Hardware and Software Features of the Humanoid Robots Developed by RoboFEI - Humanoid Team

Thiago P. D. Homem*†, Danilo H. Perico*, Isaac J. da Silva*, Claudio Vilão Jr.*, Vinicius N. Ferreira*, Aislan C. Almeida*, Flavio Tonidandel*, and Reinaldo A. C. Bianchi*

*Centro Universitário FEI, São Bernardo do Campo, Brazil
†Instituto Federal de São Paulo, Boituva, Brazil

***Abstract*—This work presents the description of the humanoid robots developed by RoboFEI - Humanoid Team (RoboFEI-HT). This paper contains an overview of the mechanical, electrical and software modules, designed and improved to enable the robots to play soccer in the environment of the RoboCup Humanoid KidSize League. It also presents the developed works, some of our work in progress and the published papers as results of this research.**

***Index Terms*—Humanoid Robot, RoboCup Humanoid League, Autonomous Robot.**

1. Introduction

This paper describes the hardware and software aspects of the RoboFEI-HT. The team was created in 2012, when the projects of the Humanoid Robots started. Two years later, in 2014, we competed in our first RoboCup, with four robots, two Newton Robots [1](developed by us) and two humanoid robots based on DARwIn-OP [2], that we called B1 Robots. Today our team still has four robots, been three of them new versions of the B1 Robot and one of the first Newton Robots.

Our research aims to perfect the autonomy of the team, by working on mechanics, electronics, movement control, vision, localization and planning. Section 2 presents an overview of our robots' hardware, section 3 explains how the software is composed and how the processes interact with each other and the environment, section 4 introduces the RoboFEI-HT's works in progress, where a brief explanation is given, and section 5 concludes the paper.

2. Hardware Design

The team consists of four robots, as shown by Fig. 1, all of them developed by the team: one Newton Robot [1] and three B1 Robots, based on DARwIn-OP [2].

2.1. Mechanical Design

The Newton robot was developed with 22 degrees of freedom, as follows: six in each leg, three in each arm, two in the torso and two in the neck; this one developed from the scratch by the team aplying equilibrium, mobility and mechanical resistance criterias for robotics.

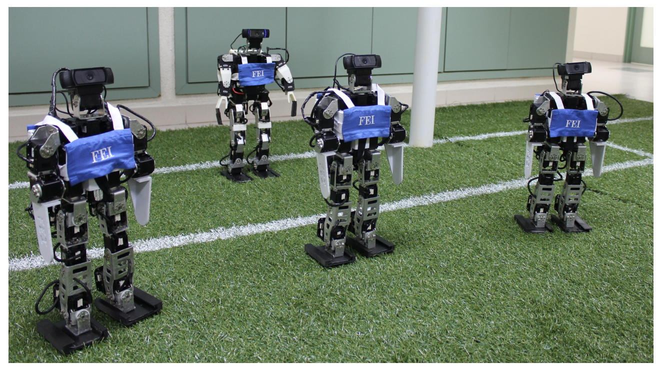

Figure 1: Our robots, the three B1 Robots in the front and the Newton Robot behind.

Based on Darwin-OP Robot [2], the team developed the B1 Robots, by studying material stress and balance, the project was improved with the replacement of some metal parts by ABS parts (designed to be made in a 3D printer), in order to maintain the strength and mobility, but with a lower weight.

2.2. Electronic and Electrical Design

Even though the team is built by two different projects, the sensors and actuators are the same, so the electronics and software are the same. The robots does not have microcontrollers, because the control and processing is performed by a Intel NUC [3] and the motors are controlled by the computer's USB port with an USB/RS485 adapter. The sensors are a webcam on the Robot's "Head" and a UM6 (ultra-miniature orientation sensor), featuring gyros, accelerometers and magnetic sensors.

3. Software Design

The team's software was developed by our group. We have been using a hybrid architecture, named Cross Archi-

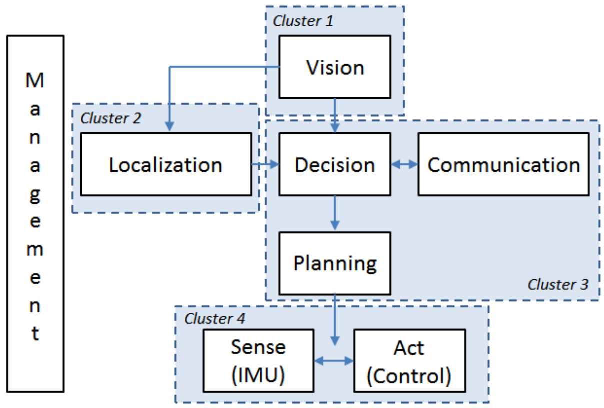

Figure 2: The Cross Architecture implemented.

tecture shown in Fig. 2, where each one of the solid line boxes in the Cross Architecture is a completely independent process for the computer [1], composed by vision, localization, decision, planning, communication, sense and control systems.

Cross Architecture is hybrid because there are some aspects of reactive paradigm and others hierarchical. To communicate between the processes, Cross Architecture uses a blackboard, so independent processes can access a global database. In the proposed architecture, the global database was created using shared memory, which contributed to increase the speed of data exchange among processes.

The Cross Architecture has also a Management process that is used to launch, synchronize and monitor all the processes.

3.1. Vision System

Vision is responsible for obtain images and process them. The robot must be able to find the ball, the goals, the field lines and other robots, as well as calculate the distances to the objects. Finding the ball, identifying the goal posts, detecting field lines and recognizing robots sequentially consumes a precious time, so vision was designed as a process with four parallel threads, being each one of these tasks a different thread.

Ball tracking and Goal recognition: As the color is no longer a discrepant feature for the ball recognition and for the goal identification in the current Robocup rules, a classifier using HAAR wavelets has been trained with several ball and goal images. The classifier used was the cascade of boosted classifiers working with haar-like features proposed by [4] and improved by [5].

Opponents and Teammates: The group implemented opponent recognition using the Histogram of Oriented Gradients (HOG) which is a solid technique widely used to recognize people in several environments and it uses as a classifier the Support Vector Machines [6]. This classifier is trained with images that has at least one robot in each image and aleatory images. Once robots are found, we need to determine to which team the identified robot belongs, that is done using segmentation of the team color inside the detection window. By using the sizes of the robots it is possible to infer their distance from the seeing robot.

3.2. Localization

Localization plays an important role in mobile robots, and gives outstanding advantage in soccer games. In order to know its position in the soccer field, as well as its direction, the robot uses the information received from the vision process.

We are implementing a qualitative approach for localizing the robots. In order to achieve this kind of localization, the Elevated Oriented Point Algebra ($\mathcal{EOPRA}_m$) [7], that is a technique of Qualitative Spatial Reasoning [8], [9] have been used.

$\mathcal{EOPRA}_m$ fits well for addressing the localization problem, because it is relative and treats the relations of orientation and distance qualitatively. Because of the fact that it is relative, $\mathcal{EOPRA}_m$ is more abstract and can be regardless of the domain, since a robot will localize itself in relation to the others.

3.3. Decision algorithms

We are using *Star Calculus* [10], with a concept of distance, to represent the qualitative position of the ball and the robots in the field and Case-based Reasoning (CBR) to select the most similar case and coordinate the actions that each robot must perform. So, we have a base of past cases and the agent coordinator checks all the time which case they can use at a certain moment, it shares with all the robots and they act on it. This work is based in a previous work on the 4-legged Aibo robots, by Ross et al. [11], and we extended the research on Qualitative Spatial Reasoning.

3.4. Movement Control

The Control system is in charge of controlling all servomotors of the body, except the ones of the head, that are controlled by the Vision system. Control process keeps checking if the robot is standing or fallen, if it's fallen the process will make it stand up. The Control also monitors the battery voltage, when it gets below the safe operating range, the robot sits down and turn off the servomotors.

Through the performed experiments to improve and speed up the walking on artificial grass, we found that for each kind of movement we needed to adjust the parameters in order to seek a fast and dynamically balanced gait.

In the config.ini archive we have added sections related to the each kind of action, as shown in Figure 3. The control process holds the attributes related to the configuration parameters of the movements, and according to the action that the robot will perform, it updates the parameters to the gait pattern generator.

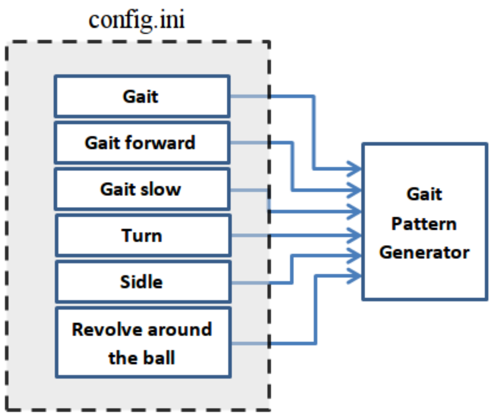

Figure 3: The implementation of the Movement Controler.

4. Work in Progress

Performing some experiments on Control Process, we proposed an approach that uses Reinforcement Learning to learn the action policy that will make a robot walk in an upright position, in a lightly sloped terrain. This work was motivated by changes in the the fields in which the robots will play at RoboCup. The field is made of artificial grass, and they are not perfectly plain, and variations in the turf cause small slopes, causing the robots to fall. The proposed system intends to address this problems, however, the experiments performed demonstrates the model efficiency to solving the more general problem of walking on sloped floors. The results shown that the use of a gyroscope is not sufficient to maintain the stability of the robot in this type of ground, and the use of other sensors such as an accelerometer, combined with Reinforcement Learning techniques to help the robot to stabilize itself during the walk seems very promising. Figure 4 presents the robot using its learned policy to maintain its stability

We are also working on the optimization values of the gait pattern generation for Darwin-Op and we propose a reinforcement learning algorithm with temporal generalizations that aims to optimize this parameter. There are several gait generation techniques that have been developed for humanoid robots and Darwin-OP robot uses a method to generate the gait pattern based on coupled oscillators that perform sinusoidal trajectories. However this gait pattern generation has several parameters for its configuration. We performed experiments in a simulated environment and the results show that the algorithm was able to learn what are the best parameters values, through the evaluation of the humanoid robot's walk performance.

On Vision Process, our first approach proposes a vision system with threads, allowing the robot to track objects and providing information such as distances and estimated localization for the robots, simultaneously. With this, Figure 5 presents the four parallel threads proposed: the ball tracking, the field line detection, the goal recognition (Figure 6), and the robot identification. Only one of these threads have the control of the pan-tilt at a given time, but all the algorithms

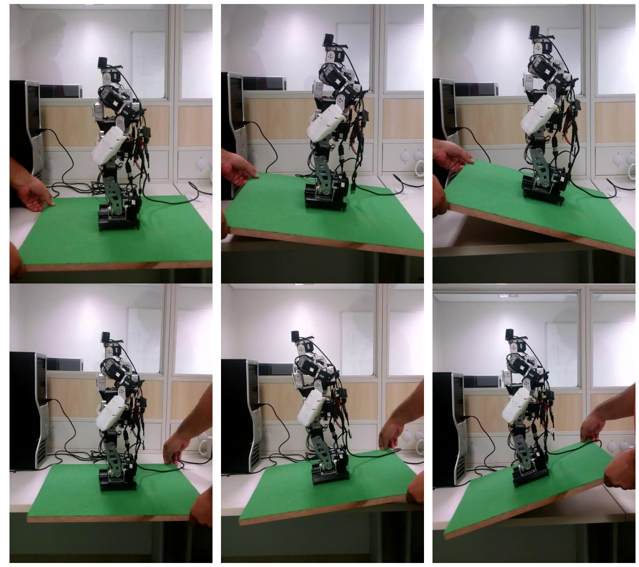

Figure 4: Robot using the policy learned during the first phase to maintain stability on an inclined board.

will continue to capture information from the environment, no matter where the camera is heading to.

Another proposal on Vision Process is our analysis of two descriptor algorithms, HAAR and HOG, and the use of one of them for recognizing humanoid robots. As many different robots are available in Robocup domain, the descriptor needs to describe features in a way that they can be distinguished from the background at the same time the classification has to have a good generalization capability. We performed the experiments using their classical classifier, AdaBoost (for HAAR) and SVM (for HOG), and although some limitations appeared in tests (like the number of available different images of robots), the results were beyond expectations. Figure 7 shows an example of a robot identification using HAAR (top) and HOG (bottom).

One of the main work in progress is on Localization Process, where we propose to develop a collaborative relative localization for vision-based multi-robot system in

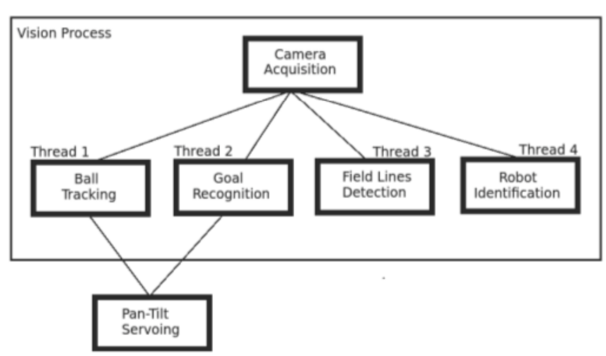

Figure 5: Vision Process modules.

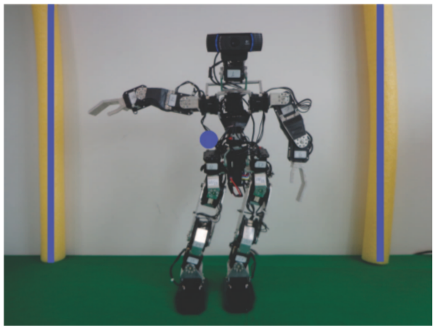

Figure 6: Vision Process - goal recognition.

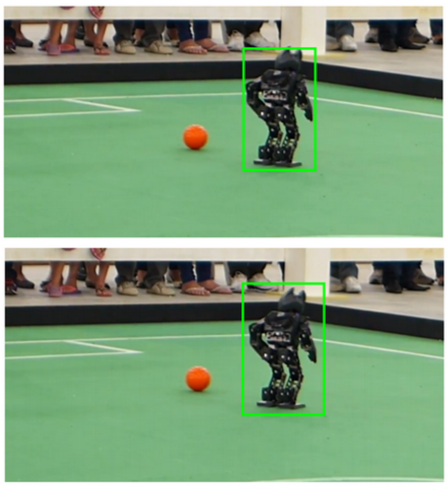

Figure 7: Robot identification using HAAR (top) and HOG (bottom)

qualitative maps, using the Elevated Oriented Point Algebra ($\mathcal{EOPRA}_m$), with the orientation inference restricted by a quantitative triangulation. The motivation of using qualitative data is to obtain a level of abstraction closer to the human categorization of space and, also, to have a more effective way of interaction between robots and humans. The initial results address that it is possible to have a localization and mapping system working over a qualitative spatial reasoning technique. Figure 8 depicts two examples of the usage of $\mathcal{EOPRA}_m$ for localization.

Finally, on Decision Process, we are working in a hybrid system integrating Case-based reasoning (CBR) and Qualitative Spatial Reasoning (QSR), allowing the robots to perform coordinated actions, like set-plays. So, we propose to use the Star Calculus with a granular distance concept to model the cases through the qualitative relations between the objects in the case and a new retrieval algorithm, that uses the Conceptual Neighborhood Diagram (CND) and a cost function to compute the similarity measure between the problem and the case base, and retrieve the most similar cases. We evaluate our approach using simulation and real humanoid robots and preliminaries results show that the

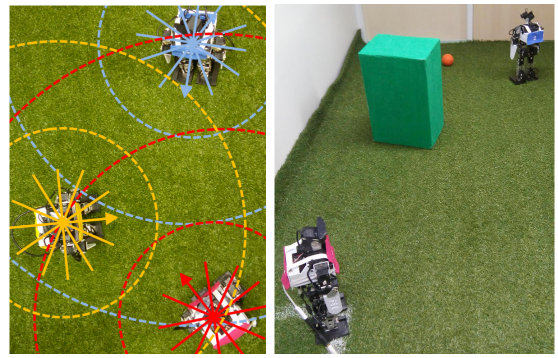

Figure 8: Two qualitative localizations: Representation in relation to the other robots or used to find an occluded ball.

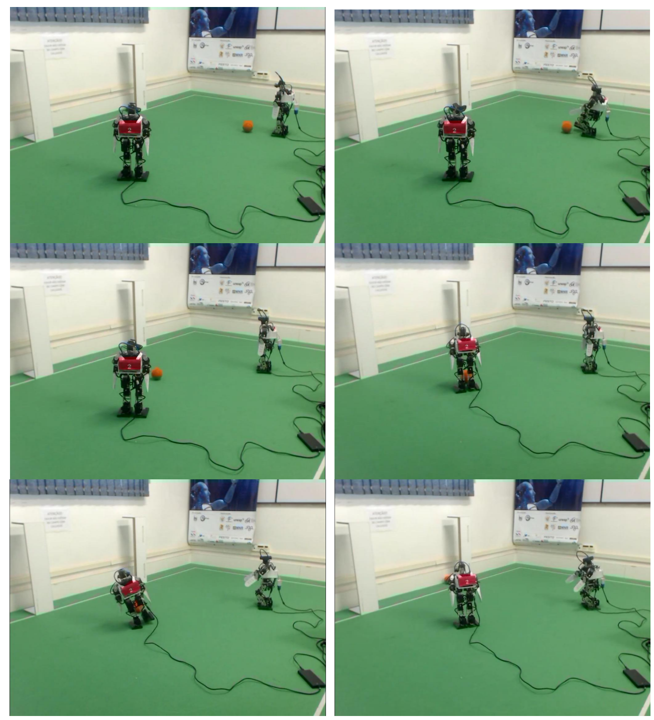

Figure 9: Decision process with CBR and QSR.

proposed approach is faster than using quantitative model and other similarities measure such as Euclidean distance. Figure 9 shows an experiment where the right robot is the coordinator and, according to the ball and left robot positions, it retrieves a case and sends, over wireless, the action that the left robot must perform.

4.1. Publications

We had several papers published at Brazilian conferences; 2 papers published and 3 papers accepted in the International Latin American Robotics Symposium [1], [12], [13], [14], [15]; 2 papers accepted in the International RoboCup Symposium [16], [17]; 1 book's chapter published by Springer [18]; and 2 papers published in major journals [19], [20].

5. Conclusion

In this paper we presented the RoboFEI-HT researches in Artificial Intelligence applied to Humanoid Robotics in the environment of the RoboCup KidSize League, although it can be adapted and applied to any robotic environment. We gave an overview on how all the different systems can work together, what each one does and what we pretend to achieve in the near future.

Acknowledgments

The authors would like to thank the Brazilian research fomentation agencies, FAPESP, CNPQ and CAPES, for the provided scholarships and Centro Universitário FEI for all available resources. Thiago P. D. Homem would also like to thank Instituto Federal de São Paulo.

References

[1] D. Perico, I. Silva, C. Vilao, T. Homem, R. Destro, F. Tonidandel, and R. Bianchi, "Hardware and software aspects of the design and assembly of a new humanoid robot for robocup soccer," in *Robotics: SBR-LARS Robotics Symposium and Robocontrol (SBR LARS Robocontrol), 2014 Joint Conference on*, Oct 2014, pp. 73–78.

[2] Romela. Darwin op: Open platform humanoid robot for research and education. [Online]. Available: http://www.romela.org/main/DARwIn_OP

[3] Intel Corporation. (2016) Mini PC: Intel NUC. [Online]. Available: http://www.intel.com/content/www/us/en/nuc/nuc-kit-d54250wyk-board-d54250wyb.html

[4] P. Viola and M. Jones, "Rapid object detection using a boosted cascade of simple features," 2001, pp. 511–518.

[5] R. Lienhart and J. Maydt, "An extended set of haar-like features for rapid object detection," in *IEEE ICIP 2002*, 2002, pp. 900–903.

[6] N. Dalal and B. Triggs, "Histograms of oriented gradients for human detection," in *Proceedings of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05) - Volume 1 - Volume 01*, ser. CVPR '05. Washington, DC, USA: IEEE Computer Society, 2005, pp. 886–893.

[7] R. Moratz and J. O. Wallgrün, "Spatial reasoning with augmented points: Extending cardinal directions with local distances," *J. Spatial Information Science*, vol. 5, no. 1, pp. 1–30, 2012.

[8] A. G. Cohn and J. Renz, "Qualitative spatial reasoning," in *Handbook of Knowledge Representation*, F. van Harmelen, V. Lifschitz, and B. Porter, Eds. Elsevier, 2007.

[9] F. Dylla, *Qualitative Spatial Reasoning for Navigating Agents: Behavior Formalization with Qualitative Representations*, ser. Ambient Intelligence and Smart Environments, 2009, vol. 3.

[10] J. Renz and D. Mitra, "Qualitative direction calculi with arbitrary granularity," in *Trends in Artificial Intelligence, 8th Pacific Rim Intl. Conf. on Artificial Intelligence, Auckland, New Zealand, August 9-13, 2004, Proceedings*, 2004, pp. 65–74.

[11] R. Ros, J. L. Arcos, R. Lopez de Mantaras, and M. Veloso, "A case-based approach for coordinated action selection in robot soccer," *Artif. Intell.*, vol. 173, no. 9-10, pp. 1014–1039, Jun. 2009.

[12] C. Vilao, D. Perico, I. Silva, T. Homem, F. Tonidandel, and R. Bianchi, "A single camera vision system for a humanoid robot," in *Robotics: SBR-LARS Robotics Symposium and Robocontrol (SBR LARS Robocontrol), 2014 Joint Conference on*, Oct 2014, pp. 181–186.

[13] D. Perico, P. Santos, and R. Bianchi, "Vision-based monte carlo localization without measurement: A qualitative approach during update phase," in *SBR-LARS Robotics Symposium (SBR LARS), 2015 Joint Conference on*, Oct 2015.

[14] I. Silva, D. Perico, T. Homem, C. Vilao, F. Tonidandel, and R. Bianchi, "Using reinforcement learning to improve the stability of a humanoid robot: Walking on sloped terrain," in *SBR-LARS Robotics Symposium (SBR LARS), 2015 Joint Conference on*, Oct 2015.

[15] C. Vilao, L. Celiberto Jr., and R. Bianchi, "Evaluating the performance of two visual descriptors techniques for a humanoid robot," in *SBR-LARS Robotics Symposium (SBR LARS), 2015 Joint Conference on*, Oct 2015.

[16] R. A. C. Bianchi and A. H. R. Costa, "Implementing computer vision algorithms in hardware: an FPGA/VHDL–based vision system for mobile robot," in *RoboCup–01: Robot Soccer World Cup V*, ser. Lecture Notes in Artificial Intelligence, A. Birk, S. Coradeschi, and S. Tadokoro, Eds., vol. 2377. Berlin, Heidelberg: Springer Verlag, 2002, pp. 281–286.

[17] L. A. Celiberto, C. H. C. Ribeiro, A. H. R. Costa, and R. A. C. Bianchi, "Heuristic reinforcement learning applied to robocup simulation agents," in *RoboCup*, ser. Lecture Notes in Computer Science, U. Visser, F. Ribeiro, T. Ohashi, and F. Dellaert, Eds., vol. 5001. Springer, 2007, pp. 220–227.

[18] D. H. Perico, I. J. Silva, C. O. Vilão Junior, T. P. D. Homem, R. C. Destro, F. Tonidandel, and R. A. C. Bianchi, *Robotics: Joint Conference on Robotics, LARS 2014, SBR 2014, Robocontrol 2014, São Carlos, Brazil, October 18-23, 2014. Revised Selected Papers*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2015, ch. Newton: A High Level Control Humanoid Robot for the RoboCup Soccer KidSize League, pp. 53–73.

[19] R. Bianchi, M. Martins, C. Ribeiro, and A. Costa, "Heuristically-accelerated multiagent reinforcement learning," *Cybernetics, IEEE Transactions on*, vol. 44, no. 2, pp. 252–265, Feb 2014.

[20] J. Gurzoni, Jose Angelo, M. F. Martins, F. Tonidandel, and R. A. C. Bianchi, "On the construction of a robocup small size league team," *Journal of the Brazilian Computer Society*, vol. 17, no. 1, pp. 69–82, 2011.