FC Portugal 3D Simulation Team: Team Description Paper

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Abstract. FC Portugal 3D team is built upon the structure of our previous Simulation league 3D teams. Our research is mainly focused on the adaptation of previously developed methodologies from our 2D soccer teams [1, 2, 3, 4, 5] to the 3D humanoid environment and on creating new coordination methodologies. In our 2D teams, which participate in RoboCup since 2000, we have introduced several concepts and algorithms covering a broad spectrum of the robotic soccer research challenges. From coordination techniques such as Tactics, Formations, Dynamic Positioning and Role Exchange, Situation Based Strategic Positioning and Intelligent Perception to Optimization based low-level skills, Visual Debugging and Coaching, the number of research aspects FC Portugal has been working on is quite extensive [1, 2, 3, 4, 5]. The research-oriented development of our team has been pushing it to be one of the most competitive (World champion in 2000 and Coach Champion in 2002, European champion in 2000 and 2001, Coach 2nd place in 2003 and 2004, European champion in Rescue Simulation and Simulation 3D in 2006, World Champion in Simulation 3D in 2006 and European champion in 2007). This paper describes the main innovations of our 3D simulation league team relating them with previous work. New skills have been developed for the simulated humanoid agent which include optimized getup front and getup back behaviors, Truncated Fourier Series based walk and a powerful front kick. The paper also includes information related to the agent architecture and low-level considerations. The current research is focused on improving these skills by developing a generic skills optimization framework, building robust mid-level skills and integrating high-level coordination mechanisms. Very good results were already achieved, in 2011, concerning the optimization of low-level skills.

1. Introduction

FC Portugal was built upon the low-level skills research conducted during previous years. Although there is still space for improvement in FC Portugal low-level skills, we feel that we currently have a very performing set of these skills. We are currently focused on the high-level decision and cooperation mechanisms of our agents. The skills have been developed using several different techniques (hill climbing, genetic algorithms, population swarm optimization).

For RoboCup 3D soccer simulation competition that was based on spheres (from 2004 to 2006), the decisive factor (like in the 2D competition) was the high-level reasoning capacities of the players and not their low-level skills. Thus we worked mainly on high-level coordination methodologies for our previous teams.

Since 2007 humanoid agents have been introduced and teams consist of only a few agents, hence research in coordination has not been very important in the 3D league. Developing efficient low-level skills, contrarily to what should be the research focus of the simulation league, has been the main decisive factor in the 3D league. However for 2011, the number of agents will increase significantly and teams will consist of 9 players making coordination, a very important issue for the efficiency of the team.

Several interesting topics are opened by the introduction of humanoid agents, including in the use of learning and optimization techniques for developing efficient low-level skills. In previous work, we have introduced methods for developing very efficient low-level skills using optimization techniques [1, 6]. This work has already conducted to the development of an efficient set of humanoid low-level skills.

2. Research Directions

New research directions include research on agent architecture, the humanoid model and its associated restrictions in terms of dynamics, sensing, and decision, will foster the development of new layered architectures for its controlling agents. The lower layers will be responsible for the basic control of the humanoid such as equilibrium while the higher layers take decisions at a strategic level. Several methods for generation of humanoid behaviors are being compared, including simulated annealing, tabu search, genetic algorithms, particle swarm optimization and reinforcement learning and how these behaviors are integrated together.

Some directions of research in FC Portugal also include developing a model for a strategy for a humanoid game and the integration of humanoids coming from different teams in a inter-team framework to allow the formation of a team with different humanoids. Opponent modelling may be a critical module in humanoid soccer, including the opponent basic behaviors performance, its positioning, etc. are factors that must be taken into account when selecting a given strategy for a game. Other research with humanoids includes intelligent sensing, because the humanoids cannot look in all directions at the same time. So, it is very important to choose the best looking direction considering all restrictions introduced by the dynamics of humanoid movement. Also heterogeneity will be important because in the future it is expected that not all humanoids will be identical, having humanoids with different capabilities introduces new problems of task assignment that will have to be dealt within humanoid teams.

3. FCPortugal 3D Agent Architecture

The FC Portugal Agent 3D [7] is divided in several packages:

- **WorldState**: Contains classes to keep track of the environment information. These include the objects presented in the field (fixed objects as flags and mobile objects as players and ball), the game state, (e.g. time, playmode) and game conditions (e.g. field length, goals length);
- **AgentModel**: Contains a set of classes responsible for the agent model information. This includes the body structure (body objects such as joints,

body parts and perceptors), the kinematics interface, the joint low-level control and trajectory planning modules;

- **Geometry**: Contains useful classes to define geometry entities as points, lines, vectors, circles, rects, polygons and other mathematical functions;
- **Optimization**: Contains a set of classes used for the optimization process. These are a set of evaluators that know how a behavior should be optimized;
- **Skills**: This package is associated with the reactive skills and talent skills of the agent. Reactive skills include the base behaviors as is the case of walk in different directions, turn, get up, kick the ball and catch the ball. Talent skills are some powerful think capabilities of the agent, which include movement prediction of mobile objects in the field and obstacle avoider;
- **Utils**: This package is related with useful classes that allow the agent to work. This includes classes for allowing the communication between the agent and the server, communication between agents, parsers and debuggers.
- **Strategy**: Contains all the high-level functions of the agent. The package is very similar to the team strategy packages used for other RoboCup leagues.

4. Agent Model

The agent model is constructed by reading a XML file that contains the body structure. This file is defines the body parts, the joints and the perceptors and the corresponding positions related to each other. The following represents an excerpt of the configuration file that is currently being used:

```
<robot type="humanoid" rsgfile="nao/nao.rsg">
   <bodypart name="lhip1" mass="0.09" />
   ...
   <joint name="lleg2" per="llj2" eff="lle2"
               axis="0,1,0" min="-25" max="45">
         <anchor part="lhip1" x="0" y="0" z="0" />
         <anchor part="lhip2" x="0" y="0" z="0" />
   </joint>
   ...
</robot>
```

This information stores the body structure information of the humanoid. Several important parameters are derived from it as, for example, the direct kinematics transformation matrices and useful measures as the center of mass. This strategy keeps the code generic and independent of the model, allowing an easy integration of different models, which allow the future integration of heterogeneous robots.

5. Bipedal Walking using TFS

One of the main areas of FC Portugal 3D team research is on automatic methodologies for the development of efficient humanoid skills. This research builds on knowledge acquired from previous projects, by several team members, on using optimization techniques to solve difficult tasks, which include bipedal walking [1,6,8]. The following sections detail the work that has been performed in order to develop an efficient and robust bipedal walk skill that leads to the currently functional omnidirectional walk of our humanoid.

Trunk sagittal and coronal plane motions are fairly repeatable [9] therefore Fourier series can be used to model the joints trajectories in these planes. In our approach, according to [10] legs joint trajectories in the sagittal plane are divided into upper and lower portions. The trajectories for both legs are identical in shape and shifted in time by half of the walking period. The Truncated Fourier Series (TFS) for generating each portion of hip and knee trajectories are formulated below.

$$\theta_h^{+} = \sum_{i=1}^{n} A_i . \sin\left(iw_h t\right) + c_h , w_h = \frac{2\pi}{T_h} \quad \textbf{(1)}$$

$$\theta_h^{-} = \sum_{i=1}^{n} B_i . \sin\left(iw_h t\right) + c_h , w_h = \frac{2\pi}{T_h}$$

$$\theta_k^{+} = \sum_{i=1}^{n} C_i . \sin\left(iw_k t\right) + c_k , w_k = w_h$$

$$\theta_k^{-} = c_k \geq 0$$

In these equations, the plus (+) sign represents the upper portion of walking trajectory and the minus (-) the lower lower portion. $i=1$ and A_i, B_i, C_i are constant coefficients. The h and k subscripts stand for hip and knee respectively. C_h ,C_k are signal offsets and T_h is assumed as the period of hip trajectory. All joints in walking motion have equal frequency, hence equation $w_k = w_h = \frac{2\pi}{T_h}$ can be derived. Parameter t_1 is the start time of knee joint lock phase and parameter t_2 represents the lock phase end time. According to [11], by specifying the start and end time of the lock phase, two parameters of t_1, t_2 could be eliminated. Therefore the number of variable for optimization to produce legs movement in sagittal plane decreased to 6.

In the sagittal plane, during human walking, the arms swing in opposite manner to legs, which helps to balance the angular momentum generated in the lower body [12, 13]. Trajectory of arms is similar to sinusoidal signal with the same frequency of the legs [12, 14]. This method allows an improvement of the accuracy of straight walking at different speeds. The equation (2) produces the arms swinging trajectories.

$$f(t) = A\sin(\omega_{arm} t), \omega_{arm} = \omega_{arm} \quad \textbf{(2)}$$

Where, A and ω are the amplitude and frequency. Since legs and arms have the same frequency, $\omega_{arms} = \omega_{legs}$. Only the best value of parameter A must be obtained.

According to [14], increasing the walking speed and amplitude from standing to running, the robot can walk more stable and faster. In our model a linear equation is used to lead the robot to increase the trajectory amplitude from zero (stop state) to desired angular trajectories. T is the parameter that determines how much time is needed for this incremental algorithm to reach the final trajectories. All angular trajectories (arms and legs) will be multiplied by K of the following equation.

$$K = time / T , time < T \quad \textbf{(3)}$$

$$K = 1, time >= T$$

The motion range in the coronal and transverse plane is smaller than the motion range in sagittal plane [15] but it has an important role to keep the balance and to reach the high speeds. The coronal motion range depends on the walking speed: at higher speeds it gets smaller. Coronal plane movements are periodic motions [9].

To produce legs' motion in coronal plane while keeping the balance of robot, we proposed a walking sequence in which feet were kept parallel to the ground in order to avoid collision, hence the ankle angle is equal to the hip's angle of the opposite leg. To generate the hip angular trajectories in coronal plane, the parameters for the following equation must be obtained (4).

$$\begin{aligned} f(t) &= H\sin(wt), t < T_h/2 \\ f(t) &= 0, t > T_h/2 \end{aligned} \quad \textbf{(4)}$$

Where, H and ω are amplitude and frequency and Th the hip period. The period of walking in sagittal plane and coronal plane is equal. Hence Th and ω are eliminated.

The best parameters to generate angular trajectories for bipedal locomotion must be found. For this kind of optimization problem several generic optimization methods such as Tabu Search, Genetic Algorithms and Particle Swarm Optimization can achieve very good results [8].

6. Optimizing Low-Level Skills

Controlling a humanoid robot with a large number of joints and thus, degrees of freedom, when performing multiple skills (turning, kicking, getting up) presents a complex problem that requires knowledge in multiple fields, including biology, mechanics, physics, electronics and computer engineering. To solve this problem the team implemented a new generic optimizer capable of optimizing any low-level skill using distinct optimization algorithms, in particular Hill Climbing, Simulated Annealing, Tabu Search and Genetic Algorithms.

The new skills optimizer was developed to allow any agent skill to be optimized using either a single computer or multiple computers connected via a network. Figure 1 is a diagram representing the configuration of the optimizer. Once started, the optimizer executes the simulator script, a shell script which starts the simulator and the monitor. It may start multiple simulators and their respective monitors in different computers if specified. It also executes the agent script which in turn starts the FCP agents. The agents connect to the simulation server and to the optimization server which will provide the agents with the behavior to execute and receive from them the performance data of the execution. Both these connections are made via TCP sockets.

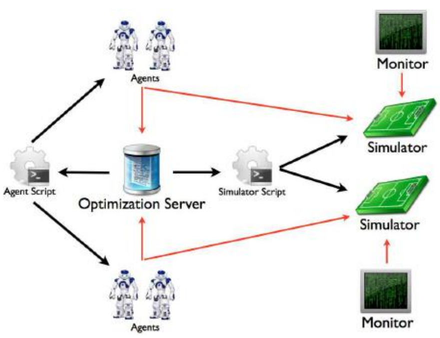

Fig. 1: Optimization Methodology Architecture

The optimization server is the core of the optimizer being responsible for the execution of the other components via the execution of scripts. It contains the functions that read the XML behaviors, run the optimization algorithms, modify the behaviors according to the algorithm, send the modified behavior (proposed solution) to the agents for execution, receive the execution data from the agents, evaluate the data according to the specified objective function and, finally, terminates the optimization process via another script. The optimization server is actually multi-threaded. Each thread is started for each agent which creates a specific TCP server.
Behaviors are specified and stored as XML files which are loaded when an agent starts. The optimization server has functions which read the behavior to be optimized from its XML file and load the behavior into an array in memory. It is this array representation of the behavior that will be modified by the optimization algorithm. This representation is then transmitted to the agents, via a socket, to be executed. The optimizer was applied to optimize several skills, as the getup front (fig 2), getup back and kick skills. It will be applied to other skills and compound skills in a near future.

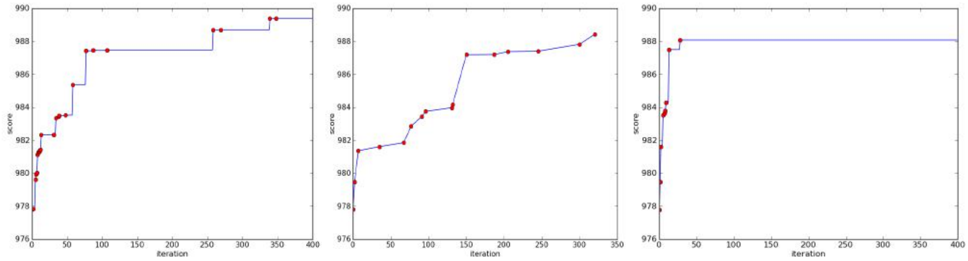

Fig. 2: Results for the Get Up optimization: a) Hill Climbing, b) Simulated Annealing, c) Tabu Search

The execution time achieved for the get up front skill was 1.1 seconds optimizing an manually tuned skill that took 2.0 s. Good optimization results were also achieved for the get up back and kick skills. For the kick skill, a distance of 5.1 m with strong robustness to variations in the initial robot to ball relative positions was achieved. A maximum kick distance of 6.4 m was reached maximizing the kick distance.

7. High-Level Decisions and Coordination

Flexible Tactics has always been one of the assets of FC Portugal teams. FC Portugal 3D can use several different formations and for each formation players may be instantiated with different player types. The management of formations and player types is based on SBSP – Situation Based Strategic Positioning algorithm [1, 4]. This enables the team to move in a smooth manner, keeping the field completely covered.
The high-level decision uses the infrastructure presented in the section 3. We also have adapted our previous researched methodologies to the new 3D environment: strategy for a Competition with a Team with Opposite Goals [1, 4, 5, 16]; concepts of Tactics, Formations and Player Types [1, 3, 4, 16]; distinction between Active and Strategic Situations [1, 4]; Situation Based Strategic Positioning (SBSP) [1, 4, 5]; Dynamic Positioning and Role Exchange (DPRE) [1, 4, 5]; Visual Debugging and Analysis Tools [1, 3, 17]; optimization based Low-Level Skills [1, 3]. Standard

Language to Coach a (Robo)Soccer Team [2, 3]; Intelligent Communication using a Communicated World State [1, 3, 5]; Flexible Set-plays for coordinating teams [18].

In 2010, our research was mostly concerned in developing optimization based low level skills for the humanoid agent and robust mid-level skills. The high-level layers of the team for 2011 will be adapted to be used in the humanoid simulator (these methodologies have already been adapted to our Simulation 2D, Simulation 3D with spheres model, small-size, middle-size [19] and rescue teams [20]).

8. Conclusions

Almost all of our research on high-level flexible coordination methodologies is directly applicable to the 3D league. The increase in the number of players of the team is welcome, enabling coordination methodologies to be useful in this league.

Robust low-level skills have been developed for the NAO humanoid model, using optimization and learning techniques, enabling us to continue the research in strategical reasoning and coordination methodologies that should be the focus of the simulation leagues inside RoboCup. A generic optimization framework for biped robots' low-level skills was developed, capable of optimizing any skill of the team. The framework has lead to good results on optimizing the kick and getup skills.

Future work will be concerned in extending the optimization methodology for skills sequences and on developing coordination methodologies enabling teams of humanoid robots to play robosoccer games in a robust and flexible manner. FC Portugal is also starting participation in the SPL - Standard Platform League in 2011. The SPL code of the team is based on the Simulation 3D code. Thus, future work will be on bridging the gap between simulation and robotics.

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References

1. Luis Paulo Reis and Nuno Lau, FC Portugal Team Description: RoboCup 2000 Simulation League Champion, In P. Stone, T. Balch and G. Kraetzschmar editors, RoboCup-2000: Robot Soccer World Cup IV, LNAI 2019, pp 29-40, Springer, 2001.
2. Luís Paulo Reis and Nuno Lau, COACH UNILANG – A Standard Language for Coaching a (Robo) Soccer Team, in Andreas Birk, Silvia Coradeschi and Satoshi Tadokoro, editors, RoboCup2001 Symposium: Robot Soccer World Cup V, Springer Verlag LNAI, Vol. 2377, pp. 183-192, Berlin, 2002.
3. Nuno Lau and Luis Paulo Reis, FC Portugal Homepage, [online] available at: Http://www.ieeta.pt/robocup, consulted on February 2010.
4. Luis Paulo Reis, Nuno Lau and Eugénio C. Oliveira, Situation Based Strategic Positioning for Coordinating a Team of Homogeneous Agents in M.Hannebauer, et al. eds, Balancing Reactivity and Social Deliberation in MAS – From RoboCup to Real-World Applications, Springer LNAI, Vol. 2103, pp. 175-197, 2001

5. Nuno Lau and Luis Paulo Reis, FC Portugal - High-level Coordination Methodologies in Soccer Robotics, Robotic Soccer, Book edited by Pedro Lima, Itech Education and Publishing, Vienna, Austria, pp. 167-192, December 2007, ISBN 978-3-902613-21-9
6. Hugo Picado, Marcos Gestal, Nuno Lau, Luís Paulo Reis, Ana Maria Tomé, Automatic Generation of Biped Walk Behavior Using Genetic Algorithms. In J.Cabestany et al. (Eds.), 10th International Work-Conference on Artificial Neural Networks, IWANN 2009, Springer, LNCS Vol. 5517, pp. 805-812, Salamanca, Spain, June 10-12, 2009
7. Hugo Marques, Nuno Lau and Luís Paulo Reis, FC Portugal 3D Simulation Team: Architecture, Low-Level Skills and Team Behaviour Optimized for the New RoboCup 3D Simulator, Reis, L.P. et al. eds, Proc. Scientific Meeting of the Portuguese Robotics Open 2004, FEUP Editions, C.Colectâneas, Vol. 14, pp.31-37, April, 23-24, 2004
8. Nima Shafii, Omid Mohamad Nezami, Siavash Aslani and Saeed Shiry Ghidary. Evolution of Biped Walking Using Truncated Fourier Series and Particle Swarm Optimization, RoboCup Symposium 2009, Jacky Baltes, Michail G. Lagoudakis, Tadashi Naruse, Saeed Shiry, editors, Springer, LNAI, Graz, Austria, 2009
9. R. J. Konz, S. Fatone, R. L. Stine, A. Ganju, S. A. Gard, S. L. Ondra. A Kinematic Model to Assess Spinal Motion During Walking, J.Biomechanics, vol. 31, pp. E898-E906, 2006.
10. L. Yang, C. M. Chew, A. N. Poo. Adjustable Bipedal Gait Generation using Genetic Algourithm Optimized fourier Series Furmulation. In: Proceedings of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 4435 - 4440, 2006.
11. N. Shafii, M. H. Javadi, B. Kimiaghalam. A Truncated Fourier Series with Genetic Algorithm for the control of Biped Locomotion. In: Proceeding of the 2009 IEEE/ASME International Conference on advanced intelligent Mechatronics, pp. 1781--1785, 2009.
12. H. Elftman, The Function of the Arms in Walking. Journal of Human Biology Vol. 11, pp. 529-535, 1939.
13. S. H. Collins, M. Wisse, A. Ruina. A 3-D Passive Dynamic Walking Robot with Two Legs and Knees. Int. Journal Robotics Research Vol. 20, pp. 607-615, 2001.
14. N. Shafii, A. Khorsandian, A. Abdolmaleki, B. Jozi. An Optimized Gait Generator Based on Fourier Series Towards Fast and Robust Biped Locomotion Involving Arms Swing. In: Proc. 2009 IEEE Int. Conf. on Automation and Logistics, pp. 2018-2023, 2009
15. D. Thewlis, J. Richards, S. Hobbs. The Appropriateness of Methods Used to Calculate Joint Kinematics. Journal of Biomechanics, Vol. 41, pp. S320--S320, 2008
16. João Certo, Nuno Lau e Luís Paulo Reis, A Generic Multi-Robot Coordination Strategic Layer, RoboComm 2007 - First International Conference on Robot Communication and Coordination, Athens, Greece, October 15-17, 2007
17. Nuno Lau, Luís Paulo Reis e João Certo, Understanding Dynamic Agent's Reasoning, In Progress in Artificial Intelligence, 13th Port. Conf. on AI, EPIA 2007, Guimarães, Portugal, December 3-6, 2007, Springer LCNS, Vol. 4874, pp. 542-551, 2007
18. Luís Mota e Luís Paulo Reis, Setplays: Achieving Coordination by the appropriate Use of arbitrary Pre-defined Flexible Plans and inter-robot Communication, RoboComm 2007 - First International Conf. on Robot Communication and Coordination, Athens, Greece, October 15-17, 2007
19. Nuno Lau, Luís Seabra Lopes, G. Corrente and Nelson Filipe, Multi-Robot Team Coordination Through Roles, Positioning and Coordinated Procedures, Proc.IEEE/RSJ Int. Conf. on Intelligent Robots and Systems – IROS 2009, St. Louis, USA, Oct. 2009
20. Luís Paulo Reis, Nuno Lau, Francisco Reinaldo, Nuno Cordeiro and João Certo. FC Portugal: Development and Evaluation of a New RoboCup Rescue Team. 1st IFAC Workshop on Multivehicle Systems (MVS'06), Salvador, Brazil, October 2 – 3, 2006