RoboFEI 2019 Team Description Paper

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Abstract. This paper presents the current state of the RoboFEI Small Size League team as it stands for RoboCup International Small Size League competition 2019, in Sydney, Australia, as well as works that are still under development. The paper contains descriptions of the mechanical, electrical and software modules, designed to enable the robots to achieve playing soccer capabilities in the dynamic environment of the Small Size League.

1 Introduction

For the RoboCup 2019, the RoboFEI team intends to use the same electronics and mechanical design that have been used over the last years, as shown in Figure 1. Some significant advances were made in our software and firmware, which was verified in the XVII Latin American Robotics Competition (LARC). We have also been able to assemble the first prototype of our new mechanical structure. Our aim now is to improve the recently built software system and the mechanical design. With our researches, we hope to bring innovations and new ideas for the community.

2 Electronics

Since RoboCup 2014, RoboFEI's team released the current electronic design as open source to the community. All the schematics, layouts and firmware are available on-line, under a Creative Commons license, in RoboFEI's web-site *(www.fei.edu.br/robofei)*. Currently, the electronic hardware remains the same update of last year, the components description are shown in table 1.

2.1 Updated Wheel Control System

We currently use a distributed control system, where, some decisions and controlling actions are made in the high-level AI software, such as determining which velocity the robot should move to reach a desired point in the field, and another

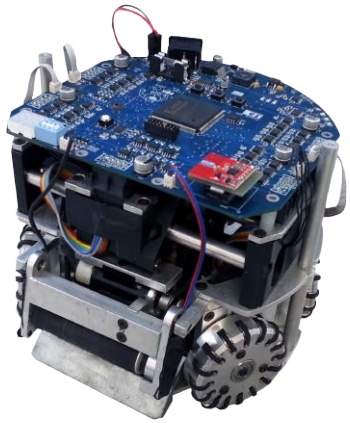


Fig. 1. RoboFEI's Robot.

Table 1. Current Electronic Description.

Device	Description
Main Board	CPU: Xilinx Spartan 3 FPGA operated with 50 MHz clock
MOSFET Driver	TC4427 working with IRF7389 MOSFET
Current Sensor	ACS712 with A/D converter AD7928
Kick Board	Boost converter topology.
Kick Storage	Two capacitors of 2700 μF, in parallel, charging up to 160V in 16s.
Kick MOSFET	IRFSL427, Id 72A DC.
Driving Motor	Maxon,EC-flat-45 50W with hall sensor.
Dribbling Motor	Maxon EC-max-22 25W with hall sensor.
Ball Sensor	TEFT4300 infra-red emission diode and photo diode pair.
Communication	nRF24L01 transceiver, 2 Mbps, 2.4/2.5 GHz.
Power Supply	LiPo, 3-cells (11.1V) and 2250 mAh capacity.

part of the control is done in the embedded firmware. To improve the performance of the robot it was studied and delimited what each part should do and how.

We fixed that all robots should receive its movement information in its own referential as V_x, V_y and $\dot{\omega}$, which are its velocities on X, Y axes and the angular velocity on its own axis respectively. The referential used was that the Y axis is perpendicular to the front of the robot and the X axis is to the right of the robot.

In order to do this, all of the kinematics were remodeled and programmed into the firmware, this can be seen in Equation 1.

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} = \begin{bmatrix} -sin(\phi) & -cos(\phi) & 1 \\ sin(\phi) & -cos(\phi) & 1 \\ sin(\phi) & cos(\phi) & 1 \\ -sin(\phi) & cos(\phi) & 1 \end{bmatrix} * \begin{bmatrix} V_x \\ V_y \\ \dot{\omega} \end{bmatrix} \quad (1)$$

Where v_i is the velocity for each of the four wheels and ϕ is the angle of each wheel, which in our case is 33º for the old structure and 32º for the new one.

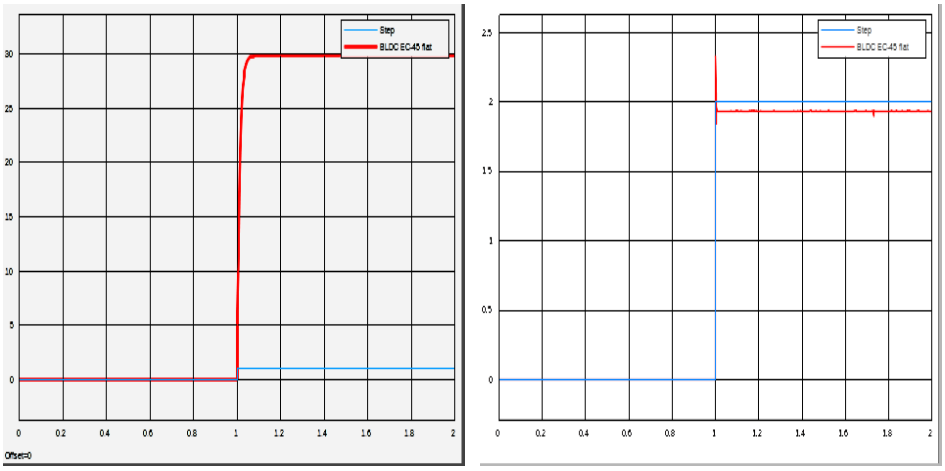
We also parameterized all velocity values on firmware and high-level software to work on the range from -100 to $+100$, where each 10 units represents approximately $0.2m/s$ for the X and Y axis.

To obtain the transfer function of the motor we've used its data sheet. The transfer function used by the team is shown in Equation 2 and was implemented using MATLAB and Simulink.

$$\frac{\dot{\theta}(s)}{V(s)} = \frac{33.5 * 10^3}{77.355 * 10^{-4} * s^2 + 13.203 * s + 1122.25} \tag{2}$$

Where $\dot{\theta}(s)$ is the angular velocity of the motor, $V(s)$ is the voltage applied and s is the Laplace complex variable.

The step response in open loop of the system is shown in Figure 2(a) and in closed loop in Figure 2(b). Where the red curve is the system output and the blue one is the step input.



(a) Open loop (b) Closed loop

Fig. 2. Step response.

Utilizing the recommendations for sintonizing controllers it is possible to have zero steady-state error and decrease the overshoot in closed loop [2]. The system output in closed loop with a PI controller can be seen in Figure 3.Where the red curve is the system output and the blue one is the step input.

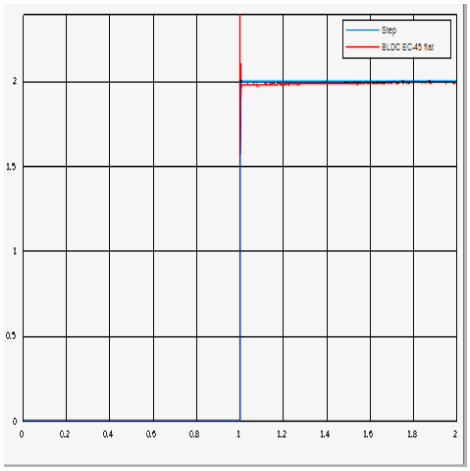


Fig. 3. System ouput after sintonizing the controllers.

The overshoot right after the step occurs given that there is no load on the motor and is not relevant to the performance of the robot. The equation of the controller can be seen in Equation 3.

$$u(s) = 3 + \frac{5}{s} \tag{3}$$

And the gains are: $P = 3$ and $I = 5$.

We've noticed that after the new controller we are able to reach higher velocities than before while maintaining control of the robot.

3 Mechanics

We've developed a new mechanical structure last year, however, it still needs some adjustments before testing in an actual game.

One of the disadvantages of the old structure is that it was made in its majority of steel parts, which made the robot quite heavy and expensive. The new structure is mostly made of 3D printing, which makes our robots lighter, faster and cheaper than the old ones. The new structure can be seen in Figure 4. Currently we aim to participate in division A and be a competitive team in it, to achieve this, most of our effort are in reducing the cost to produce more robots whilst maintaining its quality, in order to reach eleven robots.

Other disadvantage which led us to change our structure was the high maintenance time, mainly in the championships, where the time to do it is short. For example, to remove the new wheel set it is not necessary to disassemble the whole structure as it did before, now it is only fixed by two screws on the lower plate.

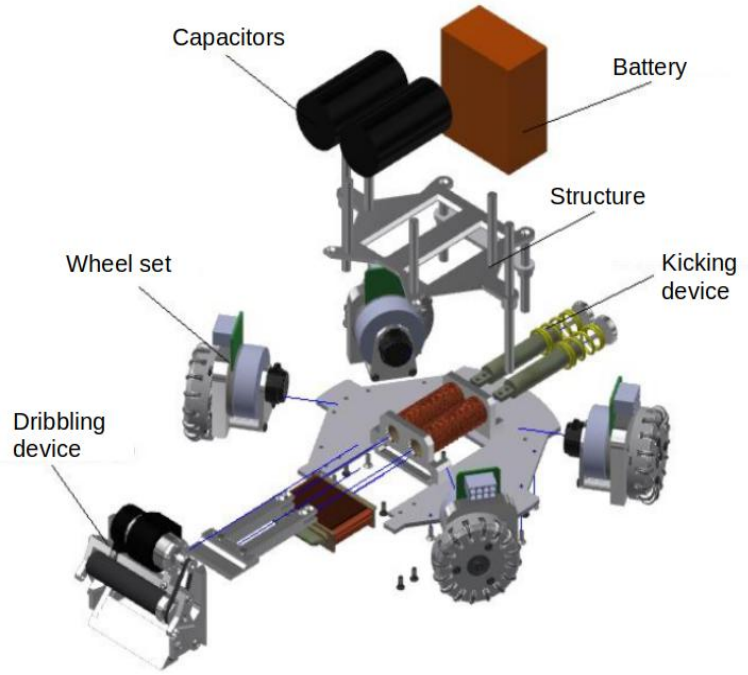


Fig. 4. Exploded view of the new structure.

Our new structure is based on a methodology called Reliability-Centered Maintenance (RCM). It is defined in [3] that RCM is a process used to determine what must be done to ensure that any structure continues to do what the users want throughout its whole life cycle.

The main results expected when using RCM are: improvement in the quality of the product, greater efficiency in maintenance and longer life cycle for expensive actives [3]. All of these aspects have great importance in our case where maintenance time is crucial between games and there are a lot of expensive parts in our robot, for example, the motors and some machined parts.

Using this methodology the new structure has reduced the maintenance time in 14% and now includes the directional kick. Since we plan on having eleven robots in the future, it's important that the maintenance of each doesn't take much time. This time was estimated as the time it took to someone who never assembled or disassembled the robot to disassemble and assemble it.

In order to use the RCM, the first step was to define the functions that the robot needs to accomplish, these were divided into primary and secondary, which are:

- Primary: Move and kick;
- Secondary: Dribble, pass and chip kick.

Given these functions it is desired that the robot can execute at least the primary ones.

Then it was determined which of the systems that compose the robot that are primary or secondary, here it was created a hierarchy diagram that represents this, it can be seen in Figure 5, the primary systems are in blue and the secondary are in red. The structural set is the one that integrates all the other systems, it is the one used to fix the batteries, capacitors and boards on the robot.

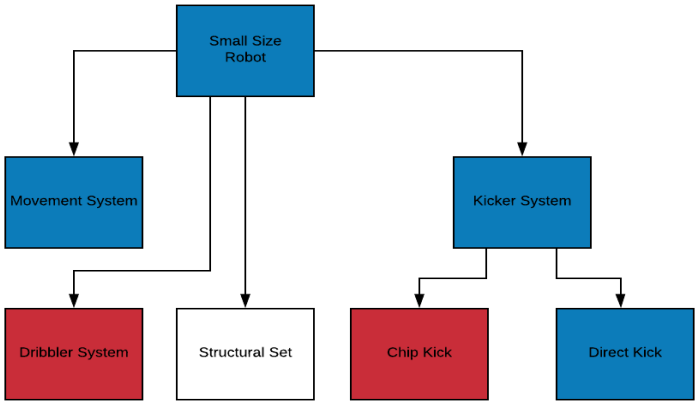


Fig. 5. Systems that compose the robot.

The next step was to create the Failure Mode and Effect Analysis (FMEA) spreadsheets to all the systems of the robot, here there will be only a example to show how this was done to the direct kick system. As seen on Table 2, on the header there are some information recommended by the authors followed by the system function. On the second column there are the possible functional failures of the system, these were identified given some laboratory and past competitions experience as well as the rules of the game.

Moving on with the FMEA, it was needed to list the causes and effects of the failures, it is important to note that here will only appear causes related to the mechanical aspect of the robot. In order to list the causes all team members were consulted, the result can be seen on Table 3.

Now it is need to evaluate the Risk Priority Number (RPN) which is the product of the severity (S), occurrence (O) and detection (D) of a given failure.

The criterion used to classify severity was that if a failure resulted in the robot not executing a primary function it would be given a value of 9 and if the failure resulted in a violation of the rules of the game it would be given a value of 10. For serious failures it would range from 6 to 8, and below 6 would be the failures that the team can still play a match without major consequences.

Table 2. Function and failures of the direct kick system.

Project:	RoboFEI Small Size
Sector:	Mechanic
System:	Direct Kick
Set:	Direct Kick
Author:	Vinicíus Medeiros Alves
Function	Functional Failures
	Not kicking the ball
Kick the ball in a straight line while	Kick with a speed higher than 6.5 m/s
maintaining contact with the ground.	Not kick in a straight line
	Make the ball bounce

Table 3. Effects and causes of the direct kick system.

Functional Failures	Effects	Causes
Not kicking the ball	Unable to score	Broken rubber band;
	a goal or pass.	Solenoid piston stuck;
		Ball Sensor misaligned;
		Piston axis unscrewed;
		Unscrewed kicker;
		Solenoid short circuited to the structure.
Kick with a speed	Violates the rules	Over dimensioned solenoid;
higher than 6.5 m/s	of the game.	Unregulated capacitor discharge time.
Not kick in a	Makes it harder to	Gap between the kicker and its axis;
straight line	execute some skills.	Unscrewed kicker.
Make the ball	Unable to score	Kicker hitting outside the center of the ball;
bounce	a goal or pass;	Ball stuck underneath the roller.

Since the occurrence is the rate that a given failures occurs, this was a little harder to evaluate, the values for each failure were defined based on the experience from past competitions, laboratory tests and the documentation of previous maintenances of the robots.

The detection is related to the method used to identify each failure, in our project it ranged from 5 to 1.

The S, O, D and RPN values for the direct kick system can be seen on Table 4. The failures with the highest RPN should be treated as fast as possible, since they represent a severe negative effect on the performance of the robot.

Table 4. Control, Severity, Occurrence, Detection, RPN and Recommended actions of the direct kick system.

Functional Failures	Control/Detection	S	O	D	RPN	Recommended Actions
Not kicking	Functionality tests.	9	7	2	126	Project revision;
the ball						Preventive and corrective
						maintenance (The priority is
						to lower the occurrence)
Kick with a speed	Adjustments using	10	5	2	100	Project revision
higher than 6.5 m/s	the Auto Referee					(Avoid both of the
						failure modes).
Not kick in a	Assembly revision and	7	7	2	98	Project revision;
straight line	visual inspection					Corrective maintenance.
Make the ball	Visual inspection	7	5	2	70	Project revision
bounce						(Avoid the failure modes).

This way, given the RPN for each failure of the system it is possible to determine which part of the robot should receive a more detailed maintenance or a special attention when projecting its mechanical components. These steps were applied on all of the systems of our robot and based on that it was decided which sets needed a complete rework.

Using the RCM method described here, one of the systems that needed a rework was the encoder support. To avoid their misalignment a new support was created, it can be seen in Figure 6, they are now fixed by two rods in the lower part of the motor support, this way we avoid shocks caused by other robots to interfere with the encoders, also, with this geometry we were able to standardize the encoder support, this facilitates the machining of them. The support must be made of aluminum because the encoder plate holes comes from the manufacturer with 2.5mm metric threads and after a few tests with 3D printing we found that trying to print threads smaller than 3mm would not give us a good result, no matter how we did the configuration of the printer.

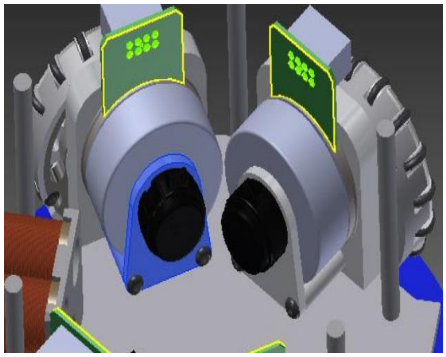


Fig. 6. Final geometry of the encoder support in blue.

4 Software

As said in our latest TDP [4], we were developing a whole new software for the team. Now we are almost done implementing all the basic functions needed, a few of the new features will be shown here.

4.1 Software Structure

Given that handling all the interface events can use quite a lot of processing in some situations, therefore we've decided to have multiple threads handling certain parts of our software. In the current moment we have three threads in total, in which, the first is used to handle everything related do the interface, receiving data from the SSL Vision and SSL Refbox, sending and receiving data to the robots. The second thread is used to process the states of the game, Referee commands, calculate the positioning of the robots, decide which robot should be a defender or attacker, calculate the position of the goalie and trajectory of each robot using the path-planner. And the third thread is used only to maintain a real-time loop for the motion control of the robots.

We still aren't using a sophisticated controlling technique to control the position of our robots, but in a near future when it is implemented there will already be a functional environment to run the controller, currently this real-time loop runs in an interval of less than $15ms$, and it is fixed that it will only return an information in the end of this period, this guarantees for us that approximately every $15ms$ our robots are receiving information correcting their velocities.

Since we are using QtCreator, all the communication between threads are done using the signal and slot mechanic, this way the information is sent simultaneously from the first thread to the second and third. Currently the threads work asynchronously, but the data shared between them is protected using a mutex. There are no priorities over which thread signal should be treated first, there is only a delay on the second thread of about five times the time consumed

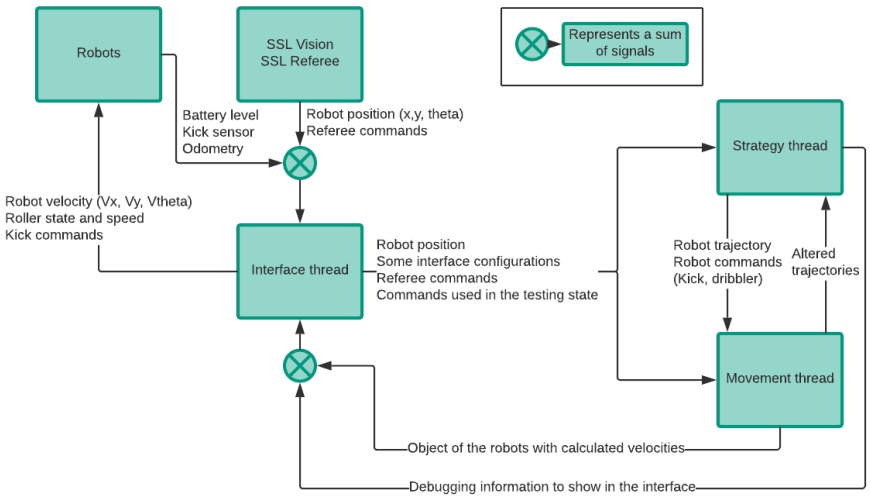


Fig. 7. Current software structure.

in one loop of the third thread, thus, the second thread generates a signal approximately every $75ms$. This response time is still being adjusted, since it must be guaranteed that all processing is done within this period. In Figure 7 it is illustrated how this works.

4.2 User Interface

Some problems we've had with our past software versions were the lack of organization on the interface and absence of configurable characteristics of the robots and skills.

The new software has only three tabs. The first is the tab used in game game, it contains the image of the field, some information's about the robots, like battery level, kick sensor and current skill, this tab can be seen in the Figure 8. The second tab is used for configuration of all the parameters available, a few of them are, serial port of the radio, SSL Vision and SSL Referee connection parameters, some constants used in skills and many others, this tab can be seen in Figure 9. The third tab is completely dedicated to do various tests with our robots, this facilitates discovering bugs in the software and mechanical/electronic problems with the robots such as bad contact in some connections of the board, this tab can be seen in Figure 10.

4.3 New Positioning System

The PSO proposed by [5] is an optimization algorithm based on a population of particles that have obtained recognition in the solution of several problems, with

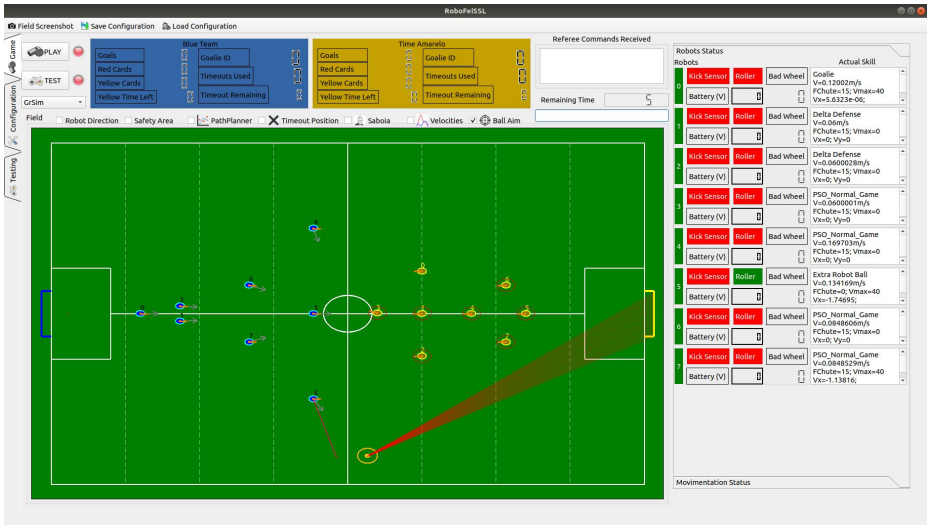


Fig. 8. In game tab.

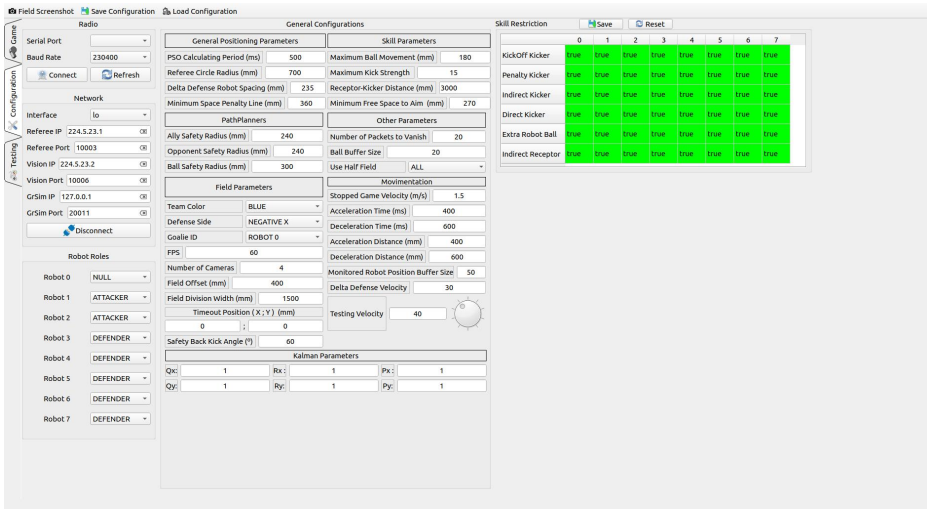


Fig. 9. Configuration tab.

simplicity and using few computational resources. The PSO algorithm objective finds an optimal solution in a search space, through the exchange of information between individuals of a population determining which trajectory each individual should take in the search space.

The velocity V and the position P of the particles is updated from the equations 4 e 5 respectively:

Fig. 10. Testing tab.

$$V_{ir}(t+1) = \omega V_{ir}(t) + c_1 r_1 (pbest(ir,t) - P_{ir}(t)) + c_2 r_2 (gbest(t) - P_{ir}(t)) \tag{4}$$

$$P_{ir}(t+1) = P_{ir}(t) + V_{ir}(t+1) \tag{5}$$

Where V denotes velocity, ir is the robot r from particle i, ω is the inertia factor used to balance global and local exploration, r_1 (cognitive part) r_2 (social part) are randomly distributed in the range $[0, 1]$, and c_1 (confidence parameter for the cognitive part) and c_2 (confidence parameter for the social part) are constant parameters called acceleration coefficients.

According to [6], a soccer match is divided into two attitudinal concepts: defense and attack. Being that defense of a team must a) cancel the finishing situations, b) recover the ball, c) prevent the opponent from progressing, d) protect the goal and e) reduce the opponent's playing space; and in the attack: a) maintain possession of the ball, b) build offensive actions, c) progress through the opponent playing field, d) create situations of finalization and e) finalize in the opponent's goal. These attitudinal concepts and other tactical principles will be prioritized in the development of objective functions applied to the defense positioning.

To test the possibility of applying the PSO algorithm, in Latin American Robotics Competition (LARC) 2018 some mathematical functions were implemented to calculate defensive positions according to the following rules:

– The minimum distance of the robots in relation to the opponent to make it difficult to move and the possibility of receiving or making passes or kick to goal;

– If the view of the robots in relation to a certain point (in this case, the goal) is blocked;
– If all opposing robots have at least one allied robot blocking the view of the goal, prioritizing the opposing robot with possession of the ball.

Initially, the grSim simulator [7] was used to validate the proposal in a real game situation as seen on Figure 11.

The algorithm runs every 200ms and the previous solution is always passed to the new run. The algorithm returns the positions of the robots and the strategy system decides which robot moves to each position (based on the shortest distance).

Fig. 11. grSim.

Tests conducted during LARC 2018 have shown that this approach can be used to find field placements during an SSL soccer game, especially in non-stop play. However, with the active game it is necessary to predict the possible movements of the opposing robots to calculate the future positioning of the robots of the team, being this the main challenge for the next competition. Other objective functions are being developed and tested to improve defense positioning (without possession of ball) and also in attack (with possession of ball).

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