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 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]. 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 and 2012). This paper describes some of the main innovations of our 3D simulation league team relating them with previous work developed by simulated RoboCup teams in 2D and 3D simulation leagues. 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, developing omnidirectional walking engine and omnidirectional kick engine and integrating high-level coordination mechanisms. Very good results were already achieved, in 2011 and 2012, 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 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 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 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. 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: 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.

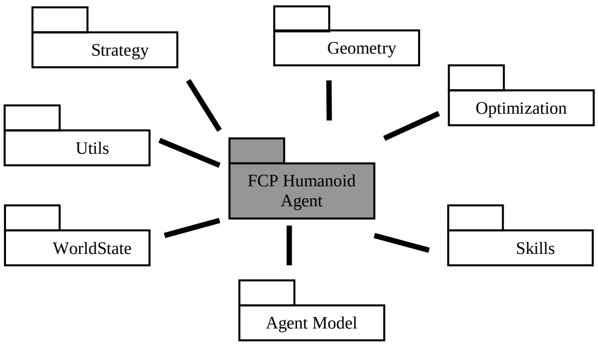

Fig. 1: FCP Humanoid Agent Architecture

4. 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="torso" mass="1.2171" />
  <bodypart name="lhip1" mass="0.09" />
  <bodypart name="rhip1" 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 this information as, for example, the direct kinematics transformation matrices and useful measures as is the case of the center of mass, which is used to ensure more stability on each generated behavior. This strategy keeps the code more generic and independent of the model, allowing for an easy integration of different models using the same code, which may allow the future integration of heterogeneous robots.

5. 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 [21].

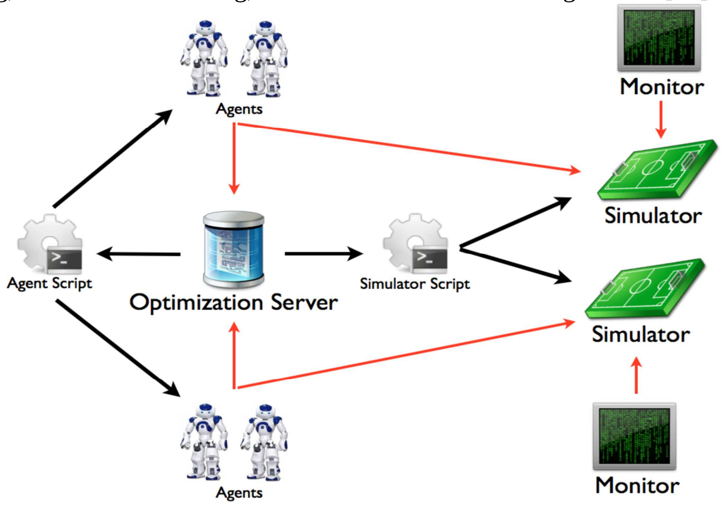

Fig. 2: Optimization Methodology Architecture

The new skills optimizer was developed to allow any skill of the agent to be optimized using either a single computer or multiple computers connected via a network. Figure 2 is a diagram representing the configuration of the optimizer. Once started with the proper parameters, 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 the agents the performance data from that execution. Both these connections are made via TCP sockets.

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 which provides an agent with the behavior to optimize and waits for the agent to finish executing the behavior, receives the experimental data sent by the agent and evaluates it, giving that generated behavior a score according to an objective function.

Behaviors are specified and stored as XML files which are loaded when an agent starts. The optimization server reads the behavior XML file and loads 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 to be executed. An agent script, specific to each behavior to optimize, is responsible for starting the FCP agents and providing them with their parameters. This allows the agents to be started on the local machine or in a remote machine. Another shell script is responsible for terminating the agents. The scripts exist for both flexibility and to isolate the server from the specifics of other components.

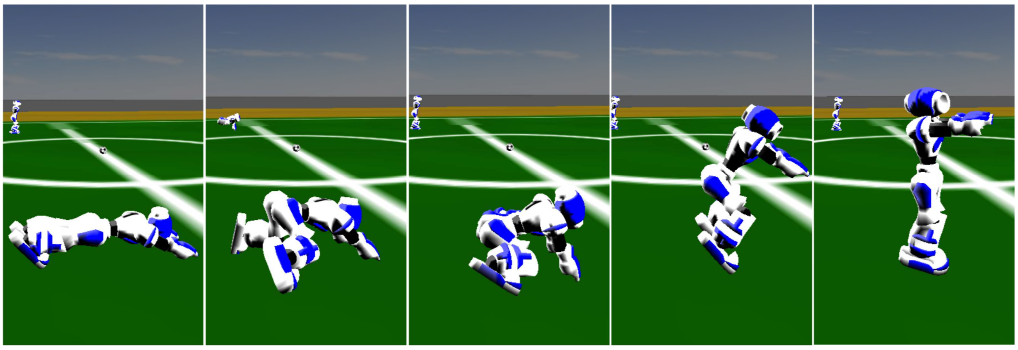

Fig. 3: Sequence of images showing the execution of the behavior specified by GetupFront.xml

The optimizer was already applied with success to optimize several skills such as the getup front skill (fig 3), getup back skill and kick skills. It will be applied to other skills and to compound skills in a near future. Results from the optimization of the getup front skill are shown in figure 4.

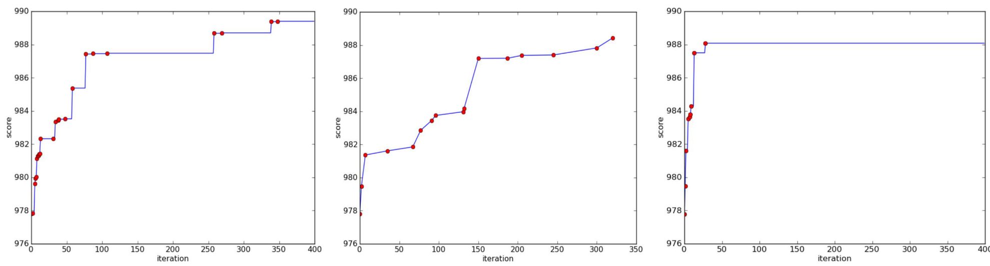

Fig. 4: Results for the Get Up optimization: a) Hill Climbing, b) Simulated Annealing, c) Tabu Search

The final time achieved for the get up front skill was 1.1 seconds optimizing an initial manually hand tuned skill that took 2.0 seconds to be executed. Very good optimization results were also achieved for the get up back and kick skills. For this last skill, a distance of 5.1 meters with strong robustness to variations in the initial robot to ball relative positions, was achieved. A maximum kicking distance of 6.4 meters was achieved maximizing only the final kicking distance parameter.

6. OmniDirectional Kick

In general, kick behavior development is based on the use of static keyframes 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.

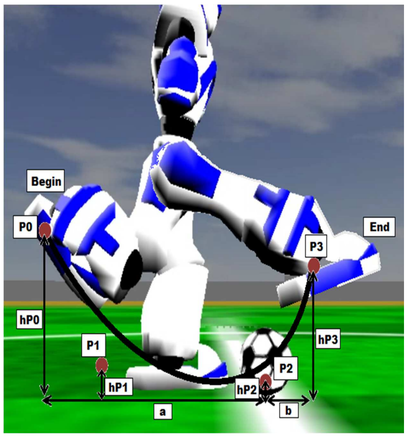

Fig. 5. Parameters used to create the movement.

Fig. 5 shows some of the parameters required to develop the movement. A description of all used parameters can be seen in Table 1.

Fig. 6 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.

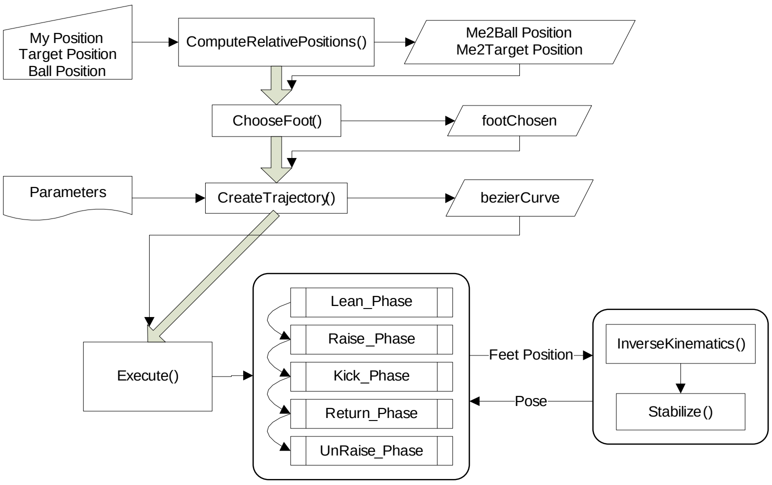

Fig. 6. Building blocks of the developed behavior.

6.1 Omnidirectional Kick Tests

The omnidirectional kick behavior was tested for:

- 3 positions (#1, #2 and #3) of the ball relative to the robot orientation (see Fig. 7);
- 5 kick directions (-90, -45, 0, 45 and 90 degrees), when possible.

Fig. 7. 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. This 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.

7. OmniDirectional Walk

Biped walking can be modeled using the movement of ZMP as reference. From the desired ZMP trajectory using a simplified model of the robot dynamics (cart-on-a-table) the trajectory of the CoM can be computed. Two sets of cart-table models are used for 3D walking. One is for the movements in frontal plane; another is for movements in coronal plane. The semantic view of a cart-table is shown in Fig. 8.

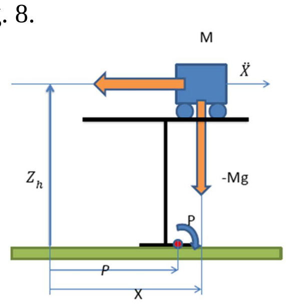

Fig. 8. Schematic view of Cart-table model and a humanoid robot

The main issue of applying Cart-table Model is how to solve its differential equations. An alternative robust CoM trajectory generation method can be found in [22][23], in which the solution of the Cart-pole model differential equation is approximated based on Fourier representation of the ZMP equation. Kajita et. al also present an alternative approach to calculate the position of the CoM from the cart-table model. This approach is based on the preview control of the ZMP reference.

We extended the work in [22] to endow the robot with a diagonal walk. First, the reference trajectory for the ZMP is formulated, and then it is approximated by using Fourier series. Finally, the position of the CoM is obtained by solving the differential equations of the cart-table dynamics. Fig. 9 shows the position of feet, on the ground plane, over t seconds, while walking diagonally.

the CoM reference trajectory is obtained by solving the Cart-Table model. Position trajectories of the swing foot are generated through Bézier curve based on predefined footsteps. The swing foot orientation is also kept parallel to the ground to reduce the effect of the contact force. Joint angles are calculated based on swing foot positions and CoM references by using inverse kinematics, then joints are controlled by simple independent PID position controllers.

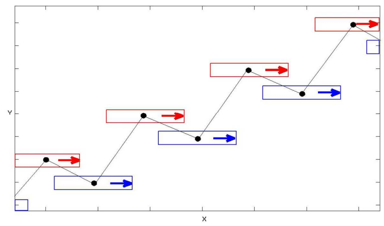

Fig. 9. Foot steps of a diagonal walking

CoM reference and CoM position projection on the ground plane for the walking scenario, which has 15 cm/s speed in X direction and 15 cm/s in Y direction, are shown in fig. 10. The generated reference CoM trajectory and execute CoM trajectory by the robot are shown in blue and red line respectively.

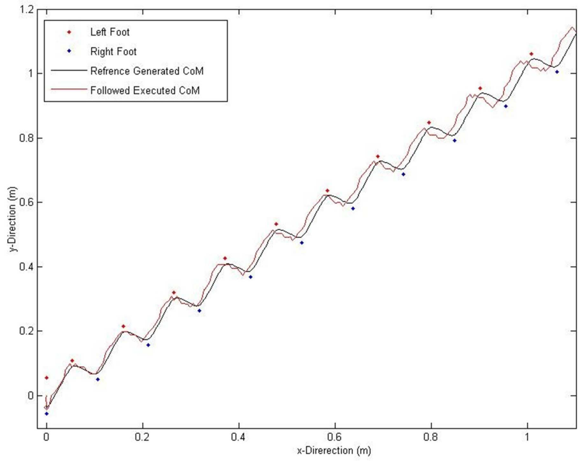

Fig. 10. CoM trajectories for a 15cm/s diagonal walk

8. 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, 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, 24, 25].
- 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 [18].

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 [19,] and rescue teams [20]).

9. 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, 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 already lead to good results on optimizing the kick and getup skills. 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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