Autonomous Micro-Robot 'Kity' for Maze Contest

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Abstract

In this paper, we propose a table-look-up immune network which is extracted from an immune network to solve problems that arise from autonomous micro-robots to achieve a given goal with limited memory and calculation capacity. This method is implemented and tested with the micro-robot 'Kity', the size of which is less than 1 $inch^3$. It is possible to generate enough rules to make the robot achieve the goal to navigate freely in a maze with a very small number of sensors. Experimental results show that the immune network can be used to control a robot in a restricted environment. Kity demonstrated its efficient algorithm by taking the 1st prize at the 4th International Micro Robot Maze Contest held in Nagoya, Japan on October 6, 1995.

1 Introduction

Since the first mechanical devices were invented centuries ago, the size of the parts was significantly reduced and the precision increased tremendously. Miniaturization of real life objects has always been a fascination for the researchers. Small models exist for everything. Powering these small objects or giving them some autonomy or even *intelligence* is still a challenge left for future generations. Small mechanisms are machined and assembled by different techniques called precision engineering, micro-mechanics or micro-mechatronics, with this last word being used when some control electronics is embedded into the system.

In this paper, a table-look-up immune network is proposd for the proper behaviors of the autonomous micro-robot in a maze. The table consists of antibodies (behaviors) extracted from an immune network[1] to solve a problem of finding a way from start point to goal point via five control points in the maze. The key technology is to implement an autonomous micro-robot sized less than 1 $inch^3$ for the achievement of a given objective with limited memory and calculation capacity.

The algorithm is implemented and tested with the micro-robot Kity, the size of which is less than 1 $inch^3$. With a very small number of sensors it is possible to generate enough rules to make the robot achieve the objective to move freely in a maze that consists of channels and nodes.

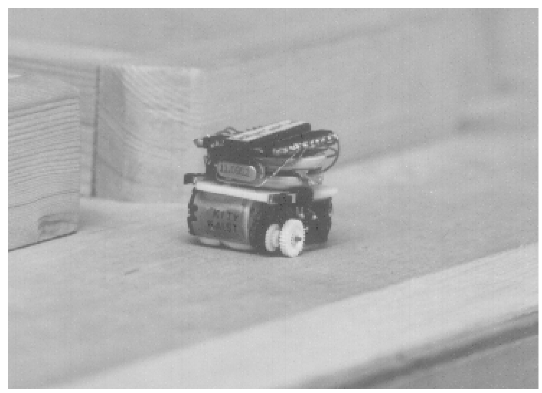

Fig. 1. Kity in the maze

The immune system, in particular, has various interesting features such as immunological memory, immunological tolerance, micro-pattern recognition, non-hierarchical distributed structure, and so on from the standpoint of engineering. In addition to this, recent studies on immunology have clarified that the immune system does not only detect and eliminate the non-self materials called *antigens* such as virus, cancer cells and so on which come from inside or outside of the living system, but play important roles to maintain its own system against dynamically changing environments. Therefore, the immune system would be expected to provide a new paradigm suitable for dynamic problem dealing with unknown environments rather than static problem. So far, several methods have been proposed to realize phenomena of the immune system from standpoint of mathematical analysis. However, the immune system has little been applied to engineering fields in spite of its productive characteristics. Based on the above facts, Ishiguro et. al. [2] studied the immune system for the engineering purpose, and applied it to the mobile robot. They expected that there would be an interesting AI technique for dynamically changing environment by imitating the immune system in living organisms.

Experiment results show that immune network can be used to control a robot in a restricted environment. Kity demonstrated its efficient algorithm by winning the 1st prize at the 4th International Micro Robot Maze Contest held in Nagoya, Japan on October 6, 1995.

2 Description of Kity

Figure 2 shows the structure of Kity, an autonomous micro-robot of less than 1 $inch^3$ in size.

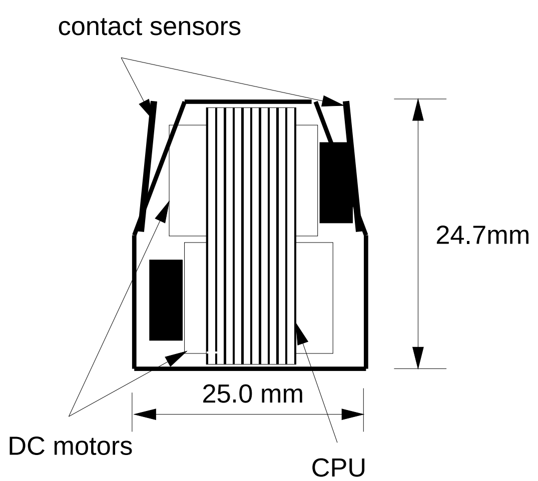

Fig. 2. The structure of Kity.

It consists of two contact sensors, two DC motors, two 3-Volt lithium batteries, and an $i8051$ compatible micro-processor [3]. An $i8051$ processor is one of widely used Intel's 8 bit micro-processors for controlling small machineries. The compatible chip has two kilo bytes of flash memory that makes it easy to install the code. To control Kity only two digital control signal outputs to the DC motors and two digital input channels to receive signals of contact sensors are used. Light weight of Kity makes it critical to choose adequate contact sensors that operate under very weak force. The wheels are geared to the DC motors with the gear ratio 9 : 100. Because only 'on-off' control is possible in the system, Kity can go forward, turn left, and right, but can take no backward motion.

3 Immune Networks

Given rich chemical environment present in a highly evolved organism, it is inevitable that foreign organisms will attempt to invade in an effort to make use of these resources. To counteract this, in vertebrates the immune system has evolved to identify and dispose of foreign materials. This is done in part by antibody molecules that tag foreign materials and mark them for eventual removal by lymphocytes, phagocytic cells, and the complement system. The specialized portion of the antibody molecule used for identifying other molecules is called the *antibody combining region* or *paratope*. The sequence of amino acids making up the paratope determines its shape and hence the set of other molecules that it can react with. If the shape of an foreign antigen molecule matches that of the paratope, the antibody can attach itself to the antigen, leading to its eventual demise. The regions on any molecule (antigen or antibody) that the paratopes can attach to are called *epitopes*. The set of all paratopes is like a very large collection of keys, and the set of all possible epitopes a very large collection of locks. Recent studies on immunology have clarified that each type of antibody has also its specific antigen determinant called *idiotope*

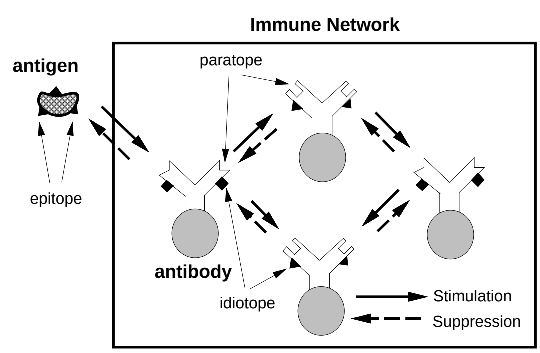

Fig. 3. Basic concept of immune network.

Based on this face, Jerene who is an immunologist proposed a remarkable hypothesis *idiotypic network hypothesis* [4]. This hypothesis explains that antibodies do not exist independently in living organism, but communicate with each other through idiotope and paratope.

This idea is schematically shown in Figure 3. These mutual interactions (stimulation and suppression) chains between different species of antibodies form the large-scale closed chain loop which works as a self and non-self recognizer. The important point of Jerne's idea is that the immune system does not act as a unit-level recognition system but as a system-level recognition system.

4 Application of Immune Network to Kity Control

A a table-look-up immune network is employed to solve problems that arise to achieve a given goal of an autonomous micro-robot. The algorithm is implemented and tested with the micro-robot Kity. With a very small number of sensors it is possible to generate enough rules to make the robot achieve the goal to navigate freely in a maze that consists of channels and nodes.

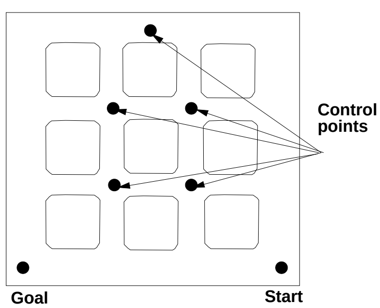

Fig. 4. Maze for 1 $inch^3$ robot.

Figure 4 shows the maze in which Kity should run. Control points are where Kity should pass by at least once. Because of limitation of the structure due to the size, we mainly focused on solving the following problems for Kity to navigate any path in the maze with only the 2 contact sensors.

- Turning a corner; left or right at a node.
- Traversing a node.
- Percepting when it is stuck by the wall because of the rough terrain on the playground.

The first two problems are graphically described in Figure 5 and 6. Figure 5 (a) shows a cornering motion. In this motion, Kity should check if it has

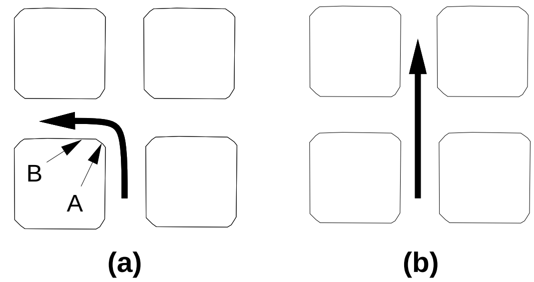

Fig. 5. Trajectories for turning a corner and traversing in a node.

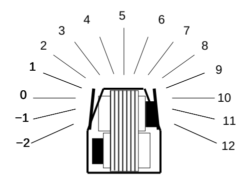

Fig. 6. Numbered orientation for antibody.

turned a corner or has not yet. Figure 5 (b) shows a going straight motion in a node. If Kity has a good command of these two motions, it is able to navigate any path in the maze by just inputting a sequence of traversing a node, turning left at a node, or turning right at a node. Here, let us define Mode 1 as a motion of traversing a node and Mode 2 as a motion of turning at a node. For these motions, antibodies are defined as in Figure 7 and Figure 8, respectively. Orientation of Kity was defined and denoted by numbers as in Figure 6. The number of antibodies used for Mode 1 is seven, and that for Mode 2 is nineteen. The longer the antigen, the smoother Kity's motion at a node in Mode 2.

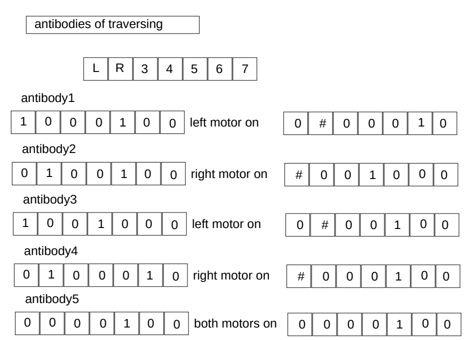

Fig. 7. Antibodies for traversing a node.

The last problem is an additional one. Because of the discrepancy of the center of wheels, it is liable to occur when Kity runs on a channel with a rough terrain. The problem should be considered in mind when attending a contest.

Figure 7 shows some examples of antibodies for traversing straight and Figure 8 for turning left. Similarly, antibodies for turning right can be defined. Two sensor information and the orientation of Kity are used for each antigen. L indicates the left-hand side sensor detects a wall, R indicates the right-hand side one does, and each element of the rest parts is a corresponding orientation. The symbol # denotes 'don't care' condition. The behavior of antibody of maximum concentration is chosen as a proper one.

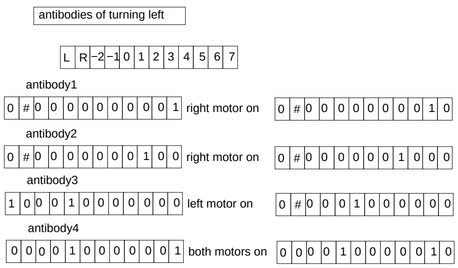

Fig. 8. Antibodies for turning left.

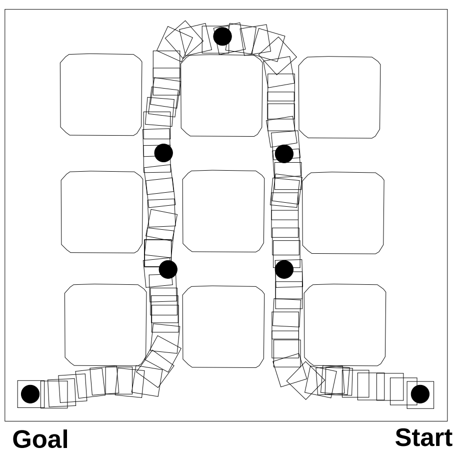

Fig. 9. Kity's Trajectory.

When Kity navigated in Mode 1, the concentration of antibodies for running straight was increased such that it could keep Kity run straight. After traversing a node and when reaching another one, it changes the mode according to the input sequence of Mode 1 and Mode 2. It was observed that when Kity ran in Mode 2 at a node, the concentration of antibodies for rotation was increased (at point A in Figure 5 (a)) and after entering a channel (at point B in Figure 5 (b)) the concentration of antibodies for going straight was increased. This makes Kity notice that it has turned a corner completely. This confirmation of having turned a corner is very important because Kity doesn't have a precise encoder or odometer. These points at which the confirmation has been done are used as internal landmarks; Kity compensates its accumulated error at these points. It was possible to generate a look-up-table that describes the sensor input and output to actuators. With this table, the calculation time could be reduced.

Figure 9 shows an experimental result of Kity in a maze. Kity's trajectory might be almost perfect one that a micro-robot can have.

5 Conclusion

Limitation in size of micro-robots makes it difficult to realize them as autonomous ones. In this paper, to achieve an objective under a restrictive environment the immune network has been used for an autonomous micro-robot. By making a look-up-table of the network results, the calculation time could be reduced. This table-look-up method makes it easy to implement in a small size micro-robot like Kity. Kity ran the shortest path in the maze with this rule table by 52 seconds at the contest, which gave the first winner place to Kity.

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References

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