Artificial Immune Systems, A New Computational Technique for Robot Soccer Strategies

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1. Introduction

Over last decades a computational intelligence technique has take more action field in engineering, this method based on biological systems provides new solutions to tackle a wide range of engineering problems. This technique is the Artificial Immune Systems (AISs) (DeCastro&VonZuben,2000), which utilizes metaphors from the immune systems in order to solve problems. From different studies and investigations, multiples techniques had surged such as negative selection, immune networks, clonal selection and others. Precisely a new technique thrives inside on AIS, its name: Danger Theory. In this chapter we used some methods for develop robot soccer game strategies.
Robot soccer presents a dynamic environment where it is possible to implement and test diverse and new computational designs. In robot soccer, specifically, SIMUROSOT from FIRA (website,2006), there are two leagues: middle and large leagues. In actual work, first one was used.
In this chapter, robot soccer strategies based on natural immune response are presented. Due to the adaptability of natural immune system with unknown pathogen, the algorithms presented carry on this feature in order to play a robot soccer game. As well as their biological inspiration, strategies based on natural immune response are exposed in several situations unknown that offer the Robot Soccer Game.

2. Background

Many fields of science have problems with systems and process identification become on inconvenient what need to be controlled. Most cases a complex process of control is used, but the best control in these cases is an adaptive control; for this reason new techniques are necessary to engage several dynamical environments, such as Robot Soccer. The researches trends towards biological inspiration because of its adaptability, some of these are: Neural networks, genetics algorithms, swarm and, recently, immune systems. Some characteristics of immune systems are learning, distributed process and memory; these features are ideals for Robot Soccer since they can provide a cognitive behaviour emergent where several agents form a team looking for same objective.

2.1 Some works related

There are several works on Robot Soccer; most of them are focused to generate highly competitive teams providing in this way more reactive teams than deliberative teams. Some works related with this chapter are described as follows. A work what develops its strategy with Artificial Immune Systems (AIS) is showed in (Guan-Chun et al 2006). Basically the strategy enables one robot in order to *select* one behaviour between pass, kick, shoot, follow and protect. For strategies evaluation, the middle league from FIRA is used; the player robot *takes a decision* by using an artificial neural network implementing on this way an action to execute. In (Guan-Chun et al 2006) an antigen is represented by environmental information, besides each robot had 6 antibodies (see figure 1) that they correspond to actions or behaviours mentioned before. In order to calculate Antigen-Antibody affinity a fuzzy logic system is used. This combination AIS-Fuzzy logic presents good results and it offers a interesting tactic for robot soccer games.

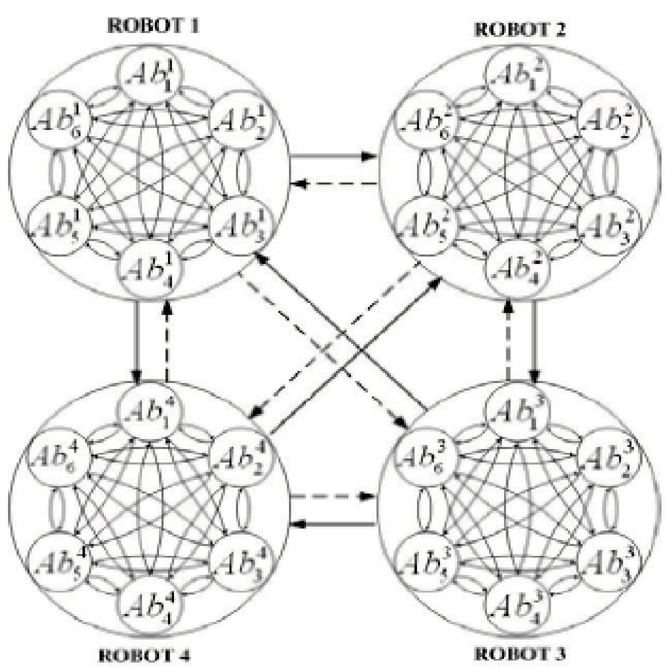

Fig. 1. Immune network used in (Guan-Chun et al 2006)

Neuronal networks, in special, a Multilayer Perceptron –MLP- is used in (Hwan at al,1997) to make learning process; however a Action Selection Mechanism (ASM) is in charged of *make* an action according to play role (see figure 2). The play roles used in that work are goalkeeper, back –defense- and forward. As well as on this work, research is focused into adaptation in dynamical systems.

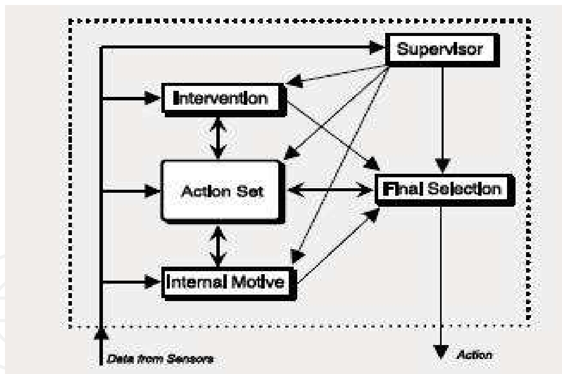

Fig. 2. ASM structure used in (Hwan at al, 1997)

In (Yu-Hwan,2005) fuzzy logic is utilized to control speed and trajectory of each robot. It also implements a "genetic regulatory network" which uses a concept of the bioinformatics field based on how genes are involved in controlling intracellular and intercellular processes. In this way play roles are assigned dynamically. Its biological inspiration for the robot soccer environment showed good results. In Figure 3 shows the system architecture implemented. Like the previous work, the comparison is restricted to the computational model used.

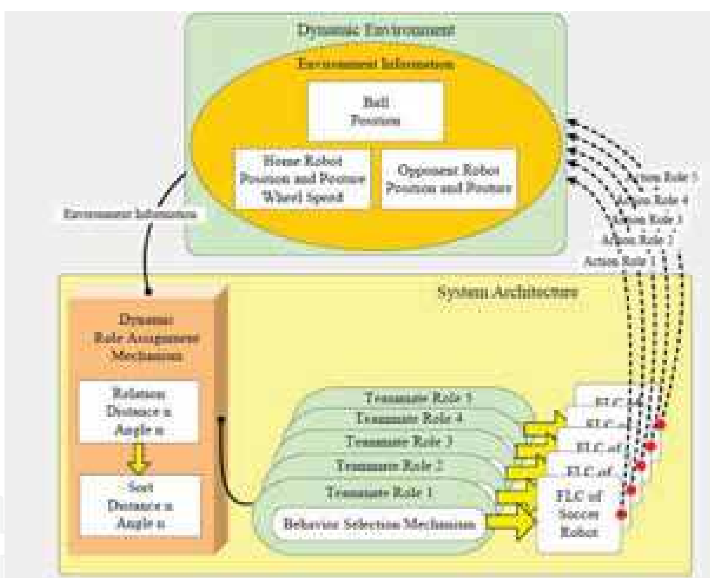

Fig. 3. System architecture used in (Yu-Hwan,2005)

In project FIBRA (Armagno at al, 2006) the ant colony technique is used in ordet to identify opponent's trajectories. Although good results are presented admits it has the disadvantage of requiring much processing time (about 4000 iterations). For decision making by using fuzzy logic like previous computational technique also has problems with the time needed for decision making, in addition, the large number of variables. In the evaluation process the following measures were used: percentage of time what the ball is played on his own or opponent's field, distributions of players on the field, number of goals, efficiency and effectiveness of attack to the opponent. At the beginning of that project was thought to an extent similar to the percentage of time the ball is played on each field, but based on human showed that football is not a very relevant, because even if a team has the ball in their dominance by one more time, this does not mean it is the best, because what counts in a championship is winning, that is, the highest number of goals scored and fewest goals received.

In work presented in (Farris et al, 1997), unlike other techniques what they develop low-level behavior such as pass and intercepted the ball and others, here high-level coordination is evolutioned using genetic programming; besides homogeneous and heterogeneous team are developed. Although it is possible to "evolve a successful team" this requires a lot of time in order to obtain reasonable results. Furthermore, although the evidence was obtained partial success (although the details were omitted here). For the evolution of team's strategies a mixed team is used because of the large number of iterations and mutation to take place, instead a pseudo-heterogeneous is implemented.

In (Thomas, 2005) the strategies are based on fuzzy logic with trajectory evolution. A model of 3 inputs - 2 outputs is developed, where the inputs are two angles and a distance, and the two outputs correspond to two wheel speeds in order to control the robot. The convergence of the algorithm of evolution is slow. Another controller 5 inputs (3 previous +2 current for each wheel) - 2 outputs is implemented. This last driver introduced improvements in behavior, but the computing time increases greatly due to the increased number of dimensions. Unlike the present chapter, control strategies are aimed at navigation and trajectory of the robot, more is not playing strategy as such for this reason is not comparable with this chapter work.

3. Immunology: Natural and Artificial

3.1 Fundamentals

The natural immune system is a complex network of specialized cells and organs that has evolved to protect the body against attacks from "outside invaders, defending infections caused by agents such as bacteria, viruses, parasites" and others (Woods, 1991). The ability of recognition is almost unlimited and it can remember past infections. In this way, when a pathogen attacks again the response is so efficient since it was recognized previously, which is known as secondary response.

Natural Immune System (NIS), specifically vertebrate immune systems has been taken as biological inspiration for Artificial Immune System (AIS). Different features of NIS are highly appealing from point of view of engineering, these are as follows:

- ✓ Uniqueness
- ✓ Pattern recognition
- ✓ Autonomy
- ✓ Diversity
- ✓ Multilayered
- ✓ Anomaly detection
- ✓ Distributivity
- ✓ Noise tolerance
- ✓ Robustness
- ✓ Learning
- ✓ Memory
- ✓ Self-organization

3.2 Natural Immune System

As mentioned above, NIS has the ability to distinguish foreign molecules or elements that can damage the body, this is known as the distinction between self and non-self. In normal situations the NIS may mistakenly identify itself as a non-cell itself and execute an attack, this is called auto immunity.

Although in NIS there are a variety of cells, some lymphocytes (type of white blood cell) are essential to mount an immune response, some lymphocytes featured are B and T; lymphocytes B complete their maturation in the bone marrow, while T cells migrate to the thymus. On the other hand, also exits dendritic cells and macrophages, first ones are found mainly in the skin, mucous membranes, lungs and spleen. Macrophages are specialized cells on to phagocyte (swallowing) large particles (e.g. bacteria) to decompose and then present them to lymphocytes. There is another type of cells with granules containing potent chemicals that kill other cells to be marked for elimination; these are known as natural killer cells (NKC). The figure below presents a classification of immune cells.

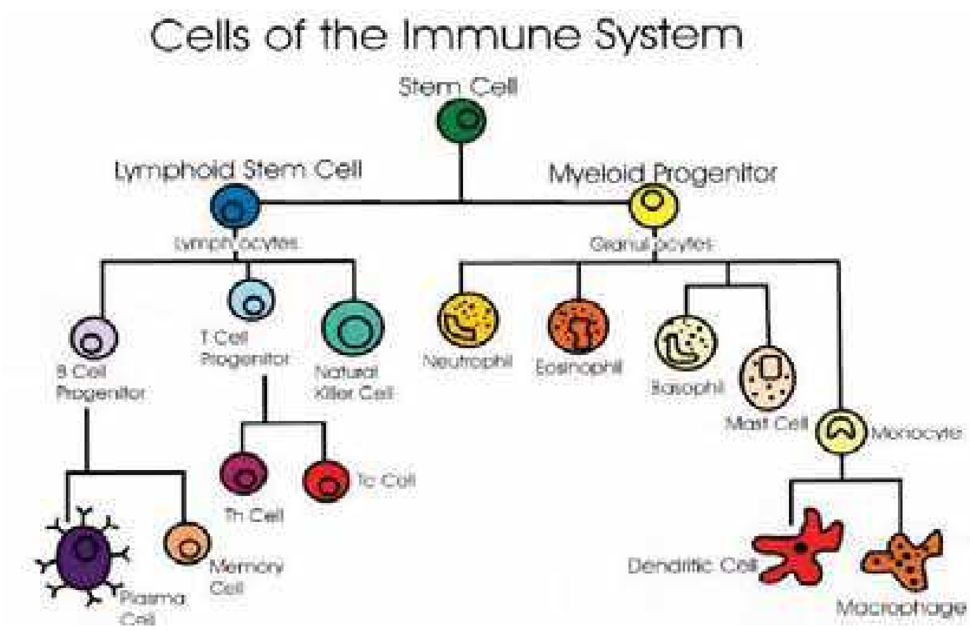

Fig. 4. Immune system cells.

Any substance or agent capableto produce an immune response are called antigens. An antigen may be a virus, bacterium or fungus, for example. When an antigen is presented, different cells can serve as antigen presenting cells (APC), these include B cells, T cells, macrophages and dendritic cells. APC role is to process a suspect foreign particles, broken down into peptides and after presente them on their surface to T cells in order to recognize antigen. Molecules that marks a cell as own are coded by a group of genes that is contained in a specific section of a chromosome, called Major Histocompatibility Complex or MHC. The MHC plays an important role in antigen identification, in particular for immune defense. Other specials molecules for immune defense are the antibodies, which belong to the family of molecules called inmunoglobinas and they are produced by B cells. Antibodies are composed of polypeptide chains which form a region V which is the area of coupling with the antibody (see Figure 5).

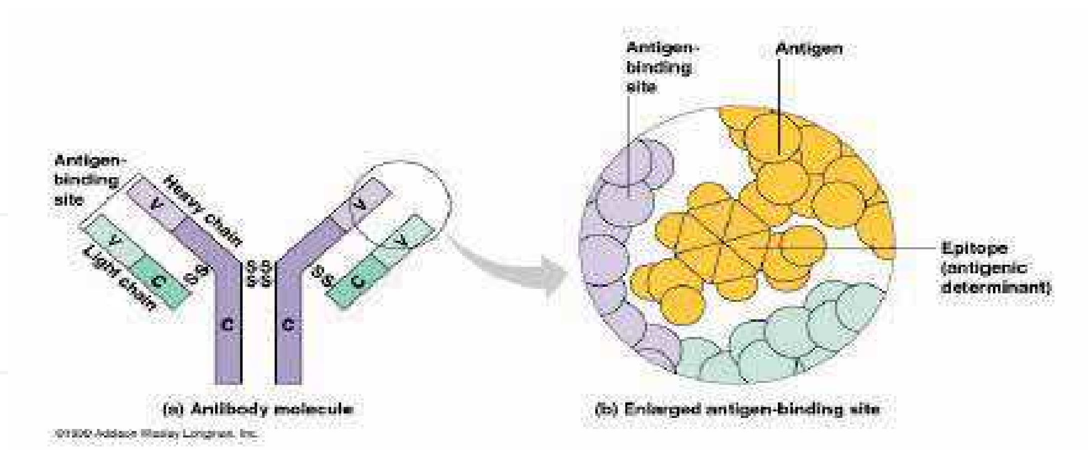

Fig. 5. Antibody structure.

The adaptive immune response is when the immune system can recognizes and selectively eliminates foreign molecules. This type of response may occur in two forms: Cellular and Humoral immunity. For development of actual chapter only the last one is taken into account. For details on the cellular immune response consult (Woods, 1991). Humoral immunity consists of the following phases: Macrophage swallows an antigen and becomes an APC, this APC divides the antigen in peptides, peptides and MHC join together to form an internally MHC-peptide molecule which one is presented on the APC surface. This stimulates to Helper T cells which recognizes the antigen through its TCR (T-Cell Receptor). Once recognition by the Helper T-cell is made, T-Cell emits two kinds of signals: CD40L and cytokines, for the purposes of this study only takes into account the last ones, since cytokines cause cell B proliferation and differentiation as clonal plasma cells and memory cells. Plasma cells secrete antibodies which are attached to the antigen in order to the natural killer cells (NKC) can be identify and eliminate them.

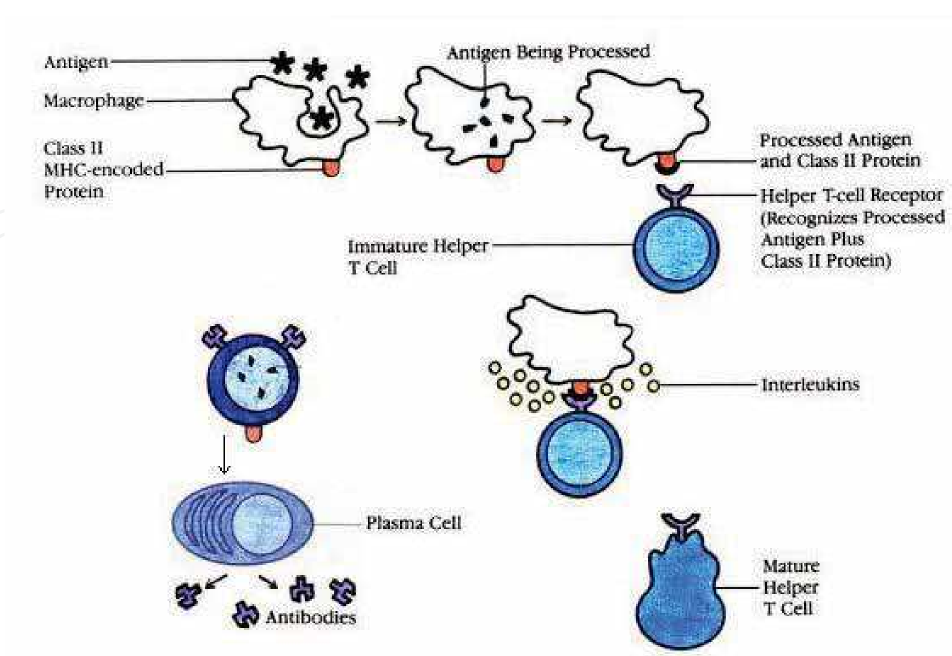

Fig. 6. Humoral Immune response process.

3.3 Artificial Immune Systems

Artificial immune systems (AIS) are adaptive systems inspired by immunological theories and observed immune functions, principles and models that are applied to solve problems (DeCastro&Timmis, 2002). Although this area of research is relatively recent, highlights several algorithms and models (website, 2009), some of them are:

- ✓ *Negative Selection Algorithm*: it is inspired mainly by the mechanism in the thymus that produces a set of T cells what are able to bind only to antigens (non-equity), items on the basis only of their own.
- ✓ *Clonal Selection Algorithm*: it is based on affinity maturation of B cells basically, this algorithm extracts two fundamental characteristics: proliferation of B cells proportional to the affinity with antigen (higher affinity, greater is number of clones produced) and the mutation undergoes the antibody (lower affinity, greater is mutation).
- ✓ *Immune Networks*: these models are based on the fact that any cell receptor can be recognized by a receptor repertoire, recognizing each other, ie, B cells are stimulated by not only antigens but also by other B cells, and this feedback mechanism leads to a memory.

3.3.1 Humoral Response Algorithm (HRA)

Here, an algorithm inspired by Humoral Immunity is developed in order to implement behavior of some robot soccer players. This algorithm uses some features of Humoral response described previously. The artificial immune response of HRA is considered in two stages: Stage or phase of activation and effector phase. In the next figure , these phases (natural immune response) are presented.

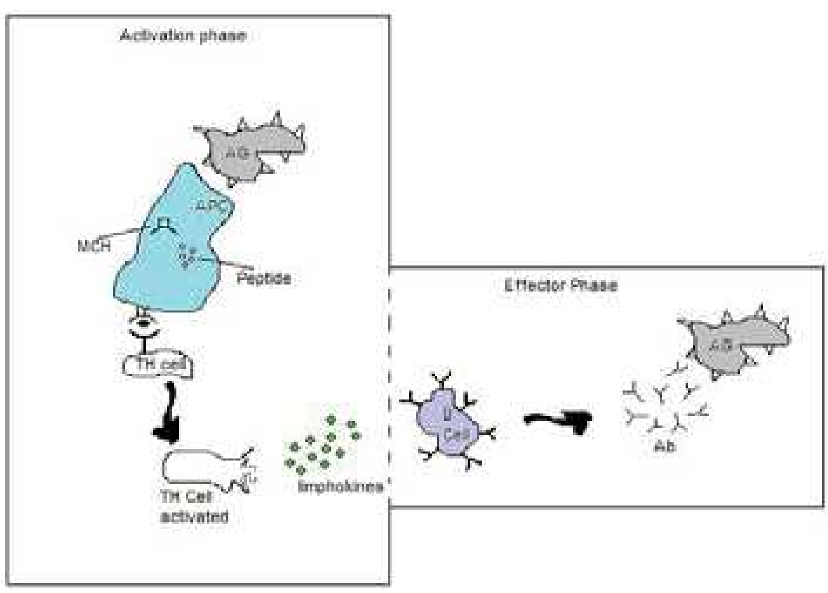

Fig. 6. Activation and effector phases.

(a) *Activation Phase:* At this stage the process of antigen identification is made, whose biological inspiration can be summarized as follows: Once reaching an antigen, an antigen presenting cell –APC- engulfs and processes it, once the molecular material is processed, it is presented on antigen surface joined to a molecule of the largest histocompatibility complex for subsequent recognition by a Helper T-lymphocyte which sends limphokynes to activate the B-cells. This stage is modeled as follow:

PRE-HRAALGORITHM

```
Begin
        For each antigen
                divide in peptides
                show MCH/peptide
                T-Helper sends limphokynes
        End For
End
```

Each time that an antigen arrives, breaks down elements that make up this antigen, for this chapter the opponent's strategy represents an antigen; peptides represent the coordinates' opponents players with respect to the ball. In order to process information of the opponent, information from the local team represents MCH and form MCH / peptide (biological point of view). According to this information the opponent's strategy is identify. Although in the biological process there is a mutation from T Helper cells, the model proposed in this work was not taken into account since it represents a high computational cost.

(b) *Effector phase:* At this stage the process of antigen elimination is carries out. The biological process modeled is showed as follows.

HRA ALGORITHM

```
Begin
 While receives limphokyne Do
   If Ab exists in memory Then
           Use Ab
   Else
           Generate Abs
           For each Ab Do
                   Calculate affinity
                   Choose Abs with best affinity
                   If exist bests Abs Then
                           Choose the best
                   Else
                           Mutation of  Antigen Image
                   End If
           End For
   End If
  End While
 End
```

Once the limphokines are received from earlier stage, the algorithm verifies if an antibody (Ab) exists into memory then it is used, otherwise generates Abs, calculates his affinity with antigen for each one and chooses the best Ab. In some cases the affinities are not the best, and then a mutation of antigen image is necessary.

3.4 Danger Theory

In 1994, Polly Matzinger proposed a theory that tries to explain why, in some cases there is no distinction between self and strange, for example, why does not the immune system reacts to foreign bacteria in food?. Matzinger proposes to change the classical theory of self/ non-self by dangerous/harmless on a new thoery called the Danger Theory. The central concept of this theory is what the immune system reacts to danger, the danger is measured by damage to cells as indicated by stress signals that are sent when the cells die so unnatural way (Aickelin&Cayzer,2002). In detail, when a cell dies in unnatural conditions it sends a alarm or danger signal that establishes a zone of danger around it (see Figure 7). In this context, B cells are responsible to produce antibodies that detect these antigens. If this detection occurs within danger zone, antibodies are stimulated and thus are activated. However, if detection is outside the danger zone, then the antibodies are not stimulated. Even if there is an affinity between antigen-antibody by outside the danger zone will not develop a cellular activation.

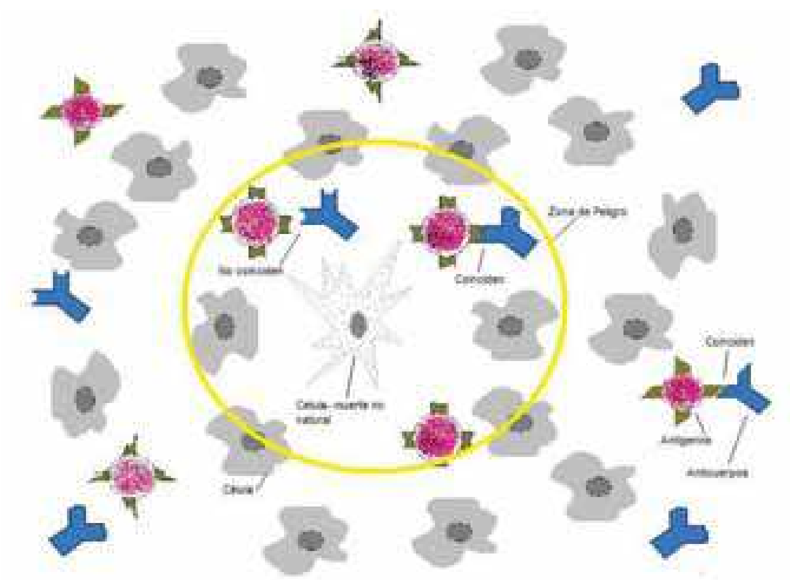

Fig. 7. Danger zone.

According to the two-signal model proposed by (Brester and Cohn,1970), antigen recognition is accomplished through two signals: signal recognition (signal one) and signal of co-stimulation (signal two), the last one really means dangerous (Aickelin&Cayzer,2002). Under the Bretscher-Cohn model, Danger Theory operates with the laws of lymphocytes, which are (Matzinger,2001):

1) A lymphocyte requires two signals to be activated, Signal One (signal recognition) comes from the junction of TCR (T cell receptor) and MHC-peptide. Signal Two comes from an APC.
2) A lymphocyte only accepts Signal Two from APC.
3) The activation phase delays a certain time and after activated, the lymphocytes not need Signal Two.

3.4.1 Danger Theory Algorithm

In order to make an abstraction of model proposed by Matzinger, it is necessary to identify certain characteristics to be implemented on this model, which one has been called DTAL (Danger Theory Algorithm). Here are the features modeled:

- ✓ Danger Zone
- ✓ Signal One
- ✓ Siganl Two
- ✓ Antigen
- ✓ Lymphocyte
- ✓ APC

Following the characteristics from model proposed by Matzinger an algorithm is generated. The proposed algorithm is presented below.

Algorithm DTAL

```
1 - Start
2 - for each antigen
3 -     detect alert (Signal One)
4 -     monitor antigen
5 -     if you receive signal then Two
6 -             danger zone set
7 -             activate lymphocyte NKC
8 -     end if
9 - end for
10 - end
```

The flexibility of this algorithm is to define a danger zone that could be placed where is needed, since there are systems which require what certain area or subsystem always is at same place in order to be monitored for abnormalities; in these cases line 6 of algorithm can be located at 1.5 to establish the danger zone. This flexibility makes the algorithm can be applied in different environments (Prieto et al, 2008).

4. Robot Soccer Strategies Inspired on Immunology

Taking the concepts of immunology treated previously strategies for robot soccer are developed, both from a classical viewpoint and from the viewpoint of danger theory.
In many cases, the strategy used by a robot soccer team is treated globally. However, this may not be appropriate since the goalkeeper carries out other functions and can be viewed as a special player. Therefore, goalkeeper strategy can be separated from the rest of team, but still must be coordinated or linked to the rest of team to achieve objective: win the game. Therefore, in this chapter we define the strategies of the players as well:

1) Goalkeeper Strategy: We propose the use danger theory to develop the goalkeeper strategy.
2) Strategy Team: For the average league soccer robots (SIMUROSOT), players, excluding the goalkeeper, is four. With these players can deploy multiple roles football game. In this case, we propose the use of the humoral response theory to develop team strategy.

4.1 Goalkeeper Strategy

In this study, APC cell will be a B cell, the lymphocyte to be activated will be a NKC (natural killer cells), antigen is the strategy of the opponent's attack and signals One and Two will be which indicate to the goalkeeper that its bow is on danger. This analogy between elements of soccer robots and immunology is detailed in Table 1.

Danger Theory Elements	Robot Soccer
APC	Goalkeeper ID-Strategy
Tissue	1/3 Home Side
Antigen	Opponent and Ball at home side
Signal One	Ball at home side
Signal Two	Opponent with ball close to penalty area
Danger Zone (Fixed)	Penalty area
Lymphocyte (NKC)	Clear Strategy-AIKIDO

Table 1. Analogy between danger theory an robot soccer.

Goalkeeper identifies if there are opponent plays that can become dangerous and end up in goal, all of these by taking into account the signals of the model. When in the course of game, the ball is on final third side of the stadium itself (see Figure 8), will trigger an alert, this is sign one, since ball position can become goal. That is why active surveillance opponent's moves in order to detect if there is danger. The goalkeeper is so attentive to receive signal Two or co-stimulation, which indicates whether the situation is dangerous or not, that signal will be present when opponent has the ball and is in proximity to penalty area.

Fig. 8. Danger zone on game field.

As human soccer, goalkeeper gets alerted when an opponent player with the ball is coming. Usually, goalkeeper is located close to the vertical post nearest where is dangerous situation. This work takes such human reaction in order to do monitoring process. In robot soccer case a fixed danger zone is used, which corresponds to the penalty area. When goalkeeper receives the two signals lymphocyte NKC is activated, which is clearance strategy, disarming the opponent's goal play. As in human and robot soccer, clearance does not guarantee full disarmament of opposing team's attack, in many cases it needs the intervention of other elements to make the response effective. The clearance strategy used by goalkeeper is taken from aikido art, a strategy proposed by (Fredman&Mon,2004). This technique uses the force that is blowing to deflect it. The strategy of goalkeeper is uses angle and speed that comes with the ball and deflected its course, away from the arc as far as possible.

4.2 Team Strategy

Since the dynamics of soccer game is necessary that resident system; in this context, local team will be capable adapting to game schema of opponent in order to win soccer match. For team strategy development, information provided by simulator is used and putted into a vector of 22 elements, which result from to combine positions *(x, y)* of all players (home and visit) and ball.

LX^0_t	LY^0_t	LX^1_t	LY^1_t	…	LX^4_t	LY^4_t	OX^0_t	OX^0_t	OX^1_t	OX^1_t	…	OX^4_t	OX^4_t	BX_t	BY_t

Where LX^i_t and LY^i_t represent local player *i* coordinates at *t* time instant. For the team strategy, an antigen represents opponent's strategy, noting that the concept of strategy used for the team is defined as formation of the opponent with regard to both ball and field game into a window of time. To determine a strategy is necessary to use a sequence of movements of the opponent into a period of time. Because of need to sample the opponent's strategy, it is essential to have a history of opponent's movements (see Table 2). For this reason, when opponent player location is needed does not take the current position but for that player's position corresponds to predicting the next move according to that history (see equations 1 and 2).

OX^0_t	OY^0_t	OX^1_t	OY^1_t	…	OX^4_t	OY^4_t
OX^0_{t-1}	OY^0_{t-1}	OX^1_{t-1}	OY^1_{t-1}	…	OX^4_{t-1}	OY^4_{t-1}
⋮	⋮			⋮	⋮	⋮
OX^0_{t-4}	OY^0_{t-4}	OX^1_{t-4}	OY^1_{t-4}	…	OX^4_{t-k}	OY^4_{t-4}

Table 2. History opponent's moves.

$$OX_{t+1} = OX_t + \frac{1}{4}\sum_{k=0}^{3}\left(OX_{t-k} - OX_{(t-k)-1}\right) \quad (1)$$

$$OY_{t+1} = OY_t + \frac{1}{4}\sum_{k=0}^{3}\left(OY_{t-k} - OY_{(t-k)-1}\right) \quad (2)$$

On this way, an antigen can be represented as follows:

OX^0	OY^0	OX^1	OY^1	…	OX^4	OY^4	BX	BY

Positions XY of opponent players — Ball Position XY

Activation stage is responsible for make acknowlegde. To perform this process is necessary take this information and process it with the Major Histocompatibility Complex-MCH- (biologically speaking). From Robot soccer point of view, MCH can be represented by XY positions from local team (10 data). Using all the information (antigen and MCH) is necessary to find the distance between each local player and each opponent player with respect to ball, thus finding opponents who are an active participation on game and what players can participate in current move, in other words, we know the opponent's strategy by the players directly involved in action game, getting an image of the antigen. This process is analogous to the decomposition of such a peptide antigen in the biological.

5. Experimentation and Results

Due to Robot Soccer environment the experiments are based on matches of 5 minutes each, depending on the category SIMUROSOT. To test the proposed strategies, it is necessary to match the team in which strategies were implemented (local) with other teams, that is, other gaming strategies. One difficulty in the robot soccer environment –FIRA- lies in the unavailability of reference test strategies or benchmark for evaluation. However, different strategies developed in the work of (Sotomonte, 2005) and (Kogan and Parra,2006) were used in experimentation. That is, used 4 strategies:

- ✓ H01-heterogeneous system model 1, M04-homogeneous system with knowledge of rules and collision detection. Both were designed by (Sotomonte, 2005).
- ✓ Rakiduam developed by Kogan and Parra in 2006. Participated in the Argentine Championship Robot Soccer (website,2008), earning fifth place among 10 participants.
- ✓ Strategy which has by default the simulator league official SIMUROSOT.

In addition, a random attack strategy is used.

5.1 Results

In order to do all experiments only game time where the ball is in action game was taken. For this reason, the number of matches is not bigger in comparison with others investigations, but inside Robot Soccer context is enough in order to prove the computational intelligence.

5.1.1 DTAL Algorithm

To determinate effectiveness of this strategy, 15 matches were carried out. Time used on these tests was 15 minutes nets –no dead times were taken into account-. In order to evaluate the strategies developed two primordial features were used: Goal Options and Goal Annotations. The first ones are which Signal Two was present, it means, antigen was recognized as dangerous.

Match	Goal Option	Goal Annotation	Effectiveness Goalkeaper (%)
1	26	2	92.30
2	52	6	88.46
3	26	0	100
4	44	6	86.36
5	42	4	90.47
6	46	8	82.61
7	56	11	80.36
8	58	10	82.76
9	58	12	79.31
10	43	9	79.07
11	36	7	80.56
12	44	10	77.27
13	60	10	83.33
14	62	12	80.65
15	47	8	82.98

Table 3. Results for DTAL algorithm

It is important highline the fact that matches use 5 opposite player vs. goalkeeper, and so the effectiveness obtained was 84.43% with a standard deviation of 6.10%.

5.1.2 HRA Algorithm

Difference between this test and before test is the combination of 2 algorithms is into this algorithm. So, following its biological inspiration the HRA algorithm use memory in order to adaptation will be successfully. Into the next figure a goal tendency is showed; this represents its adaptation a different opponents.

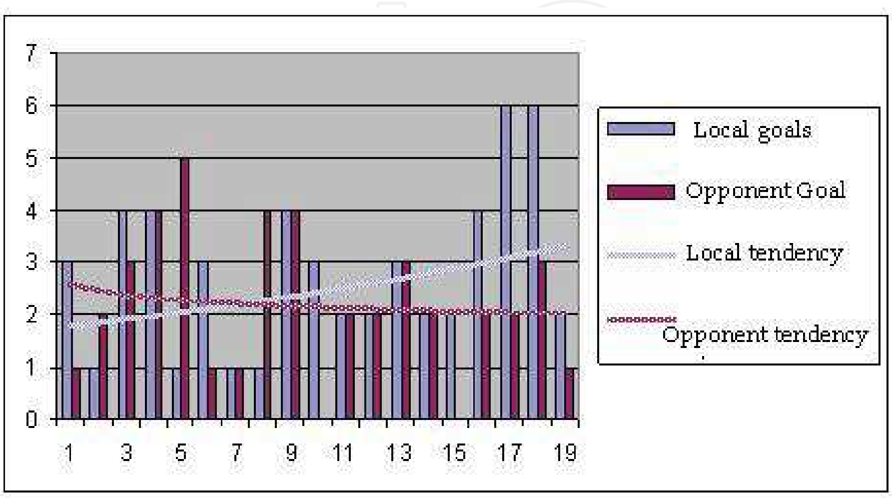

Fig. 9.

5.1.3 Analysis

In experiments for algorithm DTAL, despite the fact that goalkeeper played only against the rest of the opposing team (1 vs. 5), a high rate of effectiveness tackling opposing moves that may become a goal, was achieved. Although some aspects may improve the prediction of the position of the ball, the algorithm has many qualities to be implemented in other engineering fields. Those characteristics are the simplicity of implementation, speed of response and security system applications.

When algorithm DTAL is combined with algorithm HRA to develop the equipment, the team has characteristics of cooperation that was not formally designed, but its inspiration immune system makes this system suitable for multi-agent dynamic environments. The HRA algorithm can be implemented in other fields of action, preliminary interpretation of the environment so that its effectiveness is reflected in the particular application.

Even though the team was able to face different game situations, the method of navigation could be improved to make it much faster and generate movements that the opponent can not respond optimally, and thus will find a game much more competitive. However, in several previous works are presented various forms of navigation, but in the present study opted for a simple and effective way of navigation, since the focus of research was the application of artificial immunology concepts for a multi-agent system in highly dynamic environment.

6. Future Research

As future work, it is worthwhile to deepen some aspects of this work, besides continuing some work done. These aspects are:

- ✓ Because of work focused on a high level of abstraction, namely the implementation of strategies in play, a task ahead is to strengthen the players' actions to be implemented in a competition either domestically or internationally.
- ✓ There should be testing and improving, if necessary, the navigation system in order to be faster, since in gaming systems this is a very important feature in a competition.
- ✓ Perform other hybrid models involving computer techniques bio-inspired such as neural networks and genetic algorithms, in order to find a very competitive internationally.
- ✓ Using other platforms to interact with official simulator from FIRA to run faster actions, besides being able to implement different programming structures for the development of strategies.

7. Conclusions

Algorithms based on immunology concepts are presented; these features are used into a computational system in this case a robot soccer team in order to learn the game situations. Through interaction with the rating system, a memory is built so that its response is fast growing and adapts its behavior to different game situations regardless of the opponent.

It is important highlight that although the algorithms developed in this work, initially did not schedule for explicit communication between players (ie, between the goalkeeper and other players), thanks to the biological inspiration in immunology surges a collaborative relationship between the players in order to give a response to actions of the opponent who has not been previously scheduled. This implies that intelligent behavior emerges making results expected from these strategies developed meet the expectations raised initially.

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The idea of using soccer game for promoting science and technology of artificial intelligence and robotics was presented in the early 90s of the last century. Researchers in many different scientific fields all over the world recognized this idea as an inspiring challenge. Robot soccer research is interdisciplinary, complex, demanding but most of all, fun and motivational. Obtained knowledge and results of research can easily be transferred and applied to numerous applications and projects dealing with relating fields such as robotics, electronics, mechanical engineering, artificial intelligence, etc. As a consequence, we are witnesses of rapid advancement in this field with numerous robot soccer competitions and a vast number of teams and team members. The best illustration is numbers from the RoboCup 2009 world championship held in Graz, Austria which gathered around 2300 participants in over 400 teams from 44 nations. Attendance numbers at various robot soccer events show that interest in robot soccer goes beyond the academic and R&D community. Several experts have been invited to present state of the art in this growing area. It was impossible to cover all aspects of the research in detail but through the chapters of this book, various topics were elaborated. Among them are hardware architecture and controllers, software design, sensor and information fusion, reasoning and control, development of more robust and intelligent robot soccer strategies, AI-based paradigms, robot communication and simulations as well as some other issues such as educational aspect. Some strict partition of chapter in this book hasn’t been done because areas of research are overlapping and interweaving. However, it can be said that chapters at the beginning are more system-oriented with wider scope of presented research while later chapters generally deal with some more particular aspects of robot soccer.

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