An Immunology-based Cooperation Approach for Autonomous Robots

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Abstract

Based on the immune response and immune network theory, the main mechanisms of interaction among antibody molecules, an artificial immune agent model and an artificial immune system for multi-autonomous robots system are put forward. By simulating experiments and physical experiments, it indicates that the presented immune cooperation approach can achieve a self-organizing system that is more robust and flexible in dynamic environment.

Keywords: Autonomous robots, Cooperation; Artificial immune system

1. Introduction

More hands obviously make light work. For this reason, the interest of the Robotics community for distributed autonomous robotic system (DARS) has grown rapidly [1]-[8]. However, the continually changing world is ultimately a cruel place for robots. Each robot is a component of the system and will perceive its environments such as object and the other robot's behavior etc., and they must determine their behavior independently, and cooperate with the other robots in order to perform the given tasks very well [1]-[5]. DARS has no function to integrate the whole system. Immune system is also distributed autonomous system that protects and maintains living body. The components of immune system do not follow commands of the brain but cope with environment autonomously. In this point of view, we analogize DARS from immune system. So this analogy can be used for mechanism that decides group behavior strategy of DARS. Immune system has various functions that are ability to recognize foreign pathogens, ability to process information, .ability to learn and memorize ability to discriminate between self and non-self, and ability to keep up harmony of the whole system. It is thought that these functions of immune system can be applied to various engineering fields [9]-[10].

In this paper, based on immune response and immune network theory, we proposed an artificial immune agent model and an artificial immune system algorithm for autonomous robots. We also put forward a cooperation approach at the same time. At last, all algorithms are applied to the typical problem involved in autonomous robots: the dog and sheep problem [6]. By the simulating experiments and physical experiments, the presented immune algorithm can achieve a self-organizing system that is more robust and flexible in dynamic environment.

2. Biological Immune System

2.1. Concept of Immune System

The protection system that eliminates foreign substances that invade living body is called immune system. And an antigen can be defined as a substance that triggers immune response. Generally in vertebrates, the host system does not respond to its own proteins, and that is called immune tolerance. The basic components of the immune system are lymphocytes that occur as two major types, T-cells and B-cells. B-cells take part in humoral immunity that secrete antibody, and T-cells take part in cell mediated immunity. Each of B-cells has distinct molecular structure and produces 'Y' shaped antibodies form its surface. The antibody recognizes antigen that is foreign material and eliminates it. This antigen-antibody relation is innate immune response. The segment in an antigen that can be distinguished by antibodies is called epitope. An antigen may carry several epitopes, and this will trigger the production of several antibodies. The segment in an antibody that can identify epitope in an antigen is called paratope. An antibody cannot only distinguish an antigen, but also be distinguished by other antibodies. An antibody will be regarded as antibody in other antibodies' eyes, which is rendered by the segment called idiotope (Fig.1).

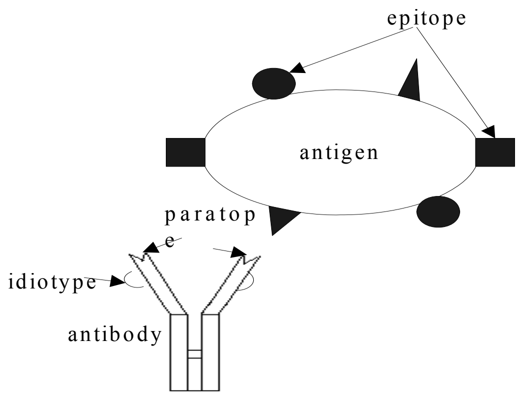


Fig.1: Interaction of antigen and antibody.

2.2. Idiotopic Network

In immune system, other antibodies can identify an antibody holding idiotope, as if it is an antigen. Thus, an antibody possesses some characteristics like an antigen's. N.K.Jerne proposed Idiotopic Network Hypothesis. The basic idea exists in that the immune system is composed of a lymphocyte network. These lymphocytes communicate mutually to achieve the main goal of immune system. According to this hypothesis, antibodies interact with each other through idiotope and paratope.

When antigens invade the body, they will trigger the production of several antibodies: Ab1. Ab1 will also trigger the production of several antibodies to resist Ab1. These antibodies are Ab2, which will do as a negative feedback factor to affect Ab1. At the same time, Ab3 will come into being to resist Ab2. There will be a network such and such repeat (Fig.2). This network has already been there even if antigens do not exist. The balance of this network will be broken once antigens come forth with a large number. The number of Ab1 will rise quickly. The number of Ab2 and Ab3 will rise as Ab1 do simultaneously until the next balance point arrives. Therefore, the concentration of the Ab1 is not only determined by the antibody's concentration but also determined by the concentration of Ab2.

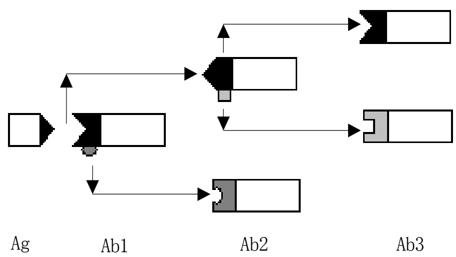


Fig.2: Idiotopic network.

3. Immune Agent and Its Cooperation

In this section, we will propose an immune agent model based on immune response and a decision making algorithm based on the immune network theory.

3.1. Immune Agent

According to the immune theory mentioned above, an immune agent is designed to simulate the immune response. The construction is described in Fig.3. Environment is considered as antigen. Agent's action is considered as antibody. There is an immunological memory base that can refresh by itself in this agent. Some immune memory pattern sets have been stored in it beforehand Immune agent would give an antibody as an action immediately if agent find the antigen in this immunological memory base. This memory base will be updated and filled continuously in order to raise the agent's intelligence. Immune response is controlled by antibody's affinity and other agent's affinity. The stimulative or suppressive signal from other agent will participate in system decision-making. The stimulative or suppressive signal is transferred by communication interface.

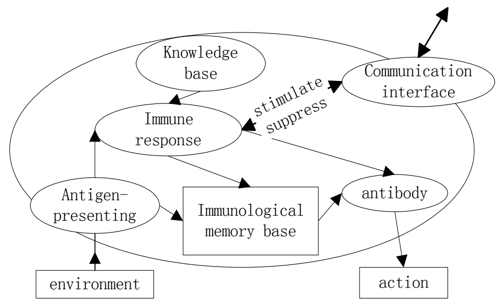


Fig.3: Construction of immune agent.

3.2. Immune Agent's Decision Making Process

Based on the Idiotopic Network Hypothesis, the concentration of the antigen is not only determined by the antibody's concentration but also determined by the concentration of other antigen. Therefore, we can describe the immune agent's decision making process as follows.

At first, immune agent notice the surroundings. It captures the environment antigen and calculates all affinities of its possible strategy. Next, Immune agent notices others' situation and captures others' affinities of their possible strategy. Therefore, it can calculate its strategy concentration by the following equations:

$$A_i = \alpha g_i + \frac{\beta}{N} S_i - K_i \tag{1}$$

$$S_i = \sum_{j=1}^{N} m_{ij} \times g_j \tag{2}$$

where j=1…N, k=1…N, both N and M correspond to the total number of antibodies in each B-cell. g_i is antibody's affinity. m_{ij} is the coefficient of stimulative or suppressive power. A_i represents the current concentration of antibody i, S_i represents the stimulative or suppressive power, K_i is natural mortality rate, and α、β are weight coefficient. S_i is calculated in equation (2). From equation (2), we get equation (1), which is the final form to calculate the concentration of an antibody. Then, the antibody with highest concentration is the selected action of the immune agent.

4. An Example

In this section, we consider dog and sheep problem as an example which the theorem can be applied to. Based on the statement of Section 3, the dog's decision making process is provided as follows.

4.1. Dog and Sheep Problem

The dog and sheep problem is a typical problem in distributed autonomous robotics system. A few dogs are trying to guide a few sheep to a specified area without exceeding the borders. And the number of dog or sheep can be changed [6]. Dog and sheep may be simulated by autonomous robot in real world. The dog and sheep problem mentioned above can be described as fellows: In the given surroundings, Dogs can obtain the positional information about sheep in their detecting range. The information involves azimuth and distance. Dogs are requested to cooperate in dynamic environment. The mission is to prevent sheep from moving away from grazing site and to send sheep into safety zone in the end. The strategy of sheep is to escape from the nearest dog and to move towards in adverse direction. The essential of this mission is to find a dynamic command list that can accomplish the job in the robotic command space.

4.2. One Dog Chase One sheep

Before stating the cooperation problem between dogs, we will analyze the chasing problem between one dog and one sheep.

As Fig.4 shows, the dog can do this easy work with potential field path planning. The Sheep(S) is the goal of the attractive field. B is obstacles point of the repulsive field.

We define the gravitational-field function as:

$$U_{at}(\boldsymbol{X}) = \frac{1}{2} k_a \left| \boldsymbol{X} \text{ - } \boldsymbol{X}_{\boldsymbol{goal}} \right|^2$$

where k_a is the numeric constant of the gravity field, $\boldsymbol{X}$ is the Dos's position vector, $\boldsymbol{X}_{\boldsymbol{goal}}$ is the Sheep's position vector.

Then we can get the attractive power F_{at}:

$$F_{at}(\boldsymbol{X}) = -\nabla U_{at} = k_a \left| X - X_{goal} \right|$$

We define the repulsion-field function as:

$$U_{rep} = \begin{cases} \frac{1}{2} k_r \left(\frac{1}{\rho(\boldsymbol{X}, \boldsymbol{X}_{\boldsymbol{obs}})} - \frac{1}{\rho_0} \right)^2 & \rho \le \rho_0 \\ 0 & \rho > \rho_0 \end{cases}$$

where $\rho(\boldsymbol{X}, \boldsymbol{X}_{\boldsymbol{obs}}) = \left| \boldsymbol{X} \text{ - } \boldsymbol{X}_{\boldsymbol{obs}} \right|$, k_r is the numeric constant of the repulsion field.

Then we can get the repulsion power F_{at}:

$$F_{rep} = -\nabla U_{rep} = \begin{cases} k_r \left(\frac{1}{\rho(\boldsymbol{X}, \boldsymbol{X}_{\boldsymbol{obs}})} - \frac{1}{\rho_0} \right) \times \frac{\nabla \rho(\boldsymbol{X}, \boldsymbol{X}_{\boldsymbol{obs}})}{\rho(\boldsymbol{X}, \boldsymbol{X}_{\boldsymbol{obs}})^2} & \rho \le \rho_0 \\ 0 & \rho > \rho_0 \end{cases}$$

The result force $F = F_{att} + F_{rep}$ acting on Dog (D) exposed to the attractive and repulsive forces moves the Dog (D) towards the direction. We defined a banded fixed force-field in order to prevent the dog from driving the sheep into opposite directions. The direction of the stress is fixed in this banded zone as Fig.4 and Fig.5 show [7].

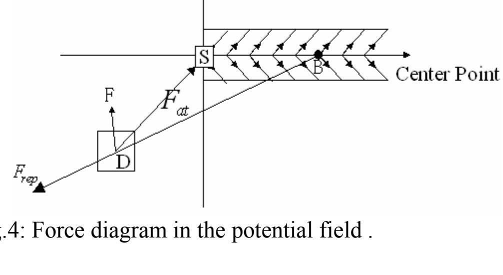


Fig.4: Force diagram in the potential field .

4.3. Two Dog Chase two sheep

When two dogs chase two sheep, algorithm is taken into account in two steps. First, two sheep are not in the safety zone. The dog's strategy is choosing one sheep to chase. In this case, dog works in the same way as chasing between one dog and one sheep.

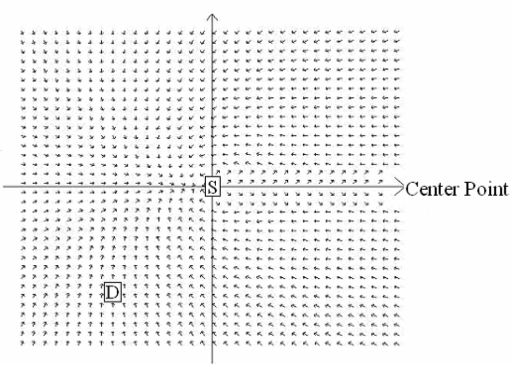


Fig.5: Dog's action in the potential field.

Secondly, one sheep is in the safety zone. Two dogs chase one sheep. Every dog must consider how to cooperate with another dog and how to achieve the object together. What is the dog's strategy in this case? Considering the direction, we realize that the dog has nine possible actions. The dog's strategy is to choose one direction as Fig.6 shows or to choose standstill. Therefore, the next problem is how to calculate the nine actions' affinity.

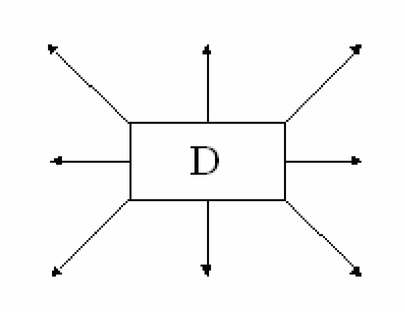


Fig.6: Possible direction of the dog .

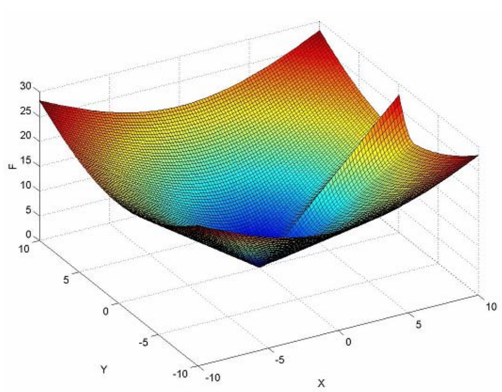


Fig.7: Result force diagram.

As Section 3 statement, environment is considered as antigen in algorithm. And it is composed of the position codes of dogs and sheep. Dog is considered as an independent immune agent, and its behavior is antibody. The ability of dog's action conquering sheep's action is affinity. Antibody's affinity is very important in the decision process of the dog. Here, we used potential field again to calculate the antibody's affinity. We calculate composite force acting on the dog in the potential field. In the banded fixed force-field, we can calculate composite force.

$$F_{new} = F + F_{\max}/2 - \sqrt{|y|} \times F_{\max}/2$$

Where y is the width of the banded fixed force-field, $F_{\max}$ is the maximum force acting to dog, F is the composite force. The force diagram in the potential field is showed in Fig.7.

If the dog is not in the banded fixed force-field, then $F_{new} = F$

Then we can get the antibody's affinity

$$g = F_{\max} - F$$

Therefore, using equation (1) and equation (2), the dog will reach a decision easily.

4.4. Simulation result

Through the decision making algorithm of the immune agent, we can get the simulation result as Fig.8 shows. Fig.9 gives better understanding to the scenario of the episode shown in Fig.8. The sheep's behavior is designed such that it escapes from the nearest dog. During the time period T1, the dog's strategy was choosing one sheep to chase. From the calculation of the concentration of antibody, D2 decided to chase S2, and D1 chased S1 despite that the D1-to-S2 is nearer than D1-to-S1. As period T1 ends, the S2 was chased into the safety zone. At this point of time, the dog's strategy was changed and cooperation for chasing occurred. The dog would consider cooperation with another dog and it would decide which direction was selected to go in next time step. Through the calculation of the concentration of selected action, D1 and D2 pulled together to chase S1 into the safety zone as Fig.6 shows.

4.5. Physical experiments

In our physical experiments, we deploy three micro-robots from MIRSOT to act two dogs and a sheep. Fig.10 shows one experimental process. We consider the circle area to be safety zone in the structured environment. With the aid of Fig.11, we can have a exact tracing for the motion of all immune agents in the running episode.

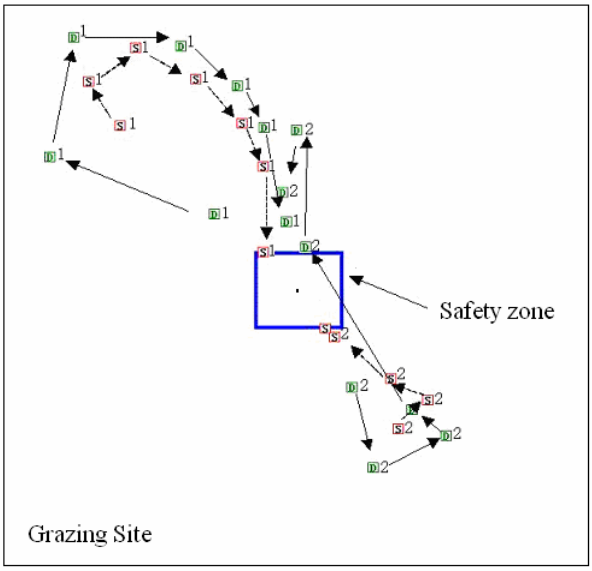


Fig.8: Simulation result.

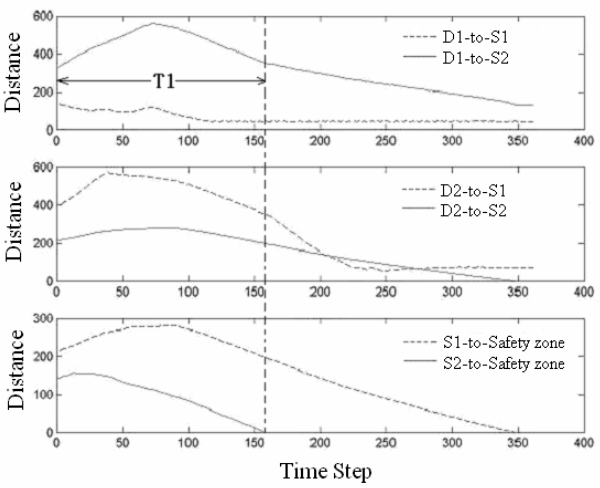
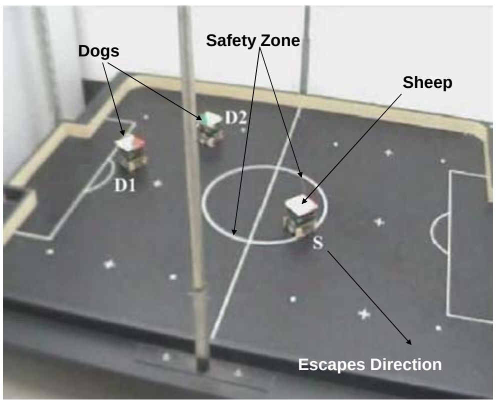
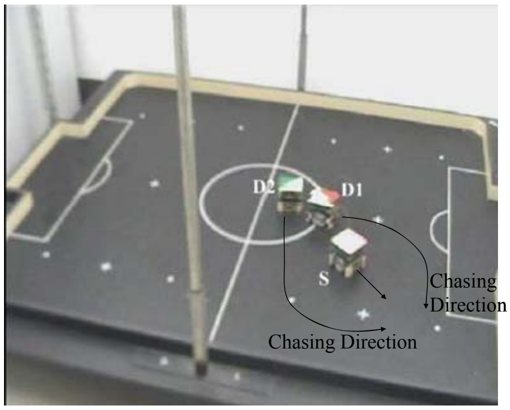


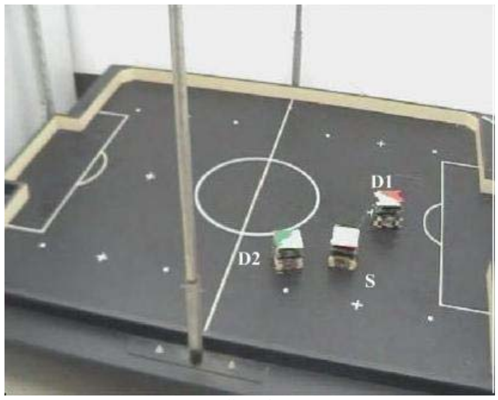
Fig.9: Episode analysis.



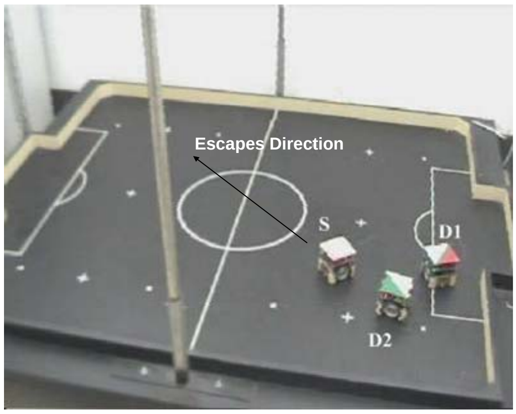
Step1



Step2



Step3



Step4

Fig.10: Experimental process

5. Conclusions

In this paper, we presented a cooperation approach based on immune system for autonomous robot in multi-robot environment. With this algorithm, autonomous robot can do his work independently. And at the same time, he can cooperate with others. Therefore, it is possible for autonomous to act like men. Last, we demonstrated the effectiveness of the algorithm by implementing it on a typical problem in distributed autonomous robotics system. By the simulation and real physical robots experiment, it indicates that the system based on this algorithm has good expandability, nice flexibility and characteristic of high response speed. It is obvious that the system constructed based on artificial immune agent is a self-organizing system adapt to the dynamic environment.

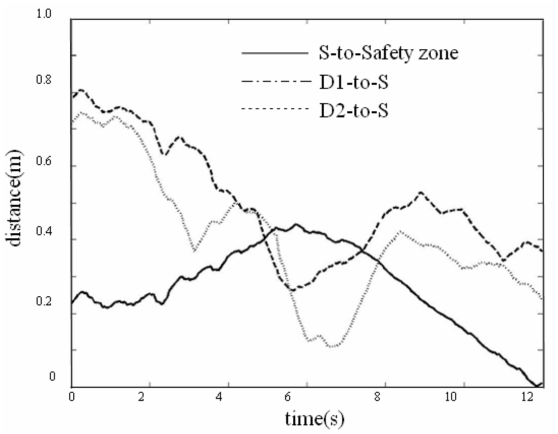


Fig.11: Episode analysis of physical experiments.

References

[1] C. K. Cheng; G.Leng, Cooperative search algorithm for distributed autonomous robots. *Proceedings of 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems,* 1: 394 – 399, 2004.

[2] Khoo, A.; Horswill, I.D.; An efficient coordination architecture for autonomous robot teams. *Proceedings of 2002 IEEE International Conference on Robotics and Automation,* 1:287 – 282, 2002.

[3] D.W. Lee, K.B. Sim, Behavior Learning and Evolution of Collective Autonomous Mobile Robots using Distributed Genetic Algorithms," *Proceedings of 2nd AScian Control Conference,* 2: 675-678, 1997.

[4] R. Alami, S. Fleury, M. Herrb, Multi-robot cooperation in the MARTHA project. *Robotics & Automation Magazine, IEEE.* 5: 36 – 47, 1998.

[5] W.Burgard, M. Moors,. C.Stachniss, F.E. Schneider, Coordinated multi-robot exploration. *IEEE Transactions on Robotics,* 21: 376 – 386, 2005.

[6] C. Schultz, J.J. Grefenstette, and W. L. Adams. "RoboShepherd: Learning a Complex Behavior". *Proc of the Robots and learning Workshop. Florida*, pp: 105~113, 1996.

[7] R. Siegwart and R.Illah Nourbakhsh, *Introduction to Autonomous Mobile Robots*. Cambridge, Mass. ; London : MIT Press, 2004

[8] Y.U.Cao, A.S.Fukunaga, A.B.Kahng, F.Meng, Cooperative mobile robotics: antecedents and directions. *1995 IEEE/RSJ International Conference on Intelligent Robots and Systems.* Volume 1, pp:226 – 234,1995.

[9] P.K Harmer, P.D.Williams, G.H. Gunsch, G.B.Lamont, An artificial immune system architecture for computer security applications. *IEEE Transactions on Evolutionary Computation,* 6: 252 – 280, 2002.

[10] F. Campelo,.; F.G.Guimaraes,; H.Igarashi,; J.A Ramirez, A clonal selection algorithm for optimization in electromagnetics. *IEEE Transactions on Magnetics,* 41: 1736 – 1739, 2005.