The Initial Investigation of the Design and Energy Sharing Algorithm Using Two-Ways Communication Mechanism for Swarm Robotic Systems

Amelia Ritahani Ismail, Recky Desia, and Muhammad Fuad Riza Zuhri

Department of Computer Science,
Kulliyyah of Information and Communication Technology,
International Islamic University Malaysia,
P.O. Box 10, 50728 Kuala Lumpur, Malaysia
amelia@iium.edu.my, {recky.qie,fuad.zuhri}@gmail.com

Abstract. Swarm Robotics (SR) is a new field of study that is mainly concerned with con-trolling and coordinating a multiple small robots. SR has several key characteristics that make it a preferable choice for a variety of tasks. The characteristics include lower cost, easiness to program, scalability of tasks and fault tolerance. The robustness from fault tolerance in SR comes from having a group of small robots working on the same task and thus enabling them to tolerate the loss of a few members of the swarm as the other members can still continue with the mission. However it has shown that continuous failure of members of a swarm such as those due to low energy have a significant impact on the overall performance of the swarm. In addition, the possibility of completion of the task is also dependent on the percentage of the swarm falling out of the group due insufficient energy. Some of the work that has been proposed by the researchers is by adding a charging station or a removable charger. However, these techniques have their own limitations. Therefore a work on having the robot(s) to charger themselves without the help of the charging station or a removable charger is proposed. But the work is only proven successful in simulation without a proper design and testing in a real robots scenario. This paper is therefore will describe our initial investigation on the design and the implementation of energy sharing algorithm using two-ways robotic swarm communication mechanism with NRF2401.

1 Introduction

Swarm intelligence (SI) is a field of Artificial Intelligence that is inspired by in-sects, birds and other animals [2, 3, and 5]. SI system consists of a group or a swarm of simple systems or agents interacting and communicating with each other and their environment. The definition of swarm intelligence denoted by [2] is:

'The discipline that deals with natural and artificial systems composed of many individuals that coordinate using decentralized control and self-organization. In particular, the discipline focuses on the collective behaviors that result from the local interactions of the individuals with each other and with their environment"

S. Phon-Amnuaisuk and T.-W. Au (eds.), *Computational Intelligence in Information Systems,*
Advances in Intelligent Systems and Computing 331, DOI: 10.1007/978-3-319-13153-5_7

Swarm Robotics (SR) is a new field of study [4, 1] that is concerned with controlling and coordinating a multiple small robots and is defined by [5] as:

> *"the study of how large number of relatively simple physically embodied agents can be designed such that a desired collective behavior emerges from the local interactions among agents and between the agents and the environment"*

According to [4, 3, and 5] robotic swarms have several advantages over their more complex individual robot and are the results of using many robots instead of just one. According to them, this is made possible because:

- It is easier to design simple robot units required for a swarm.
- Robot swarms are able to cover more area than an individual robot.
- Swarm robots are fault tolerant.
- Their effectiveness scales well with the number of members.
- The algorithms for swarms scale well and do not depend on the number of robots.
- Some tasks may be too complex for a single robot to perform.
- The communication between the robots is reduced because of the indirect interactions.
- They can accomplish some tasks that would be impossible for a single robot to achieve.

The main objective of this paper is to investigate the design and energy sharing algorithm using two-ways communication mechanism which is applied to swarm robotic systems to maintain the system's robustness with NRF2401. The rest of this paper is organized as follows: Section 2 explains on the problem definition; Section 3 describes the energy-sharing algorithm that is implemented in this paper; Section 4 explains the experimental design and Section 5 discusses the initial result which is obtained during the experiments. This paper ends with Section 6, which concludes this paper and explains our future work.

2 Problem Definition

One of the major advantages of swarm robotic systems is their robustness from fault tolerance. This is because SR has a group of small robots working on the same task and thus enabling them to tolerate the loss of a few members of the swarm as the other members can still continue with the mission. However, the work in [8] has shown that continuous failure of members of a swarm such as those due to low energy have a significant impact on the overall performance of the swarm. In this example, it relates to the time needed to complete the task. In addition, the possibility of completion of the task is also dependent on the percentage of the swarm falling out of the group due to the insufficient energy.

Because of the reason explained above, there are few algorithms that are proposed by [8] to allow robots in the swarm to share their energy without human or battery intervention. However, this work is only proven successful in simulation without a proper design and testing in a real robots scenario. This paper is therefore will describe our initial investigation on the design and the implementation of energy sharing algorithm using two-ways robotic swarm communication mechanism.

3 Literature Review

3.1 Energy Sharing

Commonly, the swarm robots use the battery charger or a charging station for their charging mechanism. [14] proposed a battery-exchanged mechanism to replace robots' with low energy with a fully charged battery. The battery station is provided with numbers of batteries that can be exchanged with any robots that have low in battery level. Therefore, if the robot's battery is about to empty, the robot needs to travel to the charging station and exchange its battery with the fully-loaded battery. As mentioned by [14], it takes around 36 seconds for each process to be completed. Furthermore, the robot also needs to travel to the charging station to exchange its battery leading to the additional travelling time for the process of changing the battery.

There is also another improved technique proposed by [15] for the charger mechanism. To save the time of recharging, a robot will be dedicated as the movable charger robot. It means that there will be one robot that works only for bringing a lot of energy to recharge the other robots when the other robots need more energy. The charger robot will continuously broadcast a message. In the time that a mobile robots battery level is lower than defined threshold level and are unable to move them, a request message will be sent to the charger robot to help them. However as mentioned by [15], there will be a case where the charger robot is out of battery in the middle of the work environment that may disturb the work of the other robots.

Due to the weaknesses described in [14] and [15], there are few proposed techniques by [8], which are inspired by the immune system that allow the robots in the system to share the energy of their battery without the help either the charging station and/or a charging robot(s). They are (1) Single Nearest Charger Algorithm, (2) Shared Nearest Charger Algorithm and (3) Granuloma Formation Algorithm. Basically, the algorithm principle is like this, the energy threshold is set to indicate the minimum energy of one robot before they can donate to another robot. If one robot send message for help so the other robot that has more energy will come and share the energy. But if one robot cannot help another robot so the robot leaves and let the other robot that have more energy to be shared to help. The techniques that are explained in [8] can help the robots in the system to share their energy and help each other as well as they can complete the task together. However, the technique is only proven successful in the simulation.

3.2 Communication between Two Robots

The energy sharing is a mechanism where a robot shares their energy to their partner when their partner needs to be charged. It means that there is cooperation between two robots or more. Therefore, if the energy sharing is implemented in a robot work system, there should be any communication between two robots or more to enable them to communicate. So the communication between robots becomes a main system that should be implemented.

Many application for mobile robots need to communicate with each other by using ad-hoc networking. [9] proposed and evaluate two routing protocols tailored for use in ad-hoc networks formed by mobile robot teams. The teams consist of Mobile Robot Distance Vector (MRDV) and Mobile Robot Source Routing (MRSR). Both protocols perform efficient routing. The simulation study shows that MRDV and MRSR incur lower overhead while operating in mobile robot network while compared to old mobile ad hoc network routing protocols.

Moreover, a new IVC communication architecture for platooning systems is proposed in [10]. Some weaknesses on DSRC are identified if used alone in such data demand scenarios. By adding a new communication technology to each vehicle, using IR and transmitting most of the control data through it, IVC constraint can be solved.

Furthermore, [11] proposed a common wireless remote control system for laboratory mobile robots. In this system, a single wireless IEEE 802.11g network is adopted for communication and a robot inside/outside two-level Client/Server architecture is utilized. This kind of system structure is suitable for latter any scale extension. Here different kinds of laboratory mobile robots are all regarded as one kind of special sensors, the system is transparent. To guarantee the IEEE 802.11g network performance in huge data transmission cases, an improved case of installing strong marine bridges for mobile robots is presented.

Another paper, [12], shows the implementation of a wireless system for the control of mobile robots using circuits with Self Timed (ST) Synchronization, implemented in reconfigurable devices FPGAs. The system is composed of a global network of small ST with the blocks of Xbee wireless transmission, of each processing unit, which will develop independent processes communicated by means of Modules of wireless transmission that form the network of activation of peripheral units. Besides that, a paper [13] shows a design of autonomous mobile platform that can be controlled using a GPS and electronic compass. The mobile robot is equipped also with MaxSream XBee Pro 2.4GHz radio modem communication module.

Moreover, for the moveable charger project [15], the robot is equipped with six infrared diodes and phototransistors for communication between the mobile charger and other swarm robots. Infrared and phototransistors of occupied docking station will be disabled during active charging. This behaviour prevent mobile robot from docking to occupied charger station.

Since different mechanisms of communication have been used by other researchers, in this paper another mechanism is proposed which is NRF2401. NRF2401 is a communication module that can be used to transmit and receive data. The NRF2401 offers the following benefits: (1) Highly reduced current consumption, (2) Lower system cost (facilitates use of less expensive micro controller) and (3) Reduced risk of ‘on-air’ collisions due to short transmission time. [16] proposed a design of group robots system based on wireless communication by using NRF2401. The result of the experiment shows that the system can achieve the wireless communication between the Master Robot and the Slave Robot successfully.

4 Experimental Setup

4.1 Robot Design

The initial experiment is done with two simultaneous robots with the design and components that are shown in Figure 1 and Figure 2. There are two part of robot body which are the upper part and the lower part. In the upper part, we put breadboard, Arduino Mega 2560 board, LCD, 3 LED's as notification, Arduino sensor shield and

NRF2401 as communication with other robots and Arduino Bluetooth module as communication with user as shown in Figure 1. The experiment has been done in 4 x 8 arenas and each cell has a measurement of 30 cm x 30 cm. The length and height of the obstacle are around 30 cm and 15 cm respectively. The horizontal and vertical value is provided to be processed by robot to construct its area of the map by calculate between the two values, start point is also given by user.

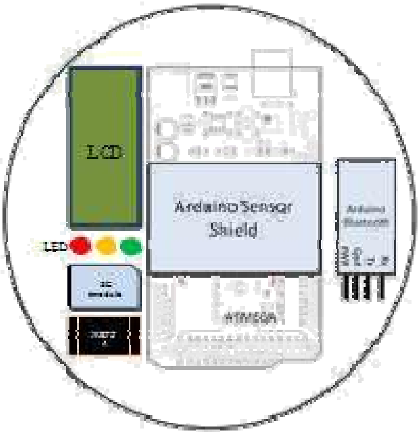


Fig. 1. The design of the upper robot body

In the lower part, we put ultrasonic sensor, driver stepper motor, stepper motor, battery box and wheel as shown in Figure 2. There are also few parameters that need to be included during the experiment. The parameters are:

- Start Point
- Destination
- Life Energy
- Energy to be shared

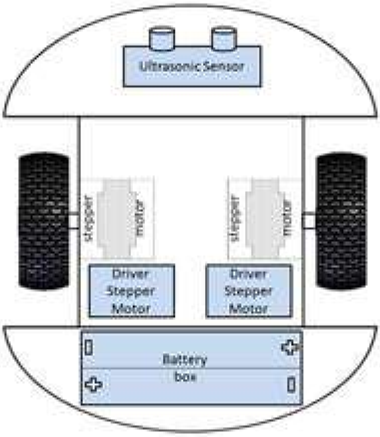


Fig. 2. The design of the lower robot body

4.2 Communication Algorithm

The algorithm describes in Algorithm 1 and Algorithm 2 below is the 2 ways communication used in- swarm robots. It contains the step by step instructions for trans-mitting and receiving command and also including energy sharing. This is how the scenario is look like. In beginning, each robot will have different energy levels; the energy will show in LED (red, yellow, green). During some activities the energy of the robot will reduce, when energy is empty the robot will stay in position and send help command and also the position, the other robot which is who is in free not exe-cute any command will go to position location of robot that ask for help, it is done by "first replay" method which is when the robot ask for help, some of robot will replay the Massage then the robot will choose the robot that who first replay the massage. After the other robot arrive, the other will give the energy to the robot by sending the random number as the energy to share from the energy but no more than half of the energy and the number of energy of other robot will reduce by number of the energy shared.

```
if  energy  is  empty
  then  robot  will  not
  move
  repeat
    robot stops listening
    robot  speak  by  sends  help  command  and  the
  position robot start listening
    wait

  if  get  notification  there  other  robot  is  going  to
    help break
```

```
      get notification other robot is arrive the robot
    position
      wait for energy transmission process
      get notification that energy sharing process is
    done turn on the notification led based on energy
    else
      continue looping
```

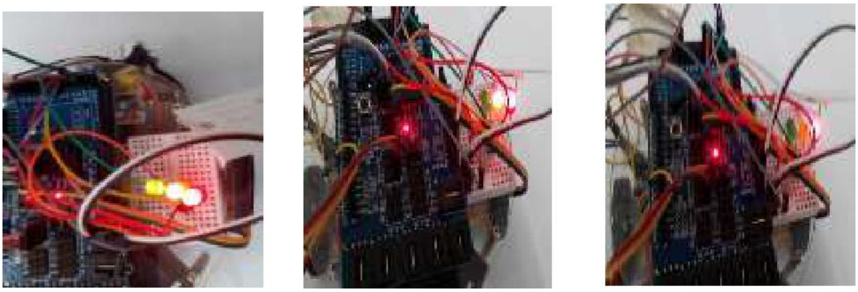
Algo. 1. Algorithm for transmitting by NRF2401, in a case of a robot that ask for help

```
if energy is not
  empty then
    if listen any help
      command then
        robot get
        destination robot
        stops listening
          robot speak by sends notification that the
        robot going to help
          go to the destination
          robot speak by sends notification that the
        robot arrive
          robot share the energy but not more than 50%
        of the energy
          robot speak by sends notification that energy
        has been shared
    robot start listening
  turn on the notification led based on energy
level else
    robot do work
```

Algo. 2. Algorithm for receiving information by NRF2401

5 Result and Discussion

During this initial experiment, we make a comparison between the energy of the robots over time. We assume that during their work, the robots move from the start point to the destination point and throughout the movement, robot's energy is reduced. There are also obstacles in the environment and the robots used the obstacle avoidance algorithm to avoid obstacles in order to arrive to the destination point. The environment in this experiment also can be dynamic due to the robot can detect moving object and will avoid the object such as the robot will avoid other robot that moving inside arena beside avoid the obstacle itself. In depicting the energy level, each robot has three LED lights that show either their energy is: (1) high, (2) medium or (3) low. This is shown in Figure 3 below. In (a) for a high energy level, three (3) LED signals is shown. Meanwhile for medium (b) and low (c), two (2) and one (1) LED signals are shown respectively.



(a) (b) (c)

Fig. 3. Energy notification as depicted in: (a) Full robot's energy with three LED is ON. (b) Medium-low robot's energy with two LED is ON. (c)Low robot's energy with only one LED is ON.

Figure 3 shows the example of the LED signals that is shown during the ex-periment. In figure 3(a) and 3(b) robot is randomly assigned high and low energy value. During the experiment, robots are assumed working by moving from start point to the destination point. The path that the robot will follow in arriving to its destina-tion is also provided. Here different colour of LED showing different energy level is shown. For example in 3(a) the robot has high level of energy followed by medium low level of energy in 3(b) with two (2) LED signal and low level of energy signal as depicted in 3(c). This is to provide information on the level of energy during the ex-periment is conducted.

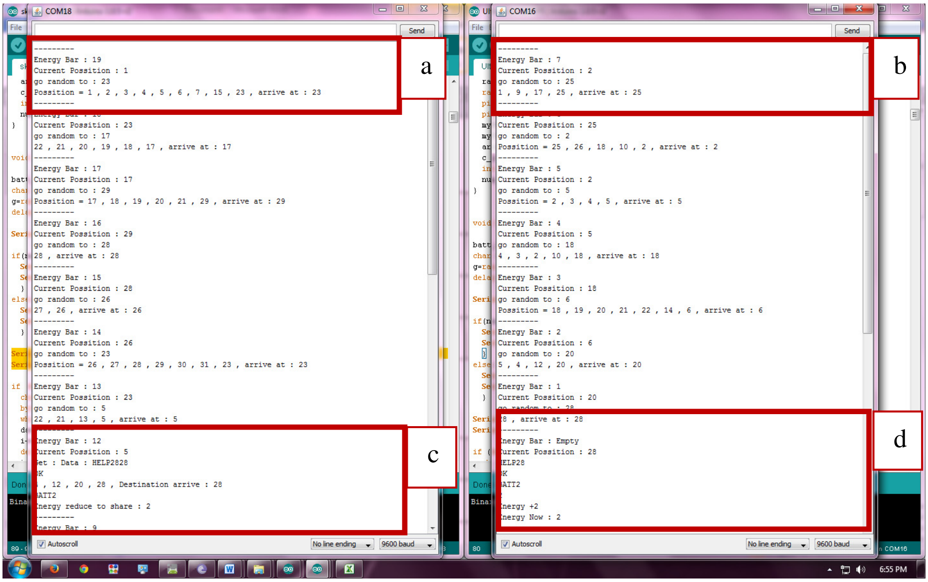


Fig. 4. The output from the algorithm testing during the experiment: (a) position and energy level of the robots; (b) Robot do its work move from start point to destination point; (c) Energy level is reaching threshold and robot starts to ask for help and receive help processes; and (d) Energy transmitting process.

During the experiment, the output is displayed using Bluetooth communica-tion between the robots and a mobile device to identify the correctness of the algo-rithms that have been developed. This is shown in figure 4(a), (b), (c), (d) and figure 5(a) and (b). Figure 4(a) and (b) show the output from the experiment that displays the position and energy level of the robot and the position of the robot is shown. In 4(c) is an example of message that the robot receives from other robot that ask for help, which is shown in figure 4(d) because of their energy level is zero. In the case of the receiver robot has enough energy, it will move to the robot with zero energy to share its energy. Then, the output shows that one of the robot's energy is reducing and another is increasing due the course of energy sharing mechanism that is conducted throughout the experiment.

The previous example is the scenario when a robot has enough energy to be shared; however there is also a scenario where the energy cannot be shared dues to the reason that both robots have low energy level. This is shown in figure 4(a) that shows the robot denies helping due to low of energy then the robot will send denied massage to other robot and continue doing its work. Figure 4(b) shows the robot get deny mas-sage by other robot to help and stay in its current position and there is no increased in its own energy.

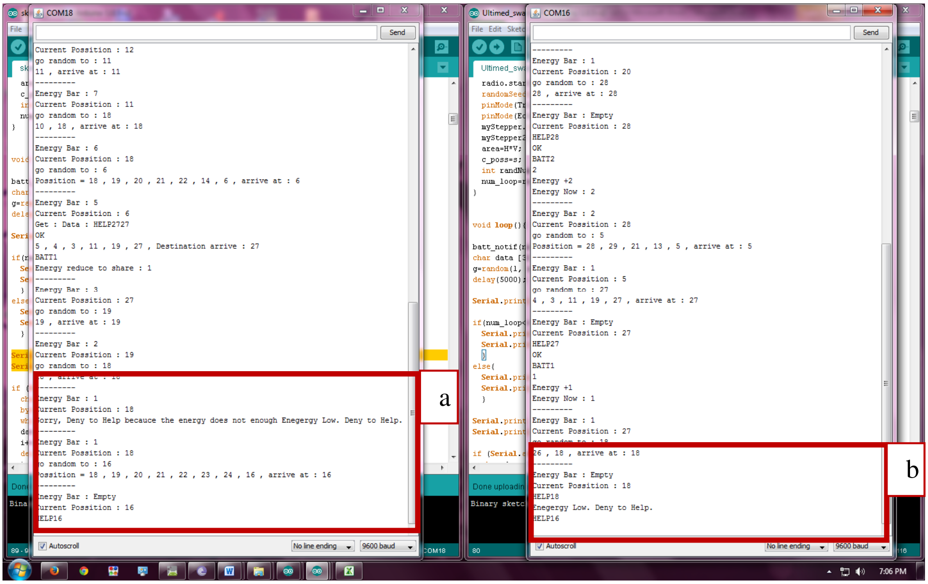


Fig. 5. The feedback that get by user during testing: (a) The robot denies to help. (b)The robot get a deny massage

In figure 6, the energy levels over time of the two robots that have used are shown. In the beginning of the experiment, one of the robots is given a high level of energy and the second robot is given a low energy. The energy levels are then reduced slowly as both robots do their work. When one of robot's energy level reach 0 or empty, the robot will stay in the current position and transmit help command and its position to the other robot. The robot will repeat this process until he get notification that his command has been listen by other robot. The other robot that gets the message will then move to the position of the robot and share the energy, energy that will give to the robot must not be more than 50% of the robot energy. However the robot can deny helping the robot with the low energy if its own energy is low.

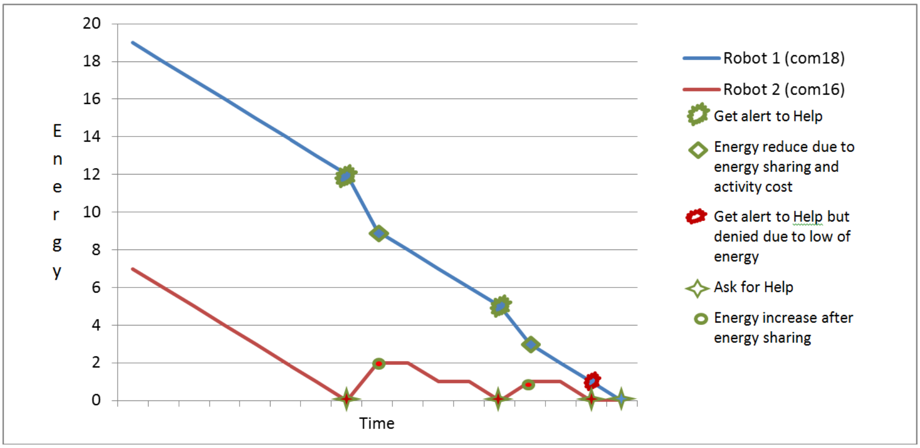


Fig. 6. The energy level of the robots during the experiment over time

6 Conclusion and Future Work

As a conclusion, the initial result that we obtained based on our design and implementation of the energy sharing algorithm has a potential to be implemented in the larger scale of swarm robotic systems. It is our hoped that the algorithm can be successfully implemented in a large swarm robotic systems to study on the effectiveness and the efficiency of the algorithm as well as the design that we have obtained so far.

Acknowledgement. This research is funded by the Ministry of Higher Education under the Exploratory Research Grant Scheme (ERGS): ERGS 13- 017-0050.

References

1. Bayindir, L., Sahin, E.: A review of studies in swarm robotics. Turkish Journal of Electrical Engineering 15(2), 115–147 (2007)
2. Dorigo, M., Birattari, M., Stutzle, T.: Ant colony optimization. IEEE Computational Intelligence Magazine 1(4), 28–39 (2006)
3. Jevtic, A., Andina, D.: Swarm intelligence and its applications in swarm robot-ics. In: 6th WSEAS Int. Conference on Computational Intelligence, Man-Machine Systems and Cybernetics, pp. 41–46 (2007)
4. Miner, D.: Swarm robotics algorithms: A survey. Technical report, University of Maryland (2007)

5. Şahin, E.: Swarm robotics: From sources of inspiration to domains of application. In: Şahin, E., Spears, W.M. (eds.) Swarm Robotics 2004. LNCS, vol. 3342, pp. 10–20. Springer, Heidelberg (2005)
6. Pineda, L.E., Eiben, A.E., van Steen, M.: Evolving Communication in Robotic Swarms Using On-Line, On-Board, Distributed Evolutionary Algorithms. In: Di Chio, C., et al. (eds.) EvoApplications 2012. LNCS, vol. 7248, pp. 529–538. Springer, Heidelberg (2012)
7. Di Caro, G., Ducatelle, F., Gambardella, L.M.: Wireless communications for dis-tributed navigation in robot swarms (2009)
8. Ismail, A.R.: Immune-Inspired Self-Healing Swarm Robotic Systems. Ph.D. dissertation, University of York, United Kingdom (2011)
9. Das, S.M., et al.: Efficient Unicast Messaging for Mobile Robot. In: International Conference on Robotics and Automation, pp. 93–98 (2005)
10. Fernandes, P., Nunes, U.: Platooning with DSRC-Based IVC-Enabled Autonomous Vehicles: Adding Infrared Communications for IVC Reliability Improvement. In: Intelligent Vehicles Symposium, pp. 517–522 (2012)
11. Liu, H., et al.: A Common Wireless Remote Control System for Mobile Robots in Laboratory (2012)
12. Ortega-Cisneros, S., et al.: Implementation of A Wireless Control System with Self Timed Activation for Mobile Robots, pp. 205–208 (2008)
13. Jaskot, K., Babiarz, A.: Autonomous Mobile Platform II. In: 12th International Carpathian Control Conference, pp. 167–171 (2011)
14. Vaussard, F., et al. (n.d.): Towards Long-Term Collective Experiments
15. Arvin, F., Samsudin, K., Ramli, A.R.: Swarm Robots Long Term Autonomy Using Moveable Charger. In: International Conference on Future Computer and Communication, pp. 127–130 (2009)
16. Cai, G., Harada, Y.: Design of Group Robots System Based on Wireless Communication. In: International Conference of Information Technology, Computer Engineering and Management Sciences, pp. 19–22 (2011)