables rapid iteration and easier integration of new features, providing a more adaptable platform for future research and competition.

While much of the code for the V4 and V6 robots was developed in-house, the motion and sensor access module for the NAO V4 robots was imported from the rUNSWift team. This module remains a key part of the V4 software, as it provides reliable low-level control of the robot's actuators and sensors.

The UnBeatables team has divided the code into several key modules that handle different aspects of robot functionality, such as motion control, perception, decision-making, and communication. These modules will be detailed in the following sections, providing insights into the structure and functionality of the software that powers the NAO robots. We currently conduct tests and runs using the B-Human 2023 code [2] as part of our ongoing research. This collaboration allows us to deepen our understanding of the NAO robot and advance our knowledge in humanoid robotics.

3.2. Locomotion

Incorporating a motion module seamlessly integrated with other components capable of executing precise movements has been a key focus of our development. To achieve this, we chose to integrate the rUNSWift motion system into our architecture. Since this system is developed in the same programming language as our framework, it allowed for superior integration compared to previous attempts where we utilized external team codes.

Our robot's autonomous behavior is responsible for determining the appropriate actions based on sensor data and information derived from image processing in the perception thread, as detailed in the following section. Once the desired action is determined, the corresponding motors are activated based on the rUNSWift motion parameters to achieve the necessary movements.

Although our current strategy relies heavily on the rUNSWift code, which has delivered strong performance, we have a long-term vision to develop our own motion library. This future library will be tailored to enhance the robot's ability to walk on artificial grass, a challenge we are actively addressing. Specifically, we have been adapting the kick routine for our NAO V6 robots.

One technique we are employing was developed by the Brazilian team Jaguar, which focuses on optimizing the strength and power of the kick. Furthermore, we have developed an approach that ensures the robot maintains a stable posture before performing the kick. Depending on the in-game situation, either of these approaches may be selected to ensure optimal performance.

3.3. Perception

The perception module is responsible for filtering sensor data, detecting and classifying features and objects, as well as mapping and locating the robot within its environment. For detection purposes, we have chosen to utilize the OpenCV library [3], given its well-developed classical computer vision algorithms.

Within this module, various detectors have been implemented for specific features. The common approach among all of them involves searching for candidates exhibiting similar characteristics and utilizing a classifier to ascertain the true matches. By segmenting the soccer field based on its green color, we can apply detectors to extract features such as side lines and the midfield circle. Goal posts and other robots can be detected outside the green area.

In previous years, two distinct methods were employed for ball detection. The first method relied on contrasting regions against the green field to detect the ball from a distance, while the second employed a machine learning model for detection when the ball was near the robot.

For the 2018 competitions, we developed a new technique that proved efficient for both far and near ball detection while maintaining low processing demand. This method is based on the Blob Detector implemented in OpenCV [4], performing logical operations between color masks and using different approaches with the robot's top and bottom cameras. This method is highly dependent on proper calibration, and to assist with that, we also developed a user interface framework for manual calibration.

From the 2019 competitions onward, we focused on creating a new ball detection module for our latest NAO V6 robots. Utilizing the Haar Cascade Classifier machine learning technique, we successfully created a robust and expedient solution, particularly adept at swiftly detecting nearby balls. Additionally, our robots can identify opponents' jerseys, enabling accurate tracking of both teammate positions and adversary team members. This enhanced functionality has remained integral to our system, contributing to our competitive performance to this day.

We are also actively studying the implementation of YOLO (You Only Look Once) versions 4 [5] and 8[6] in our current NAO robot setup. We have already trained models for these versions and are in the process of integrating them into our existing code. This would enable more precise and faster object detection, especially for dynamic and fast-moving objects, such as the soccer ball, across the field.

Additionally, we have designed a specialized code for the goalkeeper role, which uses the concept of an "aim bot" to continuously track and follow the ball. This approach is intended to ensure that the goalkeeper never loses sight of the ball, significantly improving its defensive capabilities and reaction time.

Regarding the integration of other NAO robot sensors, we currently rely on the raw data they provide, primarily using inertial sensor and sonar data for obstacle avoidance and fall management. We are also developing a localization algorithm based on the Kalman Filter.

3.4. Autonomous Behavior

During the team's participation in RoboCup Drop-In games, the development focused on creating a conservative and defensive strategy to avoid collisions, as performance and behavior were key evaluation criteria. Even now, in the major league, the individual strategy remains primarily defensive. Key states include searching for the ball, approaching the ball, aligning with the goal, executing the kicking routine, and avoiding obstacles. The goalkeeper, however, follows a distinct behavior that emphasizes spotting the ball, aligning with the goalposts, and attempting to intercept the ball.

Each robot operates both the Game Controller state machine and the individual behavior state machine. The objective is to create a collective game plan by utilizing data acquired from each robot, as well as through communication with other team robots. To this end, our team has worked on developing complementary behaviors for different players. We have also implemented distinct obstacle avoidance and kicking routines, tailored to specific robots, to evaluate their impact on the overall team performance.

By using this approach, we aim to ensure more coordinated teamwork, where each robot performs in harmony to achieve a strategic advantage on the field.

3.5. Communication

Our communication module has evolved to become more robust and is now fully integrated with the Game Controller. We are now leveraging communication more effectively, exploring its potential to enhance team coordination and performance.

The communication structure is now established, and we are actively working on incorporating relevant data to be shared among the robots. This shared information includes real-time sensor data, state information, and strategic inputs, all of which are crucial for optimizing our overall team performance. Through this enhanced communication, robots can collaborate more efficiently and make better decisions during gameplay.

In addition to this, we are developing a localization system based on the Kalman Filter, as discussed in the Perception Module. The communication module will play a vital role in the localization process by sharing positional data between robots, helping to refine the robot's estimates of its position and the environment.

Moreover, as we continue to develop a more sophisticated strategy for the team, the communication module will be utilized even more extensively to facilitate real-time decision-making and dynamic teamwork. By exchanging key data such as ball positions, robot states, and tactical intentions, we aim to improve coordination and responsiveness, contributing to a more cohesive team performance.

3.6. Past History

3.6.1 Locomotion and Mapping

For many years, at LARA, mobile robot projects were primarily developed on wheeled platforms, such as the Adept Pioneer, and on quadruped robots designed within the lab to study gait control and stabilization algorithms. With the growing interest in humanoid robotics, research shifted to smaller humanoid platforms, beginning with a Robotis Bioloid robot. This platform was equipped with supplemental pressure sensors in the feet, an Inertial Measurement Unit (IMU) at the robot's center of gravity, and a Gumstix Verdex PXA270 ARM processor. Custom-made software was developed for this platform, focusing on real-time control and data acquisition [7].

Initial experiments on posture control using inertial sensors were conducted, employing both traditional Proportional-Integral-Derivative (PID) controllers [3] and fuzzy controllers [8]. In terms of humanoid motion control, our work has primarily concentrated on improving gait speed and robustness, as well as smoothing transitions between different gait modes. Recently, we have implemented a Central Pattern Generator (CPG) to generate gait commands for a simulated humanoid robot [9]. Various non-linear models, such as Matsuoka oscillators and truncated Fourier series, were employed to represent the CPG. Given the difficulty in obtaining suitable oscillator parameters for an optimal gait, optimization methods like Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) were used to fine-tune the parameters of the coupled oscillators. These oscillators are responsible for generating joint trajectories and adjusting independent parameters to control gait speed and locomotion modes.

In addition, Raphael Resende, a former team member, proposed an extended Kalman Filter-based algorithm for localizing a humanoid robot within a soccer field [10]. This algorithm estimates the robot's distance from field structures using data from inertial sensors (e.g., gyroscopes and accelerometers) and features detected by the robot's camera to address localization ambiguities.

3.6.2 Robot Interaction

In the domain of robot interaction with the environment and humans, team members collaborated with the LIRMM team in France, working with the Fujitsu Hoap3 robot. The robot was programmed to perform collaborative tasks with humans, such as pouring water. The methodology, outlined in [11], involved the application of a novel mathematical framework to define kinematic tasks based on the relative pose between the human and the robot. The experiments focused on pose representation and computation using dual quaternions, alongside robot teleoperation based on human motion.

For the Aldebaran NAO platform, a former team member conducted research on computer vision and odometry using inertial sensors to improve localization estimates. In particular, the SURF (Speeded Up Robust Features) algorithm was employed to detect landmarks in the environment, assisting with robot navigation through a pre-defined set of landmarks [12]. Additionally, this member developed a teleoperation interface using Microsoft Kinect to capture human movements, which were then mimicked by the NAO robot [13].

Expanding on this work, Henrique Balbino developed a teleoperation solution using human body movements. The robot's environment was visualized through virtual reality, simulating the user's physical presence in the robot's environment [14]. Other team members, while based in Korea, utilized the NAO platform to manipulate objects in an industrial setting [15].

In 2016, Cristiana Miranda and Yuri Rocha developed a framework enabling communication between two robots without the use of a wireless network, addressing control techniques for cooperative humanoid robots [16]. They also worked on a paper that extended the problem of robust singularity and joint limit avoidance to the cooperative task-space, employing unit dual quaternion representation to ensure singularity-free coupled representations in the cooperative space [17].

3.6.3 B-Human Code Usage and Future Plans

A recent and notable development in our project involves the adoption of the B-Human 2024 codebase. During the CBR 2024 competition, we successfully played two official matches using the latest version of B-Human. This experience provided valuable insights into the performance and reliability of the code in real match scenarios, reinforcing our confidence in its integration with our own frameworks.

We will formally confirm via email whether we will continue using the B-Human code in future tournaments, including RoboCup 2025. Our goal is to combine the strengths of B-Human's advanced codebase with our inhouse modules to enhance perception, locomotion, and teamwork strategies. By doing so, we aim to streamline our development cycle, focus on specialized research areas, and further improve our competitive performance on the field.

4. Impact and Commitment

Historically, at LARA, projects involving the NAO platform primarily relied on simulations and virtual demonstrations of code and models. However, the formation of our team marked a pivotal moment, as we acquired two NAO robots, establishing an ideal research environment. This shift ignited a strong enthusiasm among students to delve into the world of robotics, providing hands-on experience with a real humanoid robot. Our focus on the integration of innovation, education, and technology has driven us to undertake projects that go beyond the academic sphere, creating tangible benefits for the local community.

Our team members are actively engaged with local schools and hospitals, where we showcase the capabilities of the NAO robot, discuss relevant technological topics, and teach programming skills to high school students. This initiative has had a significant societal impact, garnering recognition not only from within our institution but also from external organizations. The outreach activities have opened new pathways for future research, allowing us to explore innovative ways of leveraging the NAO platform for social causes and contribute positively to society.

In addition to our educational and community outreach efforts, our involvement in competitive environments further strengthens our commitment to innovation. These competitions provide challenges that require creative solutions, and they serve as a catalyst for the continuous improvement of our research and development efforts. The pursuit of excellence in these competitions fuels our ongoing commitment to advancing robotics and its real-world applications.

Members of the UnBeatables team have recently published a paper titled "Trajectory of Humanoid Robots with the Unscented Kalman Filter" at the 2024 Brazilian Symposium on Robotics (SBR) and the Workshop on Robotics in Education (WRE) [18]. In this paper, we detail how the Unscented Kalman Filter (UKF) can be integrated into the gait control pipeline of NAO robots to enhance real-time trajectory accuracy and robustness. This publication highlights our ongoing commitment to research in humanoid robotics, offering insights that we plan to apply to our SPL efforts in RoboCup 2025.

5. Conclusion

UnBeatables is a technology and social initiative based at the University of Brasília, driven by a diverse team of students and researchers specializing in areas such as computer vision, humanoid motion control, and various other robotics disciplines. Our primary mission is to represent Latin America on the global robotics stage while fostering knowledge sharing and promoting the advancement of science and technology in society.

As we look ahead to 2025, our participation in prestigious robotics competitions, such as RoboCup, serves as a key avenue to deepen our expertise, refine our technologies, and contribute to the democratization of robotics education. By focusing on expanding access to robotics knowledge in Latin American public universities, we strive to make a lasting impact on the region's educational landscape, ensuring that the next generation of engineers is equipped with the tools to succeed in an increasingly technology-driven world.

Our ongoing efforts are not just about building competitive robots; they are about driving technological progress and ensuring that the benefits of innovation are felt in the wider community. As we work toward achieving our goals, we continue to contribute to the scientific community, develop open-source tools, and collaborate with international teams to push the boundaries of humanoid robotics.

For RoboCup 2025, our team is eager to participate in the competition and present our advancements, having made substantial improvements in key areas such as perception, autonomous behavior, and motion control. However, we also face ongoing challenges in securing the necessary funding for travel and participation. Despite these obstacles, we remain committed to our vision of making significant contributions to both the field of robotics and the broader educational mission we champion.

With this paper, we aim to demonstrate the eligibility and potential of our team for RoboCup 2025, and we are optimistic that, with the continued support of our university and collaborators, we will be able to join the global robotics community.

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