

## EXPLORING ENERGY CHARGING PROBLEM IN SWARM ROBOTIC SYSTEMS USING FORAGING SIMULATION

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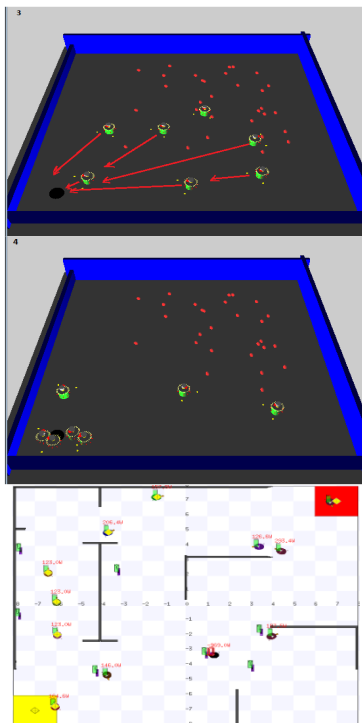
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### Graphical abstract



### Abstract

Swarm robotic systems is still a new field of study, and exploration of its applications and making use of its advantages can open the door for more research on this field in the near future. In swarm robotic systems, a number of simple robots can perform complex tasks efficiently than a single robot, giving robustness and flexibility to the group. However, robustness is one of the issues that need to be resolved as most of time the robots are suffering from low energy while performing the task. The main objectives of this paper are to highlight the robustness issue in swarm robotic systems and propose a solution to allow swarm robots to remain robust on achieving its task. To demonstrate the problem, foraging algorithm, which is inspired by ant's behaviour, is simulated to highlight the problem of low energy in swarm robotic system and its effect on its robustness. One of the solutions is mainly by using power stations or banks, but both have its own limitation which are highlighted and discussed in this paper. Finally, the paper also explains on a potential mechanism, inspired by an immune system response, that will help swarm robots overcome the problem of low energy.

Keywords: Swarm robotics, robustness, foraging, immune system response

### Abstrak

'Swarm Robotic systems' atau Sistem Kawan Robot ialah suatu bidang pengajian baru, di mana penerokaan aplikasinya boleh membuka pintu untuk lebih banyak penyelidikan di bidang ini dalam masa terdekat. Dalam sistem robotik, beberapa robot mudah boleh melakukan tugas-tugas kompleks dengan cekap berbanding daripada robot-robot tunggal. Walau bagaimanapun, ketahanan bateri adalah salah satu isu yang perlu diselesaikan kerana kebanyakan robot menghadapi masalah dengan penurunan bateri yang drastik semasa menjalankan tugas. Objektif utama kajian ini adalah untuk mengetengahkan isu ketahanan dalam kawan sistem robotik dan mencadangkan penyelesaian bagi membolehkan robot-robot tetap mempunyai tenaga bateri yang mencukupi untuk menyelesaikan tugasnya. Untuk menunjukkan masalah itu, algoritma mencari makanan, yang diilhamkan oleh tingkah laku semut, telah dihasilkan untuk membolehkan masalah dan kesan ketahanan bateri dalam sistem robotik. Salah satu penyelesaian adalah dengan menggunakan stesen kuasa atau bank bateri tetapi kedua-duanya mempunyai had sendiri yang diketengahkan dan dibincangkan dalam kertas kerja ini. Akhir sekali, kertas ini juga menerangkan mengenai mekanisme yang berpotensi, diilhamkan oleh tindak balas sistem imunisasi, yang akan membantu robot kawan mengatasi masalah sistem kawan robot.

Kata kunci: Sistem kawan robot, ketahanan bateri, sistem imunisasi

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## 1.0 INTRODUCTION

Swarm intelligence (SI) is a field of artificial intelligence that is inspired by insects, birds and other animals known in nature for their self-organized behaviour [6, 7, 13]. SI system consists of a group or a swarm of simple systems or agents interacting and communicating with each other and their environment. Swarm Robotic (SR) is part of SI that is concerned with controlling and coordinating a multiple small robots [3, 12]. Swarm Robotics (SR) is a new field of study [3, 12], defined by [13] as:

“The study of how a large number of relatively simple physically embodied agents can be designed such that a desired collective behaviour emerges from the local interactions among agents and between the agents and the environment”.

From the definition, we can understand that swarm robotics is an approach towards controlling the behaviour of multiple simple robots in a way that a collective behaviour is achieved. The field of SR was inspired by insects and ant's behaviour [3, 6, 7, 12 13]. The approach takes its inspiration from the social insects, which according to [7, 13] demonstrate three desired characteristics: robustness to partial failure, flexibility in adapting to new and changing requirements, and scalability to support larger or smaller number of members.

This new approach of a swarm of multiple small robots has many advantages over the classical approaches of single robot or man-bot. One of the most important advantages of swarm robots is robustness or fault tolerance. Robustness or fault tolerance, can be defined as the degree to which a system can still function in the presence of partial failures, which in the case of SR is achieved from the terminology itself [3]. Having multiple robots working on the same task simultaneously and coordinately allows the loss of some members of the swarm, while others continue carrying out with the task. However, the overall outcome of the task may not be the same when members of the swarm continue to fail. In the case of low energy, for example, robots will need to recharge their batteries and re-join the swarm in performing the given task, otherwise, the task will take longer time to be achieved, and the failing robots may become obstacles in the way of active robots. Not many research on the energy-charging problem in swarm robotics have been done. While [8] studied using the behavioural model to improve the energy of a swarm robotics in foraging task, [14] focused on maintaining the energy in swarm robotics. On the other hand, [11] proposed an energy-sharing algorithm inspired by an immune response, where members of the swarm share some of their own energy with low energy robots. Drawing inspiration for immune system response, [11] proposed an algorithm in which members of the swarm are compared to immunity cells fighting pathogens such as bacteria. In that scenario, a robot with low energy is thought of as an infected cell, and other robots are immune cells surrounding the

infected cell to fight the infection and not allowing it to spread. In her proposed algorithm, [11] suggested that other robots would surround the robot with low energy upon receiving a help signal initiated by the infected robot, and share some of their energy based on different methods to determine how much each robot can share. This approach of energy sharing may help robots with low energy to be recharged, but it means other members of the swarm are losing their energy at the same time. This paper uses simulation tools to study the use of power stations in swarm robotic system while performing a foraging task, as an introductory research for further development of an energy-charging mechanism for swarm robotic systems. We will have a close look into swarm robotics and its application by simulating foraging behaviour in swarm robots, and use this simulation to further clarify the energy problem. For the simulations, we will use two tools; Simbad and Player/Stage. Simbad is a 3D swarm robotic simulator that uses 3D java programming language and offers a wild range of features for educational purposes [5]. Player/Stage is a 2.5D swarm robotic simulator using C++ programming language [10].

This paper aims to 1) explore the use of simulation tools as a platform to evaluate the effect of energy loss on the robustness of swarm robotic systems in foraging task, 2) simulate the use of power stations in swarm robotic systems and identify its limitations and 3) propose an energy charging mechanisms that encapsulate the swarm behaviour to solve the problem obtained in (1) and (2). Two different simulation tools used to demonstrate basic applications of swarm robotics systems and energy charging mechanism. With Simbad simulator, foraging algorithms for swarm robotics is shown and explained in details, and the energy problem is highlighted as the result of this simulation. Then, an energy charging mechanism using power stations is simulated, shown and discussed. This mechanism allows a robot to find a power station once its energy is low. The robot is going to find the nearest power station to get the energy. It is applied in swarm foraging algorithm and simulated using Player/Stage simulator.

## 2.0 ALGORITHMS AND SIMULATION

### 2.1 Foraging

The foraging algorithm for swarm robotics is inspired by the foraging behaviour of ants. According to [8], ants mark trails leading from the nest to food and back by depositing a chemical pheromone on the ground. In order to simulate this swarm behaviour, we sent the robots into an environment with pre-specified shape, size and number of food items, in search of food. In case of an encounter with food, robots will pick it up, and move to the nest. For the implementation of this algorithm, we used the central control method where robots don't communicate with each other directly, but they report their activities to the control central where the decision is made about where the robots move,

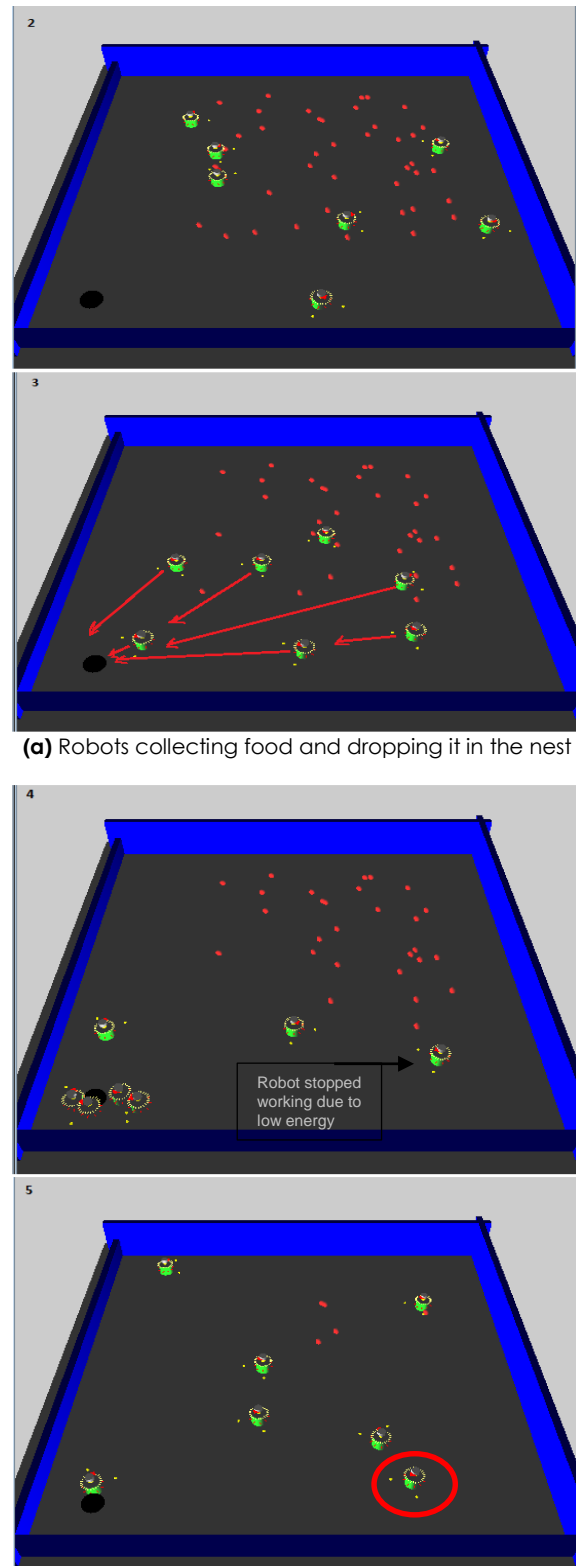
should they pick up food or drop it. Each robot also implements an avoidance algorithm that allows the robot to move in the environment while avoiding obstacles and other robots. The snapshots of the simulation on the foraging algorithm are shown in Figure 1. From the subfigure (a) in Figure 1, we can see that the environment is initialized to have 40 food items (red colour), and 7 E-puck robots randomly placed in the environment. When the simulation starts, the robots will start moving in the environment with random velocity until they encounter food, which they pick up. When a robot picks up food, it moves toward the nest where it drops it and go on again to move in the world and pick up more food. As the robots start collecting food, one robot experiences an energy shortage, and it is in need of recharge, the robot is pointed out in subfigure (b). Now the swarm is working with 6 robots instead of 7, after one robot, circled in subfigure (b) of Figure 1, cannot take part in collecting food.

With robots working in a finite environment where they move randomly and pick up food, and with the absence of a method for nearest path or shortest path to the nest, it is safe to assume that the more robots we add to the environment, the faster the task will be done. The task will finish when all the 40 foods have been collected from the environment. Table 1 shows the time and average number of trips of running the same simulation with a different number of robots.

**Table 1** Time and round trips for running the foraging simulation with different number of robots

Number of robots	Number of food items	Average trips per-robot	Task time(in seconds)
7	40	5.71	435
5	40	8	559
3	40	13.33	782

For 7 robots to pick up one food item every time and go to the nest to drop it, and assuming that all robots make the same number of trips from and into the nest to pick up and drop food, we will have an average of  $40/7 = 5.7$  trips from and into the nest for each robot, and 435 seconds to finish the task. These numbers will increase to 8 round trips in case of 5 functioning robots while 2 failed due to low energy, and a simulation time of 559 seconds. Although the system is robust in the way that the task will eventually be completed, but it can be done more efficiently and faster with all members of the swarm properly operating with sufficient level of energy. A higher average trip for every robot to make to the nest means more energy will be consumed, and it also means that the time taken to finish the task will dramatically increase with less functioning members of the swarm.



(a) Robots collecting food and dropping it in the nest

(b) 6 robots about to finish the simulation, while one robot (circled) is not working anymore due to low energy

**Figure 1** Foraging algorithm simulation using Simbad simulator

## 2.2 Energy Charging Using Power Stations

We have tested our swarm foraging robots using Sinbad simulation tool. Now using Player/Stage simulator, robots have to search for food in the environment and charge themselves in case of low energy by finding the nearest power station. Twelve robots work in an 8m x 8m square-shaped arena. Unlike the previous simulation, food in this simulation is gathered in one area indicated with a yellow colour, and the nest is indicated with a red colour. The arena used in this simulation has some barriers placed in the arena to simulate obstacle avoidance by the robots.

### 1) Operation

Behaviours of the robots in this simulation are:

- a) Work: where the robots do their foraging work. This work includes moving to the food source, grabbing the food, moving to the nest and depositing the food.
- b) Obstacle Avoid: Robot avoids obstacles, walls and other robots whenever their proximity sensors triggered.
- c) Dock (charging): Robots come to the power stations and set their positions to charge. After a group of robots is created in the arena, robots will do their work of find food and bring it to the nest. If a robot is hungry (has low energy), it will look for the closest power station to recharge. Once the nearest power station is found, the robot will move towards it and set the mode to "Dock" in order to start charging from the power station. As soon as it is fully charged, the robot will change the mode to "Undock" to release itself from the power station, and then continue the foraging work.
- d) Undock: Once they are fully charged, robots leave the power stations and do their work.

### 2) Simulation

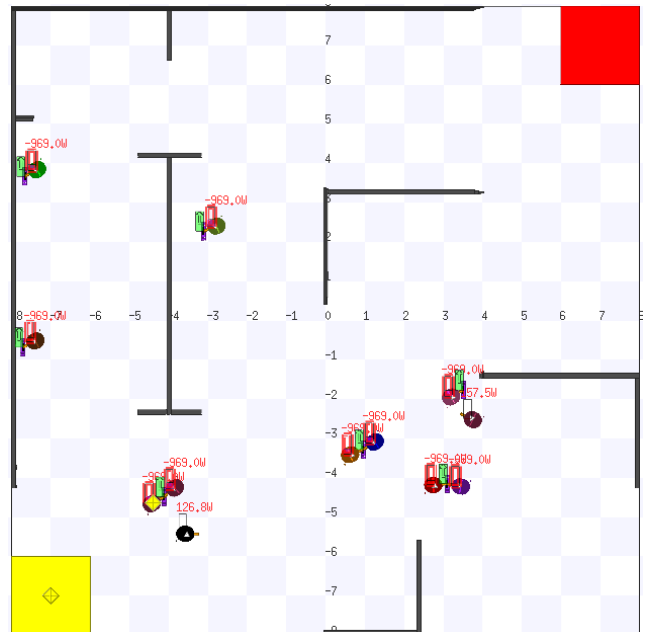
In each time step of the simulation, the robots will consume energy differently. When the energy is low, the robots are going to find the closest power stations to recharge. Recharge behaviour should be stimulated when a robot is close enough to a charging station and its internal state dictates that it needs to recharge. The behaviour should begin with the robot moving towards the charging station and attempting to dock, if the robot fails to dock, the pattern should end. If the robot successfully docks, the pattern should continue until the robot is fully charged.

A simulated world with foraging robots is shown in Figure 2, where robots, power stations, nest (red) and food (yellow) can be seen as well as obstacles and other details of the arena. The energy level of each robot is showing on top of each robot.

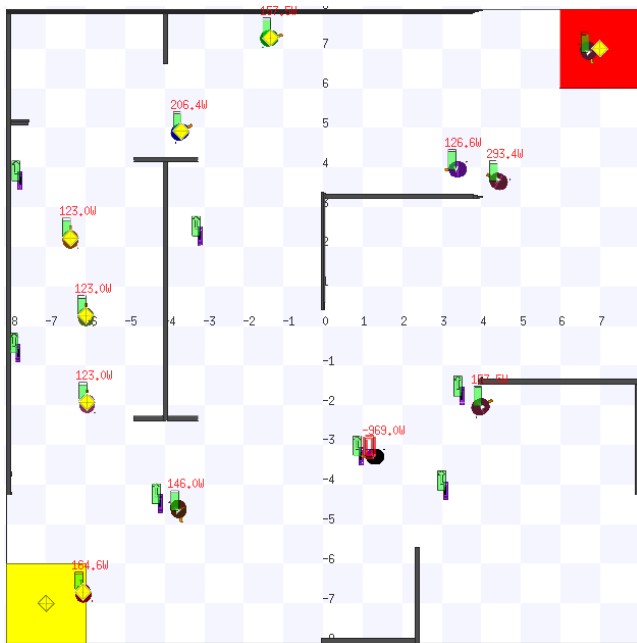
In Figure 3, robots start to charge using charging stations. Some of the robots are charging, while others are performing the work, which is carrying food to the nest as seen in Figure 4.



**Figure 2** the arena with foraging robots with their energy level shown moving in environment where power stations are deployed



**Figure 3** Foraging robots start using power stations to charge



**Figure 4** Foraging robots carrying food to the nest after charging is done

### 3.0 DISCUSSION

The foraging algorithm for swarm robotics inspired by the foraging behaviour of ants marking trails leading from the nest to food and back by depositing a chemical pheromone. We set up a swarm of robots in a world with food, and examined as the swarm engaged in the task of collecting food and dropping it into the nest. The goal of the simulation was to show the problem of losing energy and its possible effect of the overall performance on the swarm and the completion of the task. While swarm robots are more robust and fault tolerant in the way that other members of the swarm can carry on performing the task with partial failures, continuous failure of swarm units will affect the robustness of the system. Having all members of the swarm functioning and working together improves the performance of the swarm system.

Through foraging task, we examined a mechanism for energy charging. In this mechanism, power stations were used as sources of power for hungry robots to charge. This approach while seems sufficient to solve the low energy problem in a swarm system, it has limitations and shortcomings. Placing power stations in the environment where the swarm is performing their task may not be possible in every case, and it requires additional setup for the environment. Hence, it may limit the potentials of the system to be as suitable, to solve a problem or solve a task, as the setup conditions allow. In addition, it requires each robot in the swarm to have a sufficient knowledge of the environment and its setup, which contradict some applications of swarm robots such as mapping and scalability. Providing the swarm with details of the environment means that mapping in swarm robotic systems is no longer a task or an

application, but a necessity for the system to know. It also means that scalability, a desirable attribute of swarm robotic systems, is going to be limited. Scalability is the ability to expand a self-organized mechanism to support larger or smaller numbers of individuals without affecting the performance considerably [4]. It also means that the environment, which the swarm system can cover, is no longer scalable as the space now relies on the location of the power stations and the pre-mapping of the power stations' location. Another observation from the use of power stations for each robot to find and recharge itself is that it borders on being an individual behaviour rather than a swarm behaviour. Having each robot finding its nearest power station, recharge itself, then go on performing the task with other members of the swarm, can be seen as an individually driven and oriented behaviour compared to the energy sharing algorithm proposed by [11] and discussed earlier.

### 4.0 PROPOSED SOLUTION

Due to the limitations and potential shortcomings of using power stations to recharge swarm robots, and building on the proposed algorithm and its inspiration from [11], we propose a new energy charging mechanism for swarm robotic systems where additional members are added to the swarm. Using models of the process of granuloma formation in [1], we mapped the cells involved in that formation into a swarm system. Reference [1] defined granuloma formation as a medical condition that occurs because of infection of bacteria, where different types of immune cells work together to both fight the bacteria and heal the infected cells. From that mapping, [1] introduced "battery-charging robots" that initially reside in a nearby power station, and "drone guiding robots." The details of the new proposed robots and their role were further explained in [2]. [2] Suggested two mechanisms for recharging swarm robots inspired by the immune response. In the first mechanism, the proposed battery-charging robots residing at a nearby power station, will receive a signal initiated by the robots that needs to be recharged, then following the signal to find their way to the robot with low energy and charge it. The battery-charging robot does not take part in performing the task that other swarm members are involved in, and it is not necessarily equipped with the same gears and specifications as other robots. However, it has a larger battery, and it is provided with the ability of navigating and mapping large areas to find the robot requesting to be recharged. In order to overcome a possible limitation from this mechanism, [1, 2] proposed a second mechanism in which a drone guiding robots are introduced and used. Receiving a help signal initiated by a robot with low energy, a drone guiding robot will receive the signal, and use the advantage of better view of the environment, easy allocation methods and advanced allocation system to guide the battery-charging robots into the location of the robot

requesting a recharge. This mechanism makes use of the drone's ability to map large areas easily, allocate objects; identifying obstacles and finding the nearest path to make sure that battery-charging robots can find the robot requesting to be charged faster and in reliable manner, then go back to the power station until the next request comes in.

## 5.0 CONCLUSION AND FUTURE WORK

Swarm Robotics has properties that makes them more desirable and have advantages over the classical approach to robotics such as robustness and scalability. However, in the matter of low energy, the failure of members of the swarm can reflect on the overall performance and may cause the swarm to loss its fault tolerance advantage. Not much research has been done on solving the energy charging issues in swarm robotics. Inspired by an immune response, and the human body's ability to heal itself via internal communication and coordination of immune cells, we proposed a new mechanism for robots in a swarm to be recharged. The direct approach of having power station in the environment that allows robots to recharge as they need, has some limitation and can affect some applications of swarm robots, as well as require environmental setup. Based on a mapping of immune cells' interaction, we proposed the introduction of two new robots to be implemented. A battery-charging robot, equipped with a large battery, and residing at a nearby power station will come to the rescue every time it receives a signal from a robot requesting a recharge. In order to overcome certain obstacles in the environment, a drone-guiding robot is proposed. The drone-guiding robot will have the task of guiding the battery robot to the location of the robot requesting a recharge using its sky view and the ability to plan a short path and avoid obstacles. For future work, we expect the proposed energy charging mechanisms to be simulated, compared and evaluated.

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## References

- [1] Al Haek, M., Ismail A. R., Nordin A., Lau H. K. and Sulaiman, S. 2014. Modelling Immune Systems Response for the Development of Energy Sharing Strategies for Swarm Robotic Systems. *International Conference on Computational Science and Technology (ICCST)*, 2014. Kota Kinabalu, Sabah, Malaysia. 27 - 28 August 2014. ISBN: 978-1-4799-3241-2.
- [2] Al Haek, M., Ismail A. R. and Nordin A. 2014. Agent Based Modeling and Simulation of Granuloma Formation for the Development of Energy Charging Mechanism in Swarm Robots. *International Conference on Computer Engineering & Mathematical Sciences (ICCEMS)*, 2014. Langkawi, Malaysia. 4-5 Dec. 2014.
- [3] Bayindir, L. and Sahin, E. 2007. A Review of Studies in Swarm Robotics. *Turkish Journal of Electrical Engineering*. 15(2):115–147.
- [4] Bjerknes, J. and Winfield, A. 2010. On Fault Tolerance and Scalability of Swarm Robotic Systems. *Distributed Autonomous Robotic Systems*, volume 83 of Springer Tracts in Advanced Robotics: 431–444. Springer Berlin Heidelberg.
- [5] Brian, P., Gerkey, Richard, T. Vaughan, and Andrew Howard. 2003. The Player/Stage Project: Tools for Multi-Robot and Distributed Sensor Systems. *In Proc. of the Intl. Conf. on Advanced Robotics (ICAR)*, 2003. Coimbra, Portugal. July 2003. 317-323.
- [6] Dorigo, M., Birattari, M., and Stutzle, T. 2006. Ant Colony Optimization. *Computational Intelligence Magazine, IEEE*. 1(4): 28-39.
- [7] Jevtic, A. and Andina, D. 2007. Swarm Intelligence and Its Applications in Swarm Robotics. *6th WSEAS Int. Conference on Computational Intelligence, Man-Machine Systems and Cybernetics*, 2007. Stevens Point, Wisconsin, USA. 2007. 41-46.
- [8] Jong-Hyun, L. and Chang Wook, A. 2011. Improving Energy Efficiency in Cooperative Foraging Swarm Robots Using Behavioral Model. *Sixth International Conference on Bio-Inspired Computing: Theories and Applications (BIC-TA)*, 2011. Penang, Malaysia. 27-29 Sep. 2011. 39-44.
- [9] Hoff, N. R., Sagoff, A., Wood, R. J., and Nagpal, R. 2010. Two Foraging Algorithms for Robot Swarms Using Only Local Communication. *IEEE International Conference on Robotic and Biomimetic (ROBIO)*, 2010. Tianjin, China. 14-18 Dec. 2010. 123-130.
- [10] Hugues, L. and Bredeche, N. 2006. Simbad: an Autonomous Robot Simulation Package for Education and Research. *9th International Conference on Simulation of Adaptive Behavior (SAB)*, 2006. Rome, Italy. 25-29 Sep. 2006. 831-842.
- [11] Ismail, A. R. 2011. Immune-Inspired Self-Healing Swarm Robotic Systems. PhD thesis, University of York.
- [12] Miner, D. 2007. Swarm Robotics Algorithms: A Survey. Technical Report, University of Maryland.
- [13] Sahin, E. 2005. Swarm Robotics: From Sources of Inspiration to Domains of Application. *Swarm Robotics*. 4: 10–20. Springer.
- [14] Trung Dung Ngo; Schioler, H. 2006. Sociable Mobile Robots through Self-maintained Energy. *IEEE International Conference on Systems, Man and Cybernetics (SMC '06)*, 2006. Taipei, Taiwan. 8-11 Oct. 2006. 3: 2012-2017.