FC Portugal 3D Simulation Team: Team Description Paper

Nuno Lau[1,3], Luís Paulo Reis[2,4], Nima Shafii[3,4], Rui Ferreira[3,4] ,
Abbas Abdolmaleki[3,4]

nunolau@ua.pt, lpreis@dsi.uminho.pt, nima.shafii@gmail.com, ee05188@fe.up.pt, abbas.a@ua.pt

[1]DETI/UA – Electronics, Telecommunications and Informatics Dep., University of Aveiro, Portugal
[2]DSI/EEUM – School of Engineering, University of Minho, Portugal
[3]IEETA – Institute of Electronics and Telematics Engineering of Aveiro, Portugal
[4]LIACC/UP – Artificial Intelligence and Computer Science Lab., University of Porto, Portugal
http://www.ieeta.pt/robocup/

Abstract. FC Portugal 3D team is built upon the structure of our previous Simulation league 3D teams and standard platform league team. Our research on high-level soccer coordination methodologies and team plying 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 based on the previously developed ones. In our 2D teams, which participated in RoboCup since 2000 with very good results, we have introduced several concepts and algorithms covering a broad spectrum of the soccer simulation 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]. Our researches on developing low-level behaviors are mainly focused on the approaches which can also be applied on the real NAO robot with minimal adaptation. Our experiments on developing our previous standard platform league team are helps us to do our research in this direction. The research-oriented development of our team has been pushing it to be one of the most competitive over the years (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 Bremen 2006 and European champion in 2007,,2012 and 2013). This paper describes some of the main innovations of our 3D simulation league team during the last year. New low-level behaviors have been developed for the simulated humanoid agent, which was based on the controlling of the dynamics of the behaviors, by using the principle of the physical modeling. On top of the lowl-evel behaviors, optimization theqniques were also used in order to tune the parameters. 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, developing omnidirectional walking and running engine, omnidirectional kick engine and integrating high-level coordination mechanisms. Very good results were already achieved, in 2011, 2012 and 2013, concerning the improvement 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 optimization techniques (hill climbing, genetic algorithms, population swarm optimization, CMA_ES and policy learning methods) and using the principle of the physic based model.

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 in the 3D Simulation league, but the number of agents has been kept small until 2011. During this period research in coordination was not 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, during this period. However, in 2011 the number of agents has increase to 9, and in 2012 teams were composed by 11 players making finally coordination, a very important issue for the efficiency of the team.

Several interesting topics were 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. These techniques have been combined with physics based models and optimum control to derive very efficient skills. The integration of these behaviors is also a major research topic.

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 an inter-team framework to allow the formation of a team with different humanoids.

Opponent modeling may be a critical module in humanoid soccer, including the opponent basic behaviors performance, its positioning, etc. These 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. The 2014 3D Simulation rules make the use of heterogeneous humanoids obligatory and enforce research on this particular theme.

3. FCPortugal 3D Agent Architecture

The FC Portugal Agent 3D [7] is divided in several packages: each one with a specific purpose. Figure 1 shows the general structure of the humanoid agent.

- **WorldState**: Contains classes to keep track of the environment information. These include the objects presented in the field (fixed objects as is the case of flags and goals and mobile objects as is the case of the players and the 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 is the case of points, lines, vectors, circles, rects, polygons and other mathematical functions;
- **Optimization**: Contains a set of classes used for the optimization process. These classes are a set of evaluators that know how each 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.

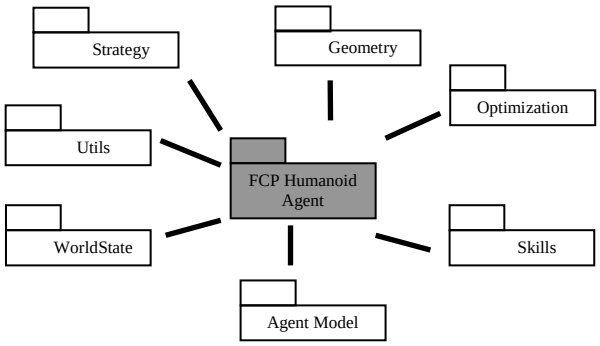

Fig. 1: FCP Humanoid Agent Architecture

4. FCPortugal 3D Low-Level Skills

In this section we briefly describe our approach to develop soccer low-level skills, such as walking, running, and kicking. Nowadays, in order to compete well in rRboCup soccer humanoid leagues, the robots should be able to perform their low level skill fast, in an omni directional manner, and also robust against the external perturbation and noises. In order to improve our low-level skills, we model the dynamics of them by using simple physical system. Then we try to apply the optimization techniques, in order to tune parameters of those models of that skill.

4.1 Modelling and Controlling the Dynamics of the Low-Level Skills

Many popular approaches used for controlling the balance of bipedal locomotion are based on the Zero Momentum Point (ZMP) stability indicator and inverted pendulum model. ZMP cannot generate reference walking trajectories directly but it can indicate whether generated walking trajectories will keep the balance of a robot or not. Kajita assumed that biped walking is a problem of balancing a cart-table model or Linear Inverted Pendulum Model (LIPM) [8], since in the single supported phase, human walking can be represented as the Cart-table model.

Biped walking can be modeled through the movement of ZMP and CoM. The robot is in balance when the position of the ZMP is inside the support polygon. When the ZMP reaches the edge of this polygon, the robot loses its balance. Biped walking trajectories can be derived from desired ZMP by computing the feasible CoM. The possible body swing can be approximated using the dynamic model of a LIPM.

LIPM model has some assumptions and simplifications in its model. First, it assumes that all masses are concentrated on the cart. Second, it assumes that the support leg does not have any mass and represents it as a massless table. Although these assumptions seem to be far from reality, modern walking robots usually have heavy trunks with electronics circuits and batteries inside. Therefore, the effect of leg mass is relatively small. One the major drawback of the LIPM is its consideration the height of the robot fixed during it movement, which is not true for many soccer low-level skills such as running or kicking, Therefore we used the inverted pendulum model which does not have this issue. Figure 2 shows how robot dynamics is modeled by an inverted pendulum and its schematic view.

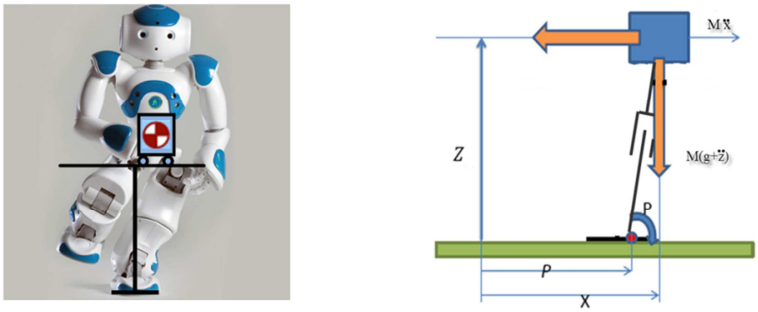

Fig. 2. Schematic view of inverted pendulum model on X direction and frontal view of the NAO robot

Two sets of inverted pendulum are used to model 3D walking. One is for movements in frontal plane; another is for movements in coronal plane. The position of Center of Mass (CoM) M is x and z defined in the coordinate system O. Gravity g and cart acceleration create a moment T_p around the center of pressure (CoP) point P_x. The Equation (1) provides the moment or torque around P.

$$T_p = Mg(x + \ddot{z} - P_x) - M\ddot{x}z \tag{1}$$

We know from [9] that when the robot is dynamically balanced, ZMP and CoP are identical, therefore the amount of moment in the CoP point must be zero, $T_p=0$. By assuming the left hand side of equation (1) to be zero, equation (2) provides the position of the ZMP. In order to generate proper walking, the CoM must also move in coronal plane, hence another cart-table must be used in y direction. Using the same assumption and reasoning equation (3) can be obtained. Here, y denotes the movement in y.

$$P_x = x - \frac{z}{g + \ddot{z}}\ddot{x} \tag{2}$$

$$P_y = y - \frac{z}{g + \ddot{z}}\ddot{y} \tag{3}$$

In order to apply inverted model in a biped walking problem, first the position of the support foot during the performing the low-level skill must be planned and defined, then based on the constraint of ZMP position and support polygon, the ZMP trajectory can be designed. In the next step, the position of the CoM must be calculated using differential equations (2) (3). One of the main issue of using the inverted pendulum, is how to solve these differential equations or how to generated trajectory , the solution of them is explained in detains in our articles , which can be found in [12] [13]and [14]. Finally, inverse kinematics is used to find the angular trajectories of each joint based on the planned position of the foot and calculated CoM. We used and developed two different inverse kinematic approaches, which were applied on the NAO humanoid soccer robot can be found in [10][11]

4.2 Omni-Directional Biped Locomotion

This section, briefly presented the design of the locomotion controllers to enable the robot with an omni-directional walking and omni-directional running. The extended details of our approach can be found in [12] [13]and [14]. Developing an omni-directional biped locomotion is a complex task made of several components.

In order to get a functional omnidirectional walk, it is necessary to decompose it in several modules and address each module independently. Figure 3, shows the general architecture of our walk engine modules and how they interact with each other to achieve stable walking. Each modules is also explains in the following.

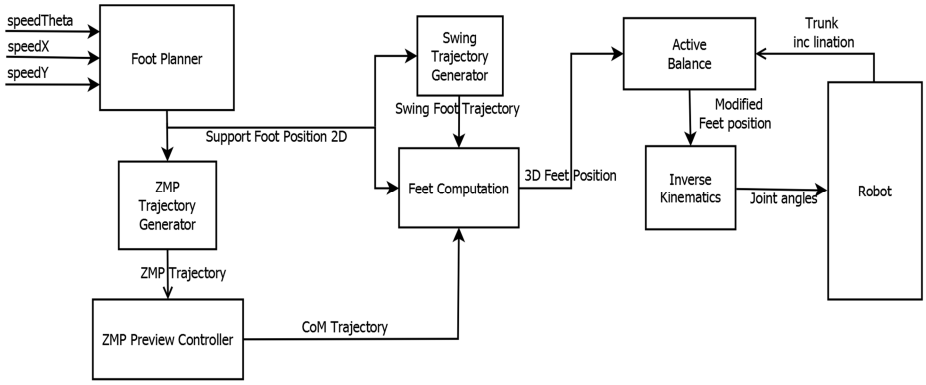

Fig. 3. Architecture of the Walk engine modules

ZMP Trajectory Generator - In this module the ZMP generated using the desired velocities. This computation takes into account only the linear component of the walk, which means to walk in any direction always looking to the same direction, like diagonal walk.

Foot Planner - One of the drawbacks of the linear inverted pendulum model is the need for a constant height. We can improve this by adjusting the CoM height using the length of the leg,

support foot position and the ground projection of the CoM. In [12] a detailed explanation is given.

CoM Trajectory generator – This module is responsible to Generate the CoM by using the dynamics equations of inverted pendulum [14] , or linear inverted pendulum [12][13].

Swing Trajectory Generator - This module is responsible to generate a tra-jectory for the swing foot. It uses the cycloid parametric equation to generate the desired trajectory.

Feet Frame Computation - After computing the support foot (ZMP) position, CoM position and swing trajectory feet position has to be computed taking into account if it is in double support phase or single (left or right) support phase. This module is responsible for computing the position and orientation of both feet relative to the CoM frame.

Active Balance - This module is where the balance of the humanoid during locomotion is controlled in order to maintain it stable. The inverted pendulum model has some simplifications in biped walking dynamics modeling; in addition, there is inherent noise in leg's actuators. Therefore, keeping walk balance generated by inverted pendulum model cannot be guaranteed. In order to reduce the risk of falling during walking, an active balance technique is applied.

The Active balance module tries to maintain an upright trunk position, by reducing variation of trunk angles. One PID controller is designed to control the trunk angle to be Zero. Trunk angles, pitch and roll, can be derived from inertial measurement unit of the robot. When the trunk is not upright, instead of considering a coordinate frame attached to the trunk of biped robot, position and orientation of feet are calculated with respect to a coordinate frame center, which is attached to the CoM position and makes the Z axes always perpendicular to the ground plane.

The transformation is performed by rotating this coordinate frame with the rotation angle calculated by the PID controller. This makes the Z axes always perpendicular to the ground plane. The feet orientation is kept constantly parallel to ground. The Transformation formulation is presented in equation (4).

$$Foot = T_{Foot}^{CoM}(pitchAng, rollAng) \times Foot \tag{4}$$

The *pitchAng* and *rollAng* are assumed to be the angles calculated by the PID controller around *y* and *x* axis respectively. Figure 4 shows the architecture of the active balance unit.

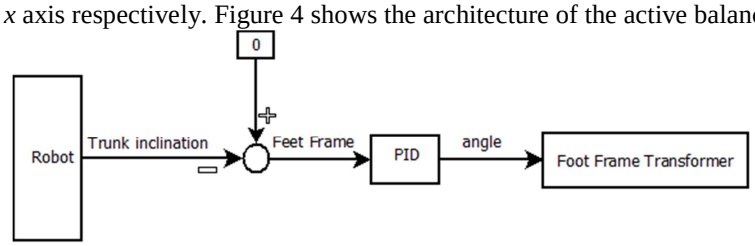

Fig. 4: Active Balance controller

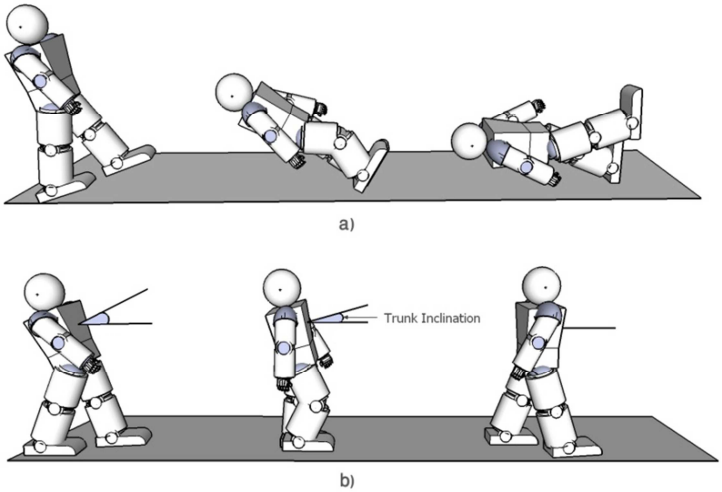

Fig 5. A scenario of walking while a robot face the inclination of the trunk, a) without using the active balance approach, b) with using the active balance approach

Running model- Many researchers, up to now, have modeled the biped walking by considering the height of Center of Mass (CoM) as a fixed constant, other biomechanical studies show that the CoM height is variant during walking and running [15]. The shape of CoM height trajectory is important for energy consumption, and it varies differently for various speeds and step length ranges [16]. Although linear inverted pendulum model (LIMP) is widely used in robotics, but robots often need to keep their knees bent in order to keep the height of CoM fixed, as the constraint of this model. Therefore, the change of the CoM height is important both for walking and running. Figure 6 and figure 7 shows a planar view of the human walking, and a walking generated by a linear inverted pendulum.

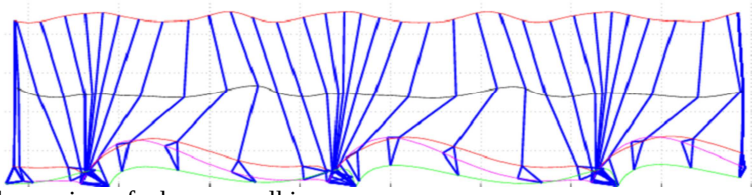

Fig 6. A planar view of a human walking

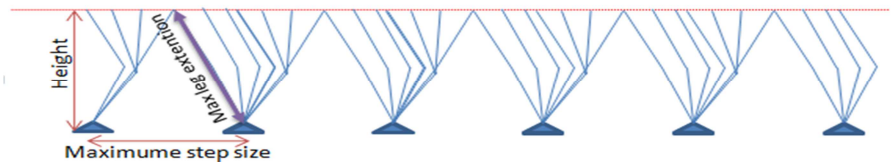

Fig 7. A planar view of a robot's walking while using the LIPM

Kagami have proposed an approach to generate walking patterns by solving the ZMP equation which can consider the CoM movement in Z axis numerically [17]. Designing the

vertical CoM trajectory is mainly studied in the context of biped running, not in humanoid walking. Kajita studied the height trajectory of the CoM that can create and modify the hopping motion [18]. In another study, the vertical trajectory is designed simply and heuristically [19]. The study of designing vertical CoM trajectory is simple up to know, and to the best of our knowledge, there is no study focused on the designing of the optimal hip height trajectory generator, particularly with respect to generate fast and stable walking.

We consider the height trajectory as the periodic movement. The CoM vertical trajectory generator is designed using the partial Fourier series. Evolutionary optimization algorithm applied in order to find the optimal hip height trajectory generator with respect to fast and stable walking. We have investigated and used the same methods in our previous walk engine [6][20][21][22].

4,1. Omnidirectional Kick

In general, kick behavior development is based on the use of static key frames for defining the trajectory of the foot. The main disadvantages of this approach are the inflexibility and the need of a preparation phase, in which the robot positions itself in order to kick the ball forward in the desired direction.

The idea of developing an omnidirectional kick is to make the kick more flexible and to kick the ball in any direction. To perform this, the robot has to compute the trajectory in real time and then make the foot follow this trajectory and propel the ball in the intended direction.

The omnidirectional kick behavior consists mainly of three modules: Inverse Kinematics module, Path Planning module and Stability module.

Fig. 8 shows some of the parameters required to develop the movement. A description of all used parameters can be seen in Table 1.

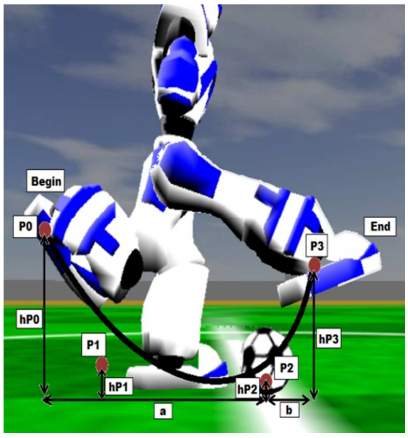

Fig. 8. Parameters used to create the movement.

Fig. 9 shows the building blocks of the behavior as well as the connections between them, inputs, outputs and generated data.

Table 1. Parameters description.

Parameter	***Description***
A	Distance from ball to curve start
B	Distance from ball to curve end
hP0	Bézier cubic curve parameters (height coordinate only). Useful to shape the curve and try different kicks)
hP1	
hP2	
hP3	
Duration	Duration of the kicking phase (see Fig. 3)
footOrientation	Angle between foot orientation and vector Ball2Target. This parameter is important to kick with different sections of the foot, e.g. front, side (inner/outer) or heel.

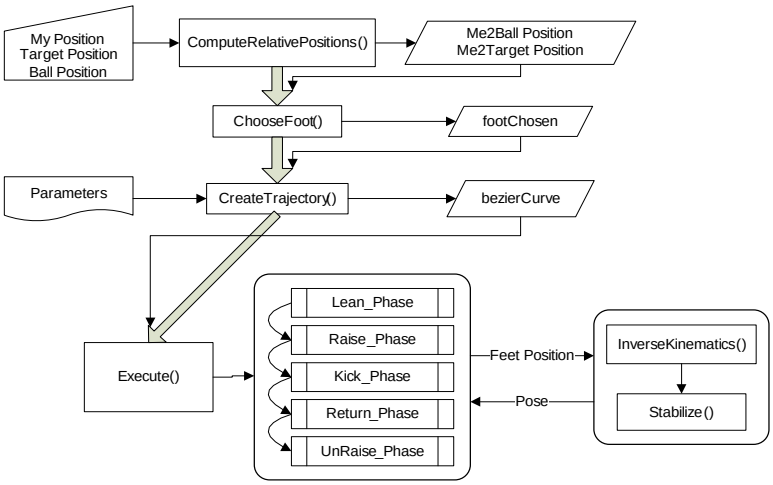

Fig. 9. Building blocks of the developed behavior.

The omnidirectional kick behavior was tested for:

- 3 positions (#1, #2 and #3) of the ball relative to the robot orientation (see Fig. 10);
- 5 kick directions (-90, -45, 0, 45 and 90 degrees), when possible.

Fig. 10**.** Ball Positions for the tests. Left is 'Position #1', center ‘Position #2’ and right is 'Position #3'

For each direction we performed the movement 10 times and 10 samples of the final ball position. We proceeded to get the average and standard deviation of the 10 samples and in the end we determined the resulting direction. These results are presented in Table 2.

Table 2. Results from the performed tests.

		-90 (x, y)	**-45 (x, y)**	**0 (x, y)**	**45 (x, y)**	**90 (x, y)**
Pos. #1	**Average (mm)**	(24, -1009)	(719, -678)	(975, -2)	(701, 681)	(31, 962)
	Standard Deviation (mm)	(17, 38)	(37, 34)	(37, 22)	(23, 43)	(16, 45)
	Direction (º)	-88.60	-43.32	-0.15	44.18	88.12
Pos. #2	**Average (mm)**	(13, -989)	(758, -741)	(1082, 2)	(721, 676)	(31, 997)
	Standard Deviation (mm)	(7, 21)	(41, 40)	(44, 4)	(31, 40)	(26, 36)
	Direction (º)	-89.20	-44.37	0.12	43.15	88.19
Pos. #3	**Average (mm)**	(11, -991)	(693, -697)	(1053, -29)		
	Standard Deviation (mm)	(3, 23)	(22, 22)	(34, 18)		
	Direction (º)	-89.35	-45.15	-1.59		

By examining the results obtained from this test we can see that the behavior can perform the movement and propel the ball in various directions. The direction value only differs a few degrees from the intended target direction, which confirms the accuracy propelling the ball. We can control the kick power by adjusting both the kick duration and the initial and final position.

The conclusion we take from these tests is that: if we configure the parameters of the behavior with some accuracy, we can get very good results. The problem is that, sometimes, it is not so easy to get the best parameters, becoming necessary the use of optimizers.

5. High-Level Decisions and Coordination

Flexible Tactics has always been one of the major assets of FC Portugal teams. FC Portugal 3D is capable of using 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]. Player's abandon their strategic positioning when they enter a critical behavior: Ball Possession or Ball Recovery. This enables the team to move in a quite smooth manner, keeping the field completely covered.

The high-level decision uses the infrastructure presented in the section 3. Several new types of actions are currently being considered taking in consideration the new opportunities opened by the 3D environment of the new simulator. 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, 23];
- Concepts of Tactics, Formations and Player Types [1, 3, 4, 23];
- 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, 24];
- Optimization based Low-Level Skills [1, 3, 28, 29].
- 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 robosoccer teams [25].

In 2012, 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 2013 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 [26] and rescue teams [27]).

6. Conclusions

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

Robust low-level skills have been developed for the NAO humanoid model, The results of low-level skills have already tested and validated on the real NAO robot, since it is based on the physical modeling of the dynamics of biped locomotion it is very robust and with minimal adaptation was used on the NAO robot. 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. Also the extended flexibility of omnidirectional kicks and walks will enable a more cooperative game style.

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 started its participation in the SPL - Standard Platform League in 2011. The SPL code of the team is entirely made from scratch based on the Simulation 3D code. Thus, future work will be on bridging the gap between simulation and robotics by developing a more realistic NAO model in Simspark enabling better portability of the simulated code to the real robot.

Acknowledgements

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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. S. Kajita, F. Kanehiro, K. Kaneko, K. Yokoi, and H. Hirukawa, "The 3D linear inverted pendulum mode: a simple modeling for a biped walking pattern generation, in IEEE/RSJ International Conference on Intelligent Robots and Systems, 2001, pp. 239–246.
9. M. Vukobratovic, D. Stokic, B. Borovac, and D. Surla, *Biped Locomotion: Dynamics, Stability, Control and Application*. Springer Verlag, 1990, p. 349.
10. Rui Ferreira, Luís Paulo Reis, António Paulo Moreira, Nuno Lau, Development of an Omnidirectional Kick for a NAO Humanoid Robot In Advances in Artificial Intelligence – IBERAMIA 2012, Lecture Notes in Computer Science, Volume 7637, Springer, 2012, pp.571-580

11. E. Domingues, N. Lau, B. Pimentel, N. Shafii, L. P. Reis, A. J. R. Neves, Humanoid Behaviors: From Simulation to a Real Robot , 15th Port. Conf. Artificial Intelligence, EPIA 2011, LNAI 7367, pp 352-364, 2011.
12. Shafii, N., Abdolmaleki, A., Ferreira, R., Lau, N., & Reis, L. P. Omnidirectional Walking and Active Balance for Soccer Humanoid Robot. InProgress in Artificial Intelligence (pp. 283-294), 2013.
13. Ferreira, Rui, Nima Shafii, Nuno Lau, Luis Paulo Reis, and Abbas Abdolmaleki. Diagonal walk reference generator based on Fourier approximation of ZMP trajectory. In Autonomous Robot Systems (Robotica), 2013 13th International Conference on, pp. 1-6, 2013.
14. Nima Shafii, Abbas Abdolmaleki, Rui Ferreira, Nuno Lau, Luis Paulo Reis, Towards Fast Walking based on ZMP Control and Central Pattern Generator. Proceeding of Dynamic walking 2013, Carnegie mellon university, 2013.
15. Kuo, A. D., Donelan, J. M., & Ruina, A. Energetic consequences of walking like an inverted pendulum: step-to-step transitions . Exercise and Sport Sciences Reviews, 33(2), 88–97, 2007.
16. Srinivasan, M., & Ruina, A. Computer optimization of a minimal biped model discovers walking and running. Nature, 437(7057), 72–75, 2014.
17. Kagami, S., Kitagawa, T., Nishiwaki, K., Sugihara, T., Inaba, M., & Inoue, H. A fast dynamically equilibrated walking trajectory generation method of humanoid robot. *Autonomous* Robots , 12(1), 71–82, 2002.
18. Kajita, B. Y. S., Nagasaki, T., Kaneko, K., & Hirukawa, H. ZMP-Based Biped Running Control , , 63–72, IEEE magazine, 2007.
19. Tajima, R., Honda, D., & Suga, K. Fast running experiments involving a humanoid robot IEEE International Conference on Robotics and Automation ,pp. 1571–1576, 2009.
20. 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. IEEE Int. Conf. on Automation and Logistics, pp. 2018-2023, 2009.
21. Shafii, N., Reis, L. P., & Lau, N.. Biped Walking using Coronal and Sagittal Movements based on Truncated Fourier Series. In Javier Ruiz-del-Solar, E. Chown, & Paul-Gerhard (Eds.), RoboCup 2010: Robot Soccer World Cup XIV , pp. 324–335, 2011.
22. 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.
23. 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.
24. 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
25. 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
26. 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
27. 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
28. Luis Rei, Luis Paulo Reis and Nuno Lau, Optimizing a Humanoid Robot Skill, Robótica 2011 - 11th International Conference on Mobile Robots and Competitions, pp. 78-83, Lisbon, Portugal, 2011 (Best Paper Award)
29. Luis Cruz, Luis Paulo Reis, Nuno Lau, Armando Sousa, Optimization Approach for the Development of Humanoid Robots' Behaviors, In Advances in Artificial Intelligence – IBERAMIA 2012, Lecture Notes in Computer Science, Volume 7637, Springer, 2012, pp. 491-500