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子計畫二：生物群體協調行為之探討與無線通訊機制之整合

(2/3)

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微型仿生生物體之研發 (2/3)
子計畫二：生物群體協調行為之探討與無線通訊機制之整合 (2/3)
Study of Group Behaviors of Biological Systems and Integration of Wireless Communication Protocol Design

計畫編號： NSC 93-2213-E-002-049-
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中文摘要

本計畫為“微型仿生生物體之研發”整合型計畫之子計畫二，主要在探討生物系統中群體內與群組間的行為科學，從了解生物系統之資訊交換機制，進而設計一套適用於多群組仿生工程系統之無線通訊協定。本子計畫第二年度主要的執行內容，依據生物群體行為模式以建立多群組動態通訊模式，同時，維持群體間彼此通訊品質之連接性。利用維持通訊品質的的演算法包括分散與集合兩種模式的演算法，以此演算法可以分別達到擴散至可能搜尋的區域，並且經由傳遞式的通訊協定，讓所有的群體聚集到所找尋到的目標物。除了理論分析之外，並且將此演算法利用電腦程式進行模擬，以及利用無線通訊模組測試，不管是電腦模擬或者是實體測試，皆已經獲得良好的初步成果。

關鍵詞：生物群體行為、動態通訊協定、群體散開演算法、群體集合演算法、射頻通訊模組

Abstract

The proposed project plans to design wireless communication protocols in a dynamical environment of micro bio-robotic systems based on the study of the group behaviors of biological systems. In the second year, the project research mainly focuses on the movement algorithms of multi-agent team or group. The movement algorithms include dispersion and concentration algorithms that are used for distributing and collecting, respectively, the team of agents under the communication limitation. The algorithms are designed based on the observation from biological system and tested on the computer simulation as well as the experimental wireless test-bed at the laboratory.

Keywords: Biological behavior, dynamical communication protocol, dispersion algorithm, concentration algorithm, radio frequency communication

I. Introduction

Multi-robots systems are an important research area nowadays. The most remarkable characteristics of multi-robot system is that robots operate in the same environment and work to complete a task cooperatively. Since the complexity of tasks or application domains is increasing, the ability of multi-robots should be enhanced [3]. So the artificial intelligence of multi-robots has been presented in recent years. And implementing the biological behaviors on multi-robots is a kind of artificial intelligence. The robots with the biological behaviors are called bio-mimetic robots, “bio-robot” for short in the following discussion.

In recent years, bio-robots system has a broad range of engineering applications. For example, military reconnaissance, surveillance, planetary exploration, and geophysical mapping are typical applications of bio-robot system [3].

The objective of the research focuses on exploration or foraging and concentration. In the exploration task the robot must spread in the environment in order to collect as much information as possible about the exploratory area. In the concentration task robots must move to the same place for retrieving the exploratory robots or transporting the target. Putting out a fire source or planetary exploration are attractive applications.

In the cooperation of multi bio-robots the communication is important. Bio-robots can exchange the information with each other and gather the collected information by communication. So the communication architecture is necessary in the multi bio-robots system [9].

In this research, the communication information is used as an input to the development of a dispersion algorithm for exploration or foraging and concentration algorithm for concentration. The detail description can be seen in the following.

II. Research Contents

Problem formulation

Figure 1 is the main concept of the algorithm. Each robot has its sensing range and communication range. There are many formation moving algorithm are developed by the information of sensor. For example, CCD camera sensor, odor sensor, and infrared sensor are very common sensor. When the target or robots are not in the sensing range of a robot, the robot would move randomly to sensing the target or robots. But the communication range of a robot is much larger than the sensing range. So if the robot can fully utilize the information which is transferred by communication, the searching process could be simplified.

The main objective of this research is that how to develop a moving algorithm only by the information of communication. However, the robots are not required to increase sensors for localization. For example, global positioning system (GPS) is a precise location sensor. The moving algorithm only utilizes common communication information to build. First one is communication link density. It is the number of neighbors. This information can tell the master robot the number of robots in the little region is large or small. Second one is the intensity of communication signal. This information can tell the robot the distance between any two robots. Because the intensity of communication signal can't be measured very precise, only the approximate distance between two robots can be obtained. These two kinds of information are not only easy to get but also doesn't need to intend any location sensor. So they are not very suitable for the development of the moving algorithm.

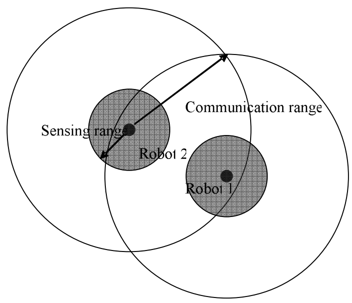

Figure 1: Relations between communication range and sensing range

The natural world is a rich source of problem-solving approaches. So the biologically inspired behavior is used to design fields of intelligence robot and simple rules on avoiding rules, swarm rules, and team formation rules for robots. Robots are obtained on the basis of summarizing some active characteristics creatures. The robot can imitate behavior of creatures to finish a complex task [12].

In order to map the biological behaviors to engineering applications, it is necessary to identify the class of mission concept first. When the mission concept is identified, an appropriate biological model can be matched to the mission. The mission of the algorithm uder development is that all robots can disperse uniformly in an unknown environment and forage the target. According to the idea, several biological models are proposed by other researchers. There are many researchers have previously examined the feasibility of mimicking biological behaviors in robotic systems. Table 1 is significant inspiration for biological models for foraging and search and finding behaviors that might be mimicked by the search robots. The search target is assumed not to leave any cues or chemical trail for robots to follow. The robot would not discovery the target until the target is in its sensing range. From the information of Table 1, in addition to the biological model of E. coli bacteria, the others are not suitable for our moving algorithm. The action after the robot senses the target is another important research.

Table 1: Biological models and associated search and find or foraging behaviors [10]

Biological Model	Class of Behavior	Behavior
E. coli Bacteria	Foraging	Random work movement
Moths	Reproduction/ Seeking Mate	Following a chemical gradient indicating increasing presence of resource.
Birds	Communal foraging	Following a competitor to locate a resource
Ants	Trail following	Following a chemical trail to locate a resource
Bees	Communication	Following a directions to locate a resource
Sharks, Bats	Hunting	Finding prey through non-visual cues
Foxes, Wolves	Landscape tracking	Environmentally determined search path

Moving Algorithm

Figure 2 is the flow chart of the moving algorithm. Before movement, each robot will check its state. If there is not any robot senses a target, the robot would run the dispersion stage, or the robot would run the concentration stage.

Figure 3 is the concept of dispersion stage. Nodes represent the bio-robots. The circle means the communication range of a robot. And the line between two nodes means that they can communicate with each. So the dispersion stage shows as Figure 3. The initial state of nodes is stay together, after the dispersion stage, they will disperse uniformly but the robots can not be partitioned.

Figure 4 displays the concept of concentration stage. The gray area is the sensing range of a robot. When one robot senses the target, it would broadcast a message to its neighbors and its neighbors would route the message to the robot which is not in the communication range of finding robot. The robots receive the message would change it state to concentration state. They would not stop until they sense the target.

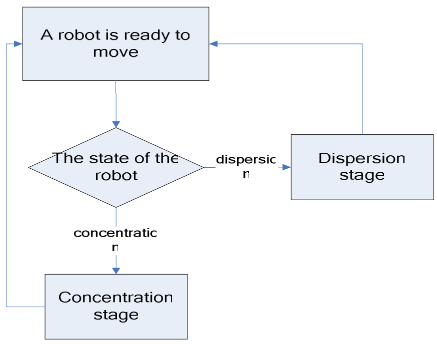

Figure 2: The flow chart of the moving algorithm

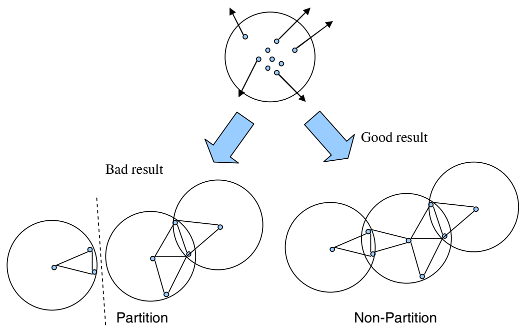

Figure 3: The concept of dispersion stage

The basic action of the robots is divided into four actions: go forward, go backward, move left, and move right. Just as shown in Figure 5.

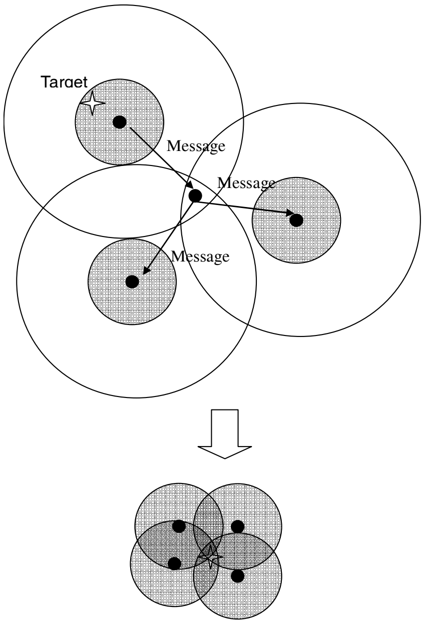

Figure 4: The concept of concentration stage

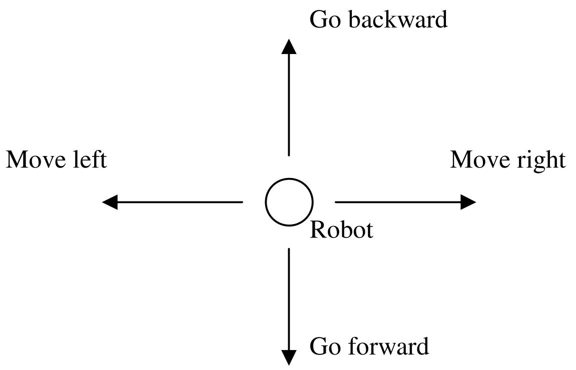

Figure 5: Behavior definition of the robot

Definition of the Moving Algorithm

n: The number of robots in the ad hoc network system.

i: The index of robots, i=1,2,3…………n.

k: The index of moving step.

$Pi(k)$: The position of the i-th node at th k-th step.

R_{ci}: The maximum distance between two nodes which they can communicate with each other.

$R_{Pi}(k)$: Partition avoiding range $R_{Pi}(k) < R_{Ci}$

$Ni(k)$: Neighbors of the i-th node

$$Ni(k) = \left\{ \begin{matrix} j = 1 \sim n \\ i \neq j \end{matrix} \,\middle|\, |Pi - Pj| \leq Ri \right\}$$

$N_{ci}(k)$: The number of neighbors of the i-th nodes at the k-th step.

$N_{pi}(k)$: The number of nodes in the i-th node's strength range at the k-th step.

Nss: The goal number of the neighbors in the $Rpi(k)$.

nd: The goal number of the neighbors.

The Dispersed Moving Algorithm

The purpose of this moving algorithm is that every bio-robot would disperse uniformly in the exploratory area. The most important behavior of a bio-robot is that robots would move to the area which the communication links density is low. But each robot should keep a fixed number of neighbors for ensuring that the robot would not lose the communication with other robots. So the communication link density (the number of neighbors N_r) is the judged information of the algorithm. We would set a goal number (nd) for the robots. If N_r of the robot is larger than nd, the robot would move to the area which N_r is smaller. On the contrary, the robot would move to the area which N_r is larger. And if the N_r is equal to nd, the robot would stay at the same position. On this condition, robot should imitate the behavior of E. coli bacterium. The E. coli bacterium behavior is the ability for robot to move according to the density of communication links of the environment.

$$Pi(k+1) = Pi(k) + Di(k)\theta i(k) \qquad (1)$$

Equation (1) is representative of the algorithm. Let $Di(k)$=>0, denote a step size that we will use to define the lengths of steps during moves. $\theta i(k)$ denotes the direction of movement. In our moving algorithm, $Di(k)\theta i(k)$ should be designed to satisfy that the number of neighbors at next steps is equal to nd.

In order to complete above purpose, $Di(k)$ is either 1 or 0. If $Ni(k)$ is not equal to nd, $Di(k)$ is 1. Otherwise $Di(k)$ is 0. It means that the step size of nodes is one unit at each step.

Because the communication links is the judged law of nodes, the large step size will change the communication link quickly. So the small step size is more suitable for this algorithm. And the small step size makes the mobility little, so the probability of partition will decrease.

$\theta i(k)$ will be decided by the communication links density. If the communication links density of a node is too high, the node would move to the position which the density is low. On the other hand, the node would move to the position which the density is high. The method which how to decide $\theta i(k)$ refers to behaviors of bacterium foraging. A node would use the past few steps of communication links density to decide the direction at this step.

<u>Designing the value of Di(k) for Dispersion</u>

-----------($N_{ri}(k) >$ (nd+1)) ‖ $N_{ri}(k) <$ (nd-1)

nd is the goal number of the neighbors. If a robot's neighbor number is larger than (nd+1), it means that there are too many other nodes in the communication range of the node. So the robot should move to the other position. The same of above, if a robot's neighbor number is less than (nd-1), it means that there too less robots in the communication range of the robot. So the robot should move to the other position. Or the robot may lose the communication with other robots.

<u>Designing the value of θ i(k) for Dispersion</u>

A. Case 1.

$\theta i(k)$ =random direction.

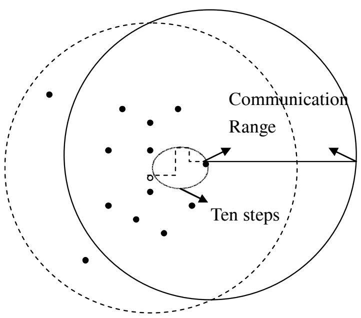

Figure 6 : The action of case 1

As shown in Figure 6, the robots in case 1, they would move ten steps in random direction to find the best direction. When robots in case 1, it would not care the difference of the number of neighbors. The dotted line is the trajectory of this case. The following situation, the node would run this case:

1. In the beginning of the moving algorithm, robots don't store any data in their memory. So they will move in random direction.
2. When the number of neighbors at this step is larger than last step. It means that the last step direction is not a good direction. So the robot would run 10 random steps to find a good direction.

B. Case 2.

If Nri(k-1), Nri(k-2), Nri(k-3), ……. and Nri(k-10) are not all the same.

Then $\theta i(k) = \theta i(k - J)$

$$J = Inf \arg \min_{j = 1 \sim 10} |Nri(k - j) - nd|$$

nd is the goal number of the neighbors. $\theta i(k)$ in this case is decided by the communication links density. The best direction from the past 10 steps is obtained. $|Nri(k - j) - nd|$ is the difference between the number of neighbors of ith node and nd. The value of the difference is smaller means that the direction of that step is closer to nd. Then the direction is the best direction. But if $|Nri(k-1) - nd|$ is larger than $|Nri(k-2) - nd|$, it means that the last step direction is not a good direction. So the robot would run case 1.

C. Case 3.

If Nri(k-1)= Nri(k-2) =Nri(k-3) …….= Nri(k-x).Then $\theta i(k)$ = random direction.

And $\theta i(k) = \theta i(k+1) = \theta i(k+2)$ ……… $\theta i(k + y)$.

Figure 7 shows the case 3. This case means that the communication links density is all the same in little region. After foraging x steps, the node would decide a direction randomly and maintain the direction for y steps. During the y steps, if the communication links density Nri(k+m) is changed, the $\theta i(k + m + 1)$ is decided by case 2. The Figure 7 is the situation of that the number of neighbors changes in the y steps duration. So the robot will decide the direction by case 2.

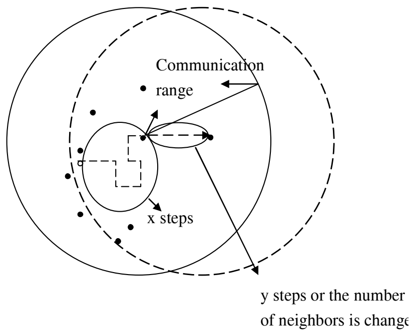

Figure 7: The action of case 3

The Concentration Moving Algorithm

The basic concept of the concentrated moving algorithm is almost the same with the dispersed algorithm. The difference is that $Di(k)$ $\theta i(k)$ in the concentrated algorithm should be designed for nodes can concentrate to a little region. $Di(k)$ is either 1 or 0, too. $\theta i(k)$ is decided by the difference of communication links and the relative position.

The concentrated moving algorithm is divided into two phase. The first phase of the algorithm is that robots move to the location nearby the sensing robot by the information of relative position. The $\theta i(k)$ at second phase is decided by the difference of communication links. If the communication links is vary in the last few steps, $\theta i(k)$ is decided by the variation. When the communication links are the same, robots would move by the spiral surge algorithm (SSA).

In the ideal case, the robot in phase one can move to the location very closed to the target. Then robot can find the target quickly by the spiral surge algorithm. But the counters may not be precise by the influence of the environment. For example, the height of the topography or the rugged surface of the plane will make counter imprecise. So the phase two is divided into two case is necessary.

Designing the value of Di(k) for Concentration

When the state of robot is set to run concentrated algorithm, the node will not stop until it sensing a target. So the $Di(k)$ of nodes are equal to one until the nodes in the desired location.

Designing the value of θ i(k) for Concentration

A. **Case 1**: $\theta i(k)$ is designed by the relative position

Each node has four counters to count the direction of the movement of the node. The four counters can support the information of relative position between the moving node and the special node. The moving node can utilize the information of relative position to move to the surroundings of the special node. In Figure 8 is an example of this case. Nodes in (a) are at their initial position, and their direction counters are 0. Figure 8 (b) is the situation that a node finds the target. The symbol "x" represents a node which senses the target. When the node senses the target, it would send a message to neighbor nodes. The content of the message should include the data of these four counters. The node which receives the message would transform its state from dispersion to concentration and send the data of finding node to its neighbors again. The concentrated node would calculate its virtual coordinates and compare it with the coordinates of the sensing node. Then the concentrated node can move to the surroundings of the finding node quickly. The node in Figure 8 would move right for 45 steps and move back for 5 steps to the surroundings of the finding node. So $\theta i(k) = \theta i(k+1) = \theta i(k+2)$ …..= $\theta i(k+44)$ =move right. And $\theta i(k+45) = \theta i(k+46)$ ….. $\theta i(k+49)$ =go back.

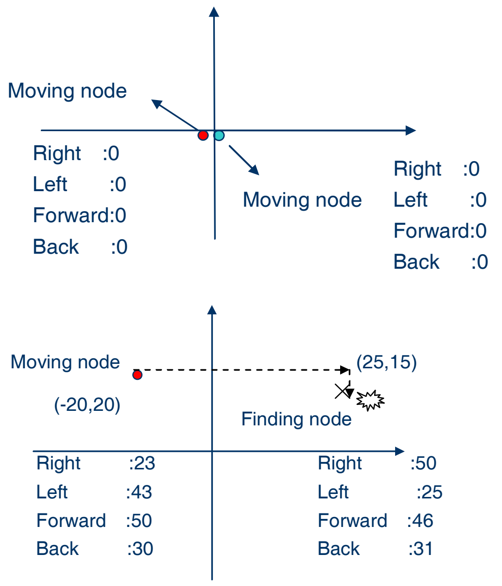

Figure 8: An example for case 1 (a)(b)

B. **Case 2**: The spiral surge algorithm(SSA)

If Nri (k-1) = Nri (k-2) =Nri (k-3) ……. = Nri (k-x), the robot would move by the spiral surge algorithm. The spiral surge algorithm is a basic search algorithm. Figure 9 is the search path of the algorithm. When the concentrated node moves to a location nearby the sensing node, it would use the spiral surge algorithm to search the target. The size of spiral gap can be set.

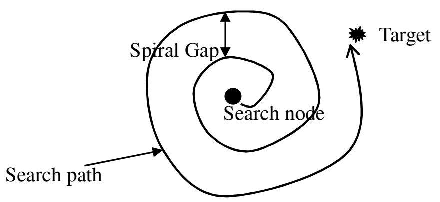

Figure 9: The spiral surge algorithm (SSA) [5]

C. **Case 3**: $\theta i(k)$ is designed by the difference of communication links

If Nri(k-1), Nri(k-2), Nri(k-3), ……. and Nri(k-10) are not all the same.

Then $\theta i(k) = \theta i(k-J)$

$$J = Inf \arg \max_{j=1\sim 10} |Nri(k-j)|$$

$\theta i(k)$ in this case is decided by the communication links density. We would find out the best direction from the past 10 steps. The basic design way is the same with dispersion algorithm. The only difference is that the dispersed algorithm finds the minimum of $|Nri(k-j)-nd|$, but the concentrated algorithm finds the maximum of $|Nri(k-j)|$. And if $|Nri(k-1)|$ is smaller than $|Nri(k-2)|$, the robot would run 10 random steps to find a good direction.

Communication Architecture

In order to accomplish the moving algorithm, we should find suitable communication architecture for bio-robots. The communication architecture that we requested is that does not rely on a fixed infrastructure and work in a shared wireless media. Such a network, called a mobile ad hoc network (MANET), where the network topology changes dynamically due to the robot mobility. Each robot functions not only a host but also as a router. The robot acts a router can forward data to other robots which are in the network but not within direct wireless communication range. [6] So routing is an important work on our research.

Physical layer

The communication hardware of the bio-robots is RF transceiver. The characteristics of RF transceiver is short communication range and can communicate with the robots which are in their transmission range.

Figure 10 is the architecture of our experiment. CC1010EB will connect with a PC by RS232. There are four nodes in the picture. The four nodes can receive data from the node which is in its communication range. There is one node is embedded in the CC1010EB, so it can print and store its data in the PC. The data will demonstrate that the moving algorithm can work on the hardware.

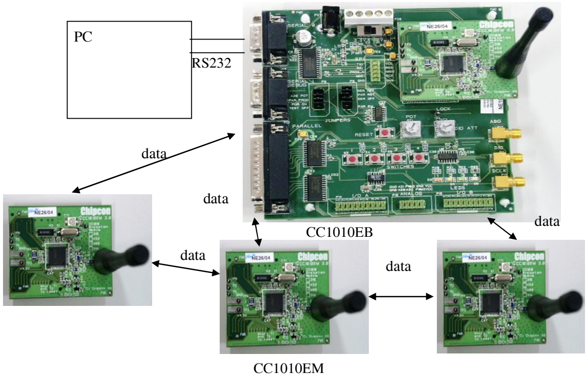

Figure 10: The architecture of the physical layer

Packet format

The Table 2 is the format for the transportation packet. The functions of each column are described as follows:

Robot ID:

Every robot should have its unique ID. Then the robot who receives the information can judge that which robot sends the data.

Time:

Each robot has a timer. When a robot is power on, the timer will enable. And when the robot wants to send data, it will get time from the timer and send the sender time out. If a robot receives a packet, it would get time from timer and store the received time for every robot. The sender time can support the information of that the packet is new or old. So the receiver can determine which packet should be drop and which should be save. The received time is important information for judging the number of neighbors. The receiver will check variance between now time and last received time. If the variance is larger than certain value, the robot will not include in the receiver's neighbors. For example, we set the certain time is 60 seconds. When the timer of robot 1 is 30senonds, robot 1 receives the packet of robot 2. Then if robot 1 doesn't receive the information till the timer of robot 1 is 90 seconds. The robot 1 will not consider robot 2 as its neighbor.

Transportation power:

The output power of robots can be controlled. The packet can be send by different power. The robot who receives the packet can judge the rough distance of sending robot. And this information can support the robot to decide the direction of movement.

Temperature:

Robots has thermo-sensor, they can measure the temperature and send it to other robot.

Routing table:

The function of routing table is avoiding the packet transfer repeated between two robots. We will discuss detail in section 4.2.3.

Table 2: The format of the transportation packet

Robot ID	Time	Transportation power	Temperature	Routing table

Routing layer

The information diffusion within a group is an important problem. There are many researches about the routing protocol. But this problem is not our subject, so we didn't do a lot of effort on this topic. Only a primitive routing protocol is used in the research. Because the robot in the network need to send data to other robots, the data should transfer one by one to the robot out the source's transmission range.

In our algorithm, the global information doesn't have destination. Because this information should be transfer to all robots in the network, we hope that it can be transferred as far as possible. So the receiver doesn't response acknowledgement and the sender doesn't send a request. The data is send to the network by broadcasting. When the data is broadcasted from robot to another robot, the packet may transfer between two robots several times. As show in Figure 11 the packet A is transferred in two nodes. For the sake of avoiding the situation, we add the routing table in the transportation packet. The routing table would store the robot ID which it ever passes. Then when a robot receives a packet, it would check its ID with the ID in the routing table. It there is certain ID in the routing table the same with the received ID, the receiver would ignore this packet.

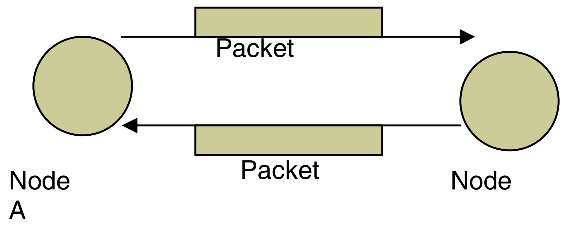

Figure 11: packet A repeats between node A and node B

III. Experiment and Simulation Result

Simulation for Moving Algorithm

In this section, we choose suitable parameter to simulate the moving algorithm. Assume that the counters in this case don't be influenced by the environment.

Parameter setting

Communication of a node: 100
Number of all nodes: 49
nd: 4
x: 20
y: 50
$Rpi(k)$: 50
Nss: 2.
The center of the plane Location of target: (720,500)
Sensing range of robot: 20
small Spiral gap: 20
large Spiral gap: 100
Initial location of the nodes for the simulation: all nodes at the center of the plane.

The Figure 12 is the process of first dispersion. The robots don't disperse to the final situation. Because that there is a node which is in the coordinates (700,500) senses the target. The triangle (△) at coordinates means a target. The node sends a finding message to other robots. The robot which receives the message would not run the dispersed action. It would move to the location nearby the sensing robot and sense the target. In the Figure 13 is the situation which all robots sense the target. When robots complete a task, they would disperse again to search other targets. As regards how to complete a task, it doesn't discuss detail in this research. So we set that if all robots sense the target, the task is completed. The Figure 5.14 is the final result of the algorithm. The center of the circle (O) is at coordinates (720,500) and the radius is equal to the sensing range of robots. So the region in the circle is the new initial position for the second dispersion.

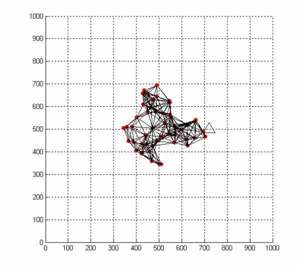

Figure 12: The process of first dispersion (times 316)

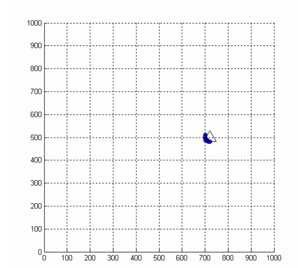

Figure 13 : The robots sense the target (times 807)

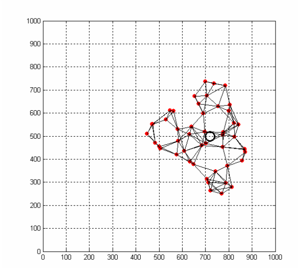

Figure 14: Final result of the algorithm (times 1610)

IV. Conclusions

In this research, the concept of bio-mimetic robots and the relationship between the behavior of animals and environment are studied. The behavior of E. coli bacteria is analyzed and modified for the implementation of the robot moving algorithms. Only the information of communication links (the number of neighbors) and rough distance between two robots is used to develop a dispersion algorithm and a concentration algorithm. This information is not only easily got but also doesn't equip any sensor or instrument. In order to avoid the partition of the bio-robots, the information of rouge distance to decrease the mobility of bio-robots is further used.

Several simulation and experimental studies are performed. Part of algorithms is implemented in the CC1010 chip and a simple communication protocol is coded in the CC1010 chip for robots transporting data one by one.

In the future, the algorithm in terms of the computing the exploratory area for n robots will be analyzed and the probability of partition and efficiency of the algorithm will be further characterized. Furthermore, the complete set of algorithms with routing protocol will be implemented in the CC1010 chip.

計畫成果自評

本計畫在第二年度依據預定之進度已完成生物系統中多群體間之通訊協定設計與運動模式之設計。此運動模式乃是基於維持群體間個體的通訊連結性，包括分散運動演算法與集中運動演算法。分散運動演算法乃是在於一個未知環境中啟動探勘或偵測時所採用的運動法則，等待群體中的任一個個體發現了目標物之後，首先將此目標物的相對位置傳遞給其他個體，然後其他個體則採取集中運動演算法向目標物的位置集中。此類演算法以成功地利用電腦軟體模擬，以及使用無線通訊平台測試完成。除此之後，此通訊協定與運動演算法亦與子計畫一的微型仿生體運動控制模組進行整合，以及搭配子計畫三有關智慧型環境感測的演算法，以利能夠建立一套具備完整之智慧型通訊，感測與運動的多群體微型仿生機電系統之研發目標。

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