

Harvesting wireless sensor node data via swarm mobile relays robots

Abstract

Harvesting wireless sensor node data by the mobile collector is a method that has received considerable attention in recent years. In this paper we investigate the problem of collecting Wireless sensor node (WSN) data when deployed randomly. To avoid networking between WSNs and base station, we use multi-robot exploration to find them, collect their data and transfer information to the base station. In this work we use a balanced way instead of full coverage exploration strategy to optimize consumed time for finding sensor node. In this approach; we combine the common spanning tree exploration and segmentation strategy to reach the acceptable method. This approach divides the exploration area into several regions and then each robot separately collects data to determine the less explored segment for more exploration. Indeed experiment results show noted algorithm.

Keywords: wireless sensor, data collection, terrain exploration, swarm robot, mobile relays, mobile elements

Volume | Issue | - 2016

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Received: August 26, 2016 | **Published:** October 18, 2016

Abbreviations: WSN, wireless sensor node; WSRN, wireless sensor and robot networks; STC, spanning tree coverage; MR, mobile relays; ER, exploration ratio

Introduction

Recent improvements in microelectronic and low power devices have led to a very advantageous device named wireless sensor network (WSN). WSN is a commonly used device to measure sensing parameter in the environment or other places.^{1,2} WSN's smart capability like size and networking make them very useful and functional.

If we want to measure a sensing parameter like moisture or temperature in a broad area like desert or forest, we need to spread too many WSN in that area.³ In this situation, networking between them is probable but we need to supply more WSN nodes or increase their signal power to transmit data in the wider range.^{4,5} Although the transmitting ranges in WSNs is usually more than sensing range but in the situation that we don't need to sense the whole field. Measuring of a sensing parameter by such approach has some disadvantages because placing more node is not economical and also putting the more sinks or relays between them is not appropriate.³ Furthermore, boosting the signal power because more energy being consumed as transmitter module in WSNs is the major energy consumer.² Since for saving energy resources in WSNs, we need to tune the transmitter signal power in the lowest range.⁶ However, deploying WSN is another issue that needs concern in full networked WSN's nodes, so it is needed to choose a point to place the nodes and sinks.⁷ Indeed in non-networked nodes, we can spread them with a helicopter without any concern of their location when we want to make a random sample of some parameters in the field.^{8,9} So in this scenario, we can use the mobile robot to collect and harvest their data. By using mobile collector, without knowledge about WSNs position, we go through exploration algorithm in unknown environments. The problem of exploration area is a key for harvesting and servicing wireless sensor node. Moreover, this field is going to combine the wireless sensor network and robot we go through the

new area named wireless sensor and robot networks (WSRNs). WSNs and multi-robot systems¹⁰ are the results of WSRNs systems. Swarm robot system which works like an ant, fish and any other biological collectives is appropriate kind of mobile robot which wants to do the job as a team work.¹¹ In this paper, we use swarm robot as wireless sensor mobile sink to collect WSNs data. Swarm robots.¹² Is a kind of multi-robot systems which is one of the current discussions in recent years? Swarm robotic consists of several mini smart robots; they can be used instead of very complicated robots, especially in exploration tasks as they can be separated easily in the area. As soon as swarm robots enter to unknown environment to fulfil the specific task, they start to communicate between each other to grasp more knowledge about environment and also the tasks.¹³ Swarm robot communication is similar to other multi-robot systems communication and several studies have been produced in this field.¹³⁻¹⁵

In this study, we use the peer to peer architecture to maintain a way of transferring data among swarm robots. Indeed for exploration algorithm we use spanning tree¹⁶⁻¹⁷ that is improved with segmentation strategy¹⁸ that helps swarm robot to explore the area for finding the wireless sensor nodes.

- i. We show the advantage of our algorithm to fulfil exploration task in an unknown area like harvesting wireless sensor data. In section.
- ii. We consider on related work. The system overview is in section.
- iii. Section.
- iv. Is about servicing task. Spanning tree algorithm was discussed in section.
- v. Section.
- vi. Is about improving spanning tree with segmentation strategy in section.
- vii. We describe the experiment result about robot specification and simulation setting, in section.
- viii. We discuss and analyse the result .Finally, we conclude remark and future work in section.

Related works

In this paper we use swarm robot for harvesting WSNs data, this task is related to the swarm foraging for energy grasping¹⁹ harvesting data from the wireless node by using mobile collector is related to different studies in wireless sensor network deploying and connectivity along with a mobile sink and a mobile node. Liu et al.¹⁹ in his work show 4 different strategies for foraging robots, these strategies differ in cues. Liu describes the cues as internal, environment and social. Li et al.²⁰ presents two major tasks for servicing wireless sensor network. The technique presented in their work consists of two parts. First is task allocation in which a task is assigned to one robot when it appears to be fulfilled, in practice negotiation algorithm for doing the task. Koutsoukolas et al.²¹ suggests trajectory algorithm to localize wireless sensor networks. This study has shown that 2-H technique is very effective in reducing error in localization wireless nodes. Using WSNs in urban area and collecting their data with mobile collector is the featured idea in Konstantopoulos²² Study This study suggests and simulates technique of using the urban vehicles with fixed trajectories for carrying mobile sink. Data gathering with using Mobile collector for our research was proposed by Ma et al.²³ they used spanning tree coverage for mobile tour and decomposed tree to sub-trees and found the shortest tour for each of them.

Another area that related to our research is communication in multi-robot system. Several studies have been done about communication in multi-robot are based on Bluetooth radio. Tardioli et al.²⁴ described enforcing network connectivity by using spring-damper model. In this model, spring-damper saves the connection without breaking. Another aspect of their study is to present the whole system for a rescuing mission with a separate module which guarantees system conception. Most of the exploration algorithm was retrieved from frontier based algorithm by Yamauchi²⁵ in this method; robots try to find safe and free obstacle way to continue the tour to achieve the goal. A regular grid map has presented by Moravec and Elfes²⁶ A cell in this grid can be defined as free, occupied or unknown. For selection any of these options, all kind of range sensor can be used. Yamauchi uses this grid to define a frontier base algorithm. In his work the frontier cell is a free cell that can be next to one unknown cell. The market principle is another way to select a particular location for exploration which was used in Zlot et al.^{15,27} works. In market approach each palace bids is based on cost factor for robots like travelling distance or terrain. The aim of market concept is to minimize the cost and increase benefit for exploration. In a work done by Gerkey and Mataric et al.²⁸ Auction-based technique is used to achieve efficient task allocation. Mataric et al.²⁹ presents another method for task allocation, they analyse team performance in broad experiment. The Hungarian method³⁰ is another way for assigning task which is used by KO.³¹ The hybrid reactive/deliberative approach which has been shown by Julia³² solves this problem. Hybrid approach with restricted safe zone can deal with local minima problem. Segmentation of the environment is a kind of exploration. This strategy was addressed by Wurm²⁸ that divides the area to segments and then allocates each segment for individual robot and move robot to allocated segment. In this method some benefit was achieved, first is overall exploration time is reduced and the robots team work was balanced for each robot also this strategy can help to avoid interference between robots. Furthermore Segmentation strategy can reduce redundant exploration in multi-robot team work.

Spanning tree coverage (STC) is another exploration algorithm which can be applied in offline or online mode for constructing the

tree,¹⁶ presented 3 different algorithms for coverage of continuous area which are based STC algorithm. The method was presented in this paper is based on single robot exploration. In Gabriely's work, area divided into disjointed cell which is used for expanding the spanning tree. The first algorithm in Gabriely work is off-line which constructs spanning tree before starting exploration. The second version is an on-line version of STC which uses some sensor to detect the environment for identifying obstacle and constructing spanning tree. Finally, the third one is an ant like version, in this type of STC; robot explores the unknown environment by leaving pheromone to mark the place which is explored. Instead of single robot, multi-robot system can be used too.³³ In his work introduce one multi-robot exploration task which avoids backtracking by robots. They use off-line method of spanning tree algorithm. A spanning tree algorithm which is based ant-like pheromone spreading and implementing with multi-robot system was presented by³⁴ in this study pheromone-like marker used for as a coordinator between robots to cover the terrain³⁵ Demonstrated multi-robot coverage based STC algorithm. In this work the area is divided between robots and each robot explores own section. Also in this algorithm like other terrain consists of several grid cells. Also³⁶ are improving his last work named simultaneous Multiple STC (S-MSTC,S-MSTC) use ant-type robot like natural ant. Furthermore this algorithm can deal with narrow opening in coverage area.

In addition to avoiding obstacle we use wall follower method³⁷ Our work uses these methods and improves it, and then we have one exploration algorithm for finding wireless sensor nodes, harvesting their data and moving them to the base station. The robots that can do described task named mobile relays (MRs).

System overview

In this section, we first describe the swarm system behaviour to collect data from wireless sensor nodes. Then we address the strategy to transferring data to the base station, along with describing limitation of the system.

Swarm robots when enter to an unknown environment, firstly they trying to communication with each other to grasp the information about tasks. In our work they should find the sensor that like foraging in natural swarms. Communication between robots is another aspect of swarm's robots that is similar to communication in natural swarming such as spreading pheromone and tactile communication in ants³⁸ and dancing in bees. In this paper we proposed communication like tactile in ants and they tactile each other using wireless signal. Tactile communication in ants is used for recanting each other³⁸ and also in robots swam is used for transferring data between each other. The information needed to be transferred in our work about regions and WSNs nodes in the regions in which robots want to communicate with each other.

We suppose that in this work WSNs are separated randomly for instance they deployed with helicopter. With this consumption we do not have any knowledge of their position as they don't have any positioning devices like GPS. We also suppose that WSNs always are in sleep mode and can be exited from this mode by sending bacon signal from a robot. Another aspect of WSNs is their energy consumption which makes manufacturers very sensitive in this issue. However transmitting range in WSN is effective in energy consumption. So we propose that transmitting range is minimum as only can provide the biggest obstacle in environment because robots can go through the obstacle. Thus, using sleeping mode and minimum

transmitting range, we decrease the energy consumption and the life time of WSN nodes in our work. In discussion of mobile collector or mobile elements in wireless sensors network we have different kinds of these elements.

In this section, we discuss about the servicing task for harvesting wireless sensors data. As we described in previous section, initially when sensors are deployed over the field we have not any knowledge about their position. Robots can save WSN's node position after collecting their data in first time. MRs has duty of collecting and saving data in its memory and then carries these data to the base station or a sink.

By having WSN's position we can use other path planning algorithm like travelling salesperson problem (TSP) to make shortest path for meeting all sensors. In this work each node's data needs to be collected in one hop, that is a robot only collects one node data in every transaction without any nodes in between. If a few WSN's nodes are in a robot's transmitting range, their data is collected one by one.

(Figure 1) presents an environment with deployed WSNs and one robot which are wandering in environment. In two wireless sensors are in robot's transmitting range, in this situation robot reads sensors data one by one in order by beacon signal, that is, the sensor data which sends the first beacon signal is first read by the robot.

The frequency of collecting period depends on the environment where WSNs are used. In this work, we focus on first time collecting because after that robot can save position of each WSN and can get better result by using other static algorithm. Also, the transmitting range in WSNs must be very low because of energy used mobile collector. Besides energy other problems such as noisy environment can be addressed by mobile collector. Indeed reliability in this method is high as each sensor is visited by a robot and robot can wait for responding from WSN to ensure that its data is collected.

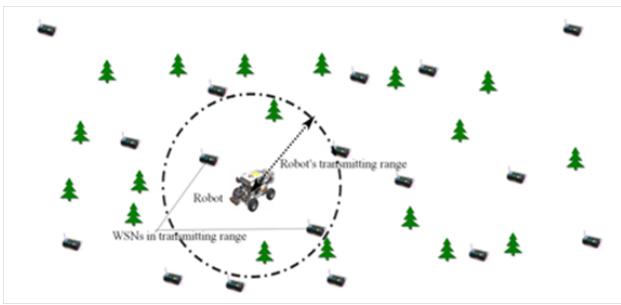


Figure 1 Environment with robots and WSNs.

Proposed spanning tree coverage scheme

In our work, we use spanning tree algorithm for exploration and coverage task. For finding wireless sensor nodes, we need to complete coverage algorithm. Also by using swarm robot which is a kind of multi-robot system, we need to have a capable algorithm to this system. Simultaneous spanning tree coverage with multiple robots (S-MSTC) which was described is used in our work with some changes.³⁶ This algorithm determines the initial position of each robot at first. However we use this algorithm with segmentation strategy that is needed to change the algorithm with capability to be in every position to construct new spanning tree. For this purpose, at first we need an on-line version of spanning tree algorithm for constructing

the spanning tree immediately.

On-line exploration needs kind of range finder sensor to recognize obstacle in unknown terrain. Indeed for constructing spanning tree robot, grid image of terrain in their memory is needed. Grid's cells size should be in relation to the range of vision of sensor (r_{sensor}) and also the transmitting range ($r_{\text{transmitter}}$) of mobile relay robots. In (Figure 2A) we can see the robot in environment with its surrounding range of wireless range and also range finder sensor. Sonar sensor is used as range finder sensor in this work. Each sonar sensor has 90 degree view angle that 4 of them have been used in each robot. By providing 4 sensors the whole 360 degree around robot is covered (Figure 2B). Shows girds cells in sensor range and transmuting range. Green cells in are completely covered cells by range finder sensor and grey cells plus green cells are fully covered by transmitting device which is built on the robot.

(A) Sensor and wireless range (B) Covered cells by robot

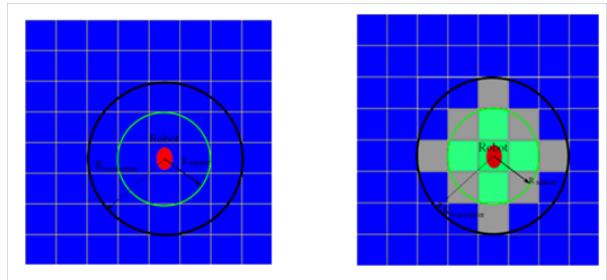
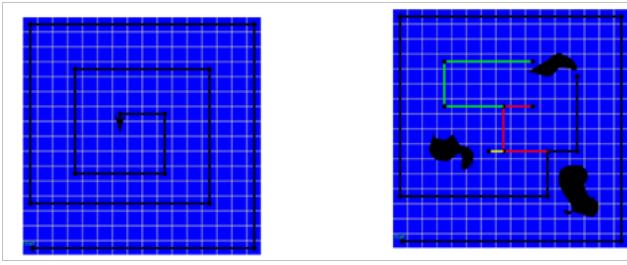


Figure 2 Sensor and wireless transmitter range.

Constructing spanning tree in our algorithm starts with the initial point of robot and continues in contraclockwise direction. In on-line algorithm, robots start to investigate environment by their sensor for finding free cell and then mark the cell as free. Cells also can be marked as obstacle if robot determines it as obstacle. In addition, robot marks two next cells in 4 directions (90°, 180°, 270°, 360°) as explored cell. When robot starts moving, it first goes to the one free cell in next forward after that if robot reaches an obstacle or explored cells, it changes the direction in contraclockwise manner. (Figure 3) Show how one robot explores the environment in free obstacle environment and with-obstacle environment. Environment without any obstacle is shown in (Figure 3A). In this figure exploration robot constructs simplest kind of spanning tree which is like a spiral path. In free obstacle environment, robots only need to have knowledge about boundary of region to path planning. In this algorithm, robots move along the edge of spanning tree. The purpose of algorithm is to find wireless nodes, the overlapping mean sending signal from two sides which can reduce out miss finding.

In environment with obstacle object; some cells are occupied by obstacle such as exploration field in (Figure 3B). In this situation, algorithm constructs non-geometric shape spanning tree because our assumption is that in natural world we cannot see any congruent shape obstacle. In this algorithm the method for avoiding obstacle is wall follower strategy. With wallflower algorithm, robot recognize the obstacle and it is moving across the obstacle to finding free cell or find explored cell that described before. Indeed algorithm deals with obstacle as a wall to find its door. If robots finds free cell, it moves to it and continues its exploration based on defined algorithm. But if robot hits the cell marked as explored, it comes back to the first cell where the robot needs to change its direction because of obstacle. To

enable the robot to do this, spanning tree algorithm needs to be written recursively. (Figure 3) we can see drafted spanning tree's branches in different colours. These are new branches added to the tree as encountering explored cells by robot. There are parent and child relations between branches. For example in (Figure 3) the yellow and green branches are child of red branches and the parent of red is initial black branches. This hierarchical relation between branches is used when robot cannot find any free cell to explore in its frontier cells. By having this relation, robot can move back to its parent or ancestor for finding new path and extending the spanning tree to explore whole area.



(A) Environment without obstacle. (B) Environment with obstacle.

Figure 3 Two spanning tree in different environment.

Using segmentation strategy to improve spanning tree

Exploration with spanning tree by multi robots system like swarm robot poses some problems. Dividing exploration task between robots is one of them. Swarm robot consisting several robots should work together as group to increase the efficiency.¹² Group working in swarm robot means that each individual robot does not have sufficient knowledge and ability to solve a task, so they need to collaborate with each other. In exploration task the main group decision in swarm robot is to determine area for each robot to explore. When swarm robots enter to an unknown environment they haven't any knowledge about the environment after a while by communication among each other they gradually increase their knowledge. In initial condition of task exploration, robots have a few choices to divide task between each other. If robots divide environment to segments they can randomly or in order select a segment to start exploration.

After a while of initial exploration and more interaction between robots, selection of segment for each robot can be based on some factors. A factor we use in our algorithm for segmentation strategy is exploration ratio (ER) for each segment. If we have same number of robots and segments without obstacle and robots have same speed, and segment's size and shape are similar, ER needs to be the same all time for each segment. However environment with obstacle and different number of robots and segments makes ER as individual for each segment. Also robots have to return back to base station for moving their collected data to it. This return cause to change ER in segments as robots don't came back to exactly same cell that they were. Different number of WSNs is another factor that has effect on ER. We use ER in the algorithm as parameter for choosing a segment for a robot.

Each robot has a table in its memory that saves all segment exploration ratios, when two robots see each other they start to share their data with each other and update their data. In sharing process one kind of data that is transferred between them is how many cells are

marked as explored or obstacle in each segment. Each robot uses this data to obtain information about exploration ratio. After calculation of exploration ratio each segment, he robot compares these ratio to find minimum one and move to it if differs from current segment. This comparison between segments' ERs consists of handicap for current segment. Handicap means of current segment's exploration ratio because of avoiding jitter noise in exploration. In order to evaluate segmentation strategy we calculate the probability of the existence of one WSN node in one cell.

When robots start to explore, they know the boundary of their exploration area so they can divide it into a grid and know how many cells are in this grid. Furthermore, robots can determine cells by positioning devices installed on the robots and each cell has x and y of its position. Also robots save a table of cells and their properties when a cell is marked as explored or as obstacle cell. So we have number of free cells as:

$$N_{fc} = N_{tc} - N_{mc} \quad (1)$$

Where, N_{tc} is number of total cell in environment grid and N_{fc} number of free cells and N_{mc} is number of marked cells. N_{tc} Denoted by

$$N_{tc} = \left| \frac{\text{Area size}}{\text{cell size}} \right| \quad (2)$$

In this model we suppose WSN nodes deployed randomly, so if robots divide the area into several regions, It is predictable the number of WSN nodes in a region. Indeed the number of cell deployed in the field is given by base station or operator to the robots. Initially when robot starts to explore, they do not have any factor to choose a region for exploration, so the probability of WSNs in any region is the same for a robot. After a while of exploration, the number of explored cell and free cell is changed. The little change at first does not differ greatly but after a while by increasing change in robot, the probability of being WSNs node in region changes. If we suppose that the probability of being a WSN that have not found yet in free cells:

$$P(E_{wsn}^c) = \frac{N_{tw} - N_{fw}}{N_{fc}} \quad (3)$$

Where E_{wsn}^c is existence of one missed WSN(or WSN have not found yet) node in a free cell c and N_w is total number of wireless sensor node that we have at first and N_{fw} is number of founded cell in a robot that found them by itself. N_{fw} Is kind of data which is transferred for updating in sharing process between swarm robots indeed unfounded wireless nodes definitely should be in free cell so for calculating probability of being more unfounded nodes we calculate probability of finding free cell by a robot in a region as:

$$P(F_x^{fc}) = \frac{R_x^{fc}}{N_{fc}} \quad (4)$$

In (4) F_x^{fc} is finding a free cell in region x by a robot and R_x^{fc} is number of free cell in region x. Robot can calculate this number because they know the boundary of each region and they save the position of explored cell so by calculating area of a region robot know the area of this region and also by:

$$R_{fc}^x = \left\lfloor \frac{\text{Area size of } R_x}{\text{cellsize}} \right\rfloor - (N_{R_x}^{Ec}) \quad (5)$$

Where R_{fc}^x is number of explored cell in region R_x . For evaluating segmentation strategy the probability of finding WSN nodes in less explored region or segment is higher than others. By using (3, 4) we have the equation for calculation the probability of being Unfunded WSN's nodes in region through:

$$P(E_{UWSN}^{R_x}) = \frac{N_{tw} - N_{fw}}{N_{fc}} * \frac{R_{fc}^x}{N_{fc}} \quad (6)$$

$$P(E_{UWSN}^{R_x}) = \frac{(N_{tw} - N_{fw}) R_{fc}^x}{N_{fc}^2} \quad (7)$$

The probability of existing unfounded WSN nodes in a region. If in a region ER is very low it's mean that R^x is high. Because when robot explores in an environment one of job of robot is to mark grid cells in this environment as value that was described before. R^x Show the number of unmarked cell in region R. As in formula (5) shows how can calculate R^x . In (7) if we have higher number of unmarked or unexplored cell in a region R^x , this region have more chance for a robot to find remaining WSN's nodes.

Segmentation strategy affects on balancing between segments for exploration. When robots start to investigate environment and find wireless sensors they unconsciously explore one or a few region more than another. However by using segmentation strategy we can balance ER between segments as well. Another fact that helps this strategy improve the group working is that wireless sensors cover only a small area around them not full coverage of an environment so we do not need explore whole the field cells by cells for finding them.

Experiment result and system specification in simulator

In this section, we describe how to simulate this work for evaluating the system. We use player/stage simulator³⁹ for simulating and design the field. We run the simulation on Linux Ubuntu 11 operation system installed on pc with dual core 2.4 GHz CPU and 2 gigabyte of ram. Player/stage consists of two layers one is player used for control robots and another is stage where environment and the other details of robot entered and controlled by it. We run the experiment with different number of WSNs for evaluating the algorithm. Player/stage has ability to control multi-robots system specially swarm robot because of using COM port interface for controlling them which due to no confusion between them. In our work we have 5 swarm robots (5 robots selected as system configuration and speed) for exploration task these robots are equipped with sonar range finder for determining obstacle. Each robot consists of 4 sonar sensor to provide whole 360° around the robot. Sonar sensor in this experiment has range of 1 meter. Also each robot has wireless device for communication with other robots with range 2 meter. For communication between robot and WSNs we also propose that 2 meter is maximum distance for transmitting among them.

Distance of 2 meter is selected because it is optimal distance for some wireless communication like Bluetooth. For wireless

communication we suppose that covered area by wireless sensor network has circular shape. In reality this shape is different but we can say at least we can find minimum radius of circle in the real shape in wireless transmitting. Robots in this system is differential robots with two driving control. One is forward-speed that moves the robot in forward and backward direction. Second driving control in robots is turning-speed which pushes robot to turn around in right and left direction. We set the forward speed at 1.8 m/s as it is reliable speed to find WSNs.⁵

Simulation system with simple spanning trees

For evaluating our algorithm first we simulate the whole system with a simple spanning tree with swarm's robots. In this system we deploy WSNs node randomly in an area with distinct size. The area has circular shape as we only need give to a robot a radius from the centre of this circle. We put the base station or sink in the centre of area. Robots have to collect and save data in their memory, and transfer them to the base station. We suppose that robot memory only can save 3 WSN's data. When each robot encounters 3 WSNs nodes and collects their data, it needs to move in base station and transfer its collected data to base station. We give the exact position of base station to all robots at first. When robot finds third WSN and collects its data it goes to the base station for evacuation of its memory and moves data to the base station. After each evacuation task, robots try to find the nearest free cell and start to construct the new spanning tree there for finding another 3 WSN's nodes.

In (Figure 4) we can see the stage environment for running simulation, in this stage robots were placed in the bottom of field. We have 50 randomly deployed sensors in this field which are blue and one base station in the centre that is red. (Figure 4) contain a big circle that shows the field of exploration. This environment contains some black free shape that we put them in the field as obstacle. (Figure 4) shows a few minute after running simulation. In this picture we can see overlapping between paths of spanning tree that robots constructed them because of delaying in updating. If robots update their information only with encountering each other then they explore same place explored before by another robot. Swarm robots don't know which place explored by their partner but by being one robot in transmitting range of another they can share data with each other and avoid exploring the same cells again.

Simulation system with simple spanning trees

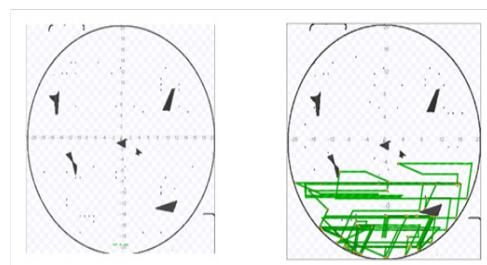


Figure 4 (A) Simulation environment, (B) is initial time of exploration with simple spanning tree algorithm.

Experiment's assessment consists of running algorithm with five swarm robots in an environment with different number of WSN's nodes. The area of the environment is 1256m². Numbers of nodes in separate simulations are 20, 30, and 50 which we repeat the system running 50 times for each of these. We chose these numbers on

density of WSNs from low to high.⁵ In alliteration, location of WSNs nodes was selected randomly by algorithm. The finishing condition of algorithm is finding all WSN's nodes.

Simulation with improved algorithm

The second part of our experiment is running our improved algorithm that described in previous section. For testing the algorithm, we run the same last experiment. Robots make the different segments in environment by dividing the field into sections. This division is based on the vertical and horizontal line. These lines crossover each other on the centre of field. In player/stage these two lines are default lines in the field. In initial state of this algorithm each of robots in system select a section for exploring. In (Figure 5) Initial path of robot exploration is shown by green line. In this image screen shot of simulator, we can see how segmentation strategy at first deployed robots between segments in balanced way.

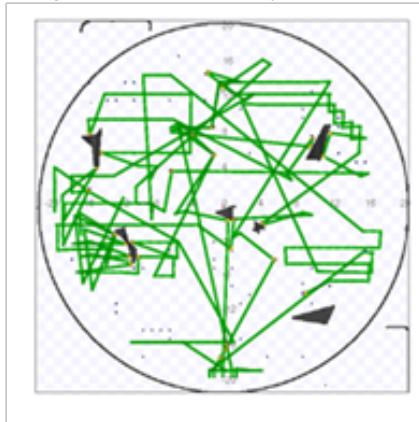


Figure 5 Initial exploration of improved algorithm.

Evaluation parameters

For evaluating this algorithm we describe some parameters in the program written for player/stage. One of these parameters which is very important and also is the base of our improvement indicator is total time of finishing task. It means that all WSN's nodes data are collected by swarm robots. Another parameter we use for evaluation the algorithm is total energy which is used during the task. To calculate this, two forces that are needed to move robot should be calculated. One is forward and direct force in robots which is a constant value. If we want precisely calculate this value, slope of path should be calculated. But in our experiment we propose a constant value for every movement in robot. Furthermore we suppose that if robots want to go from one point to another point in straight path then robot use a constant value related to distance between two points. But for turning around, the energy consumed is more than only moving in one direction⁴⁰ so we calculate a bigger number around 3/2 moving forward for it. For example for passing two points named 'A' and 'B' by a robot first we calculate the distance between them by:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (8)$$

Where d is distance between two points and x_1, y_1 is position of point 'A' and x_2, y_2 are positions of point 'B'. For calculation of the energy in changing direction we first calculate angle between two points by:

$$\alpha = \tan^{-1} \left(\frac{y_2 - y_1}{x_2 - x_1} \right) \quad (9)$$

Where α angle between two is points and x_1, y_1 is position of point 'A' and x_2, y_2 is position of point 'B'. Moving actuators in robot are biggest energy consumer. Indeed wireless device in robot that implemented on robots for transmitting data is another source of energy consumer. For calculation of energy consumed by transmitting devices we count the number of packet received or sent by a robot during the exploration task. For describing the energy unit in our algorithm, we define a variable named energy. For each move in robot in direct path and for passing each cells in grid, is one unit and for every meter that robot has to change direction is summed up with 3/2 of an energy unit. Finally for each 10 packet robots send or receive we add one unit to our energy variable in program. So that our equation for calculation of energy is: Where d_i is robot's move in movement, α_j is angle of changing direction in j movement and P_k is number of receiving and transferring data packages by robot in K transaction between robots.

Performance analysis

The last part of our experiment is testing and comparing two algorithms that described before. For getting these result we run algorithm with five robots in same environment with 20, 30, 50 wireless nodes. Experiment consists of calculation of the average of 50 iterations from each algorithm. Results show the comparison of total time, total energy and number of packet transferred between robots and WSNs nodes. Also the number of moving data to base station was counted.

$$\text{energy} = \sum d_i + \frac{3}{2} \sum |\alpha_j| + \frac{1}{10} \sum P_k$$

In (Figure 6A) we can see the chart that shows average total time for both spanning tree and segmentation algorithms. This chart contains the average of completion time for 3 different numbers of wireless sensor nodes. Completion times in (sec) and calculated by the average of 50 iterations for each environment with different number of WSNs. In all situation segmentation, average completion time is less than simple spanning tree algorithm. In area with 20 nodes we can see the difference about 56% between both algorithms which segmentation algorithm has 56% more efficiency in completion time. Experiment result in (Figure 6A) for 30 nodes shows the efficiency about 53% is less than 20 nodes experiment.

The second chart in (Figure 6B) shows the energy efficiency of our algorithm compared to spanning tree algorithm. In previous section we described each unit for energy consumption as amount of energy that a robot needs for moving in direct direction for passing 1meter. In this chart we can see the difference between two algorithms and also different environments of WSN's nodes. In sparse area in the term of number of wireless sensors we can see in environment with only 20 WSNs segmentation strategy has energy efficiency about 44% better than single spanning tree algorithm. Chart in (Figure 6B) also provides comparison for 30 nodes in which energy consumed in segmentation algorithm is 21% less than spanning tree. For energy consumption in environment with 50 nodes we can see segmentation strategy consumes about 14 present less energy than only spanning tree algorithm in average. As we can see in term of energy and completion time of combination segmentation strategy and spanning tree is more effective than using only spanning tree algorithm. This efficiency is higher in environments with sparse nodes, which is proof by experiment results. Percentage of efficiency in time and energy is more in the field with 20, 30 nodes rather than 50 nodes. (Figure 6C)

provides information about average transferred packet between robots, and robots and wireless sensors. These packets contain sensory data transferred between wireless sensors and robots and contain explored and marked grid cell that transferred between swarm robots.

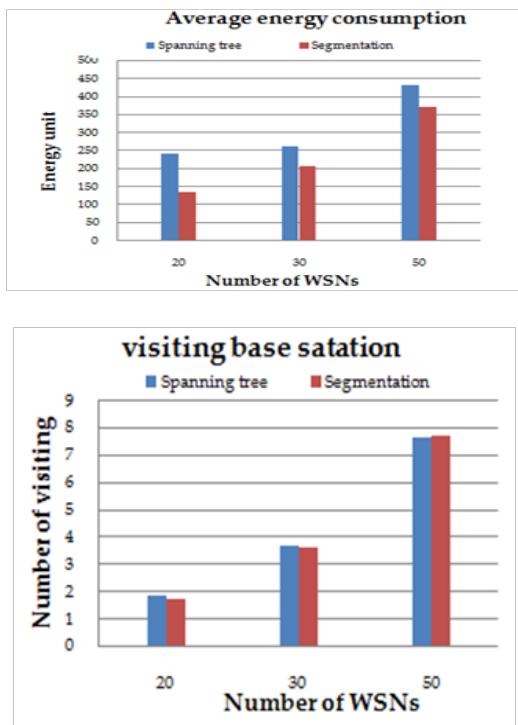


Figure 6 Performance result.

Transferring packet in simulation with 50 nodes increased drastically as the overlapping in coverage of transmitting range between robots goes up. Also average transferred packets consist of packet between robots and base station; these types of packets are collected sensory data and explored cell data. Transferring packets rate is another option that has effect on energy consumption. In (Figure 6C) we can see different number of robot with different rate of energy consumption. In this chart for single spanning tree algorithm by 20 and 30 nodes, transferring packet rate not differ too much but with 50 nodes system transfers more packet. In segmentation strategy for transferring packet we can see all environments have lower rate than solely spanning tree algorithm. The first factor that has effect on transferring packet is that robots in segmentation meet each other less than spanning tree because of separating into segments.

(Figure 6D) presents average frequency of returning back to base station for each robot. The average of all robots in both algorithms is almost equal with a tiny difference. Because for defined number of nodes, robots have to back to base station in equal frequency. In our experiment for harvesting 3 wireless sensor robots have to go back to the base station for dumping their memory to base station. In we can see the average of returning to base station for each robot in all iterations of both algorithms. In this chart we can see number of returning to base station differs for robots. (Figure 7) provides the segmentation algorithm efficiency for dividing task between robots. In this chart we can see the standard error for every robot is based on

their number of dumping memory to the base station. This standard error is calculated as difference between average number of returning back to base station for all robots and one robot. In (Figure 7B) we can see this error is higher in simple spanning tree rather than segmentation strategy in each robot and average of all robots. Results of calculation standard error in returning back show the efficiency of segmentation strategy in dividing task between robots. Harvesting WSN's data and dumping them to the base station is the main task. In this system harvesting task should be divided equally between swarm robots to give meaning to the team work and use all robots in same manner as they have limited source of energy.

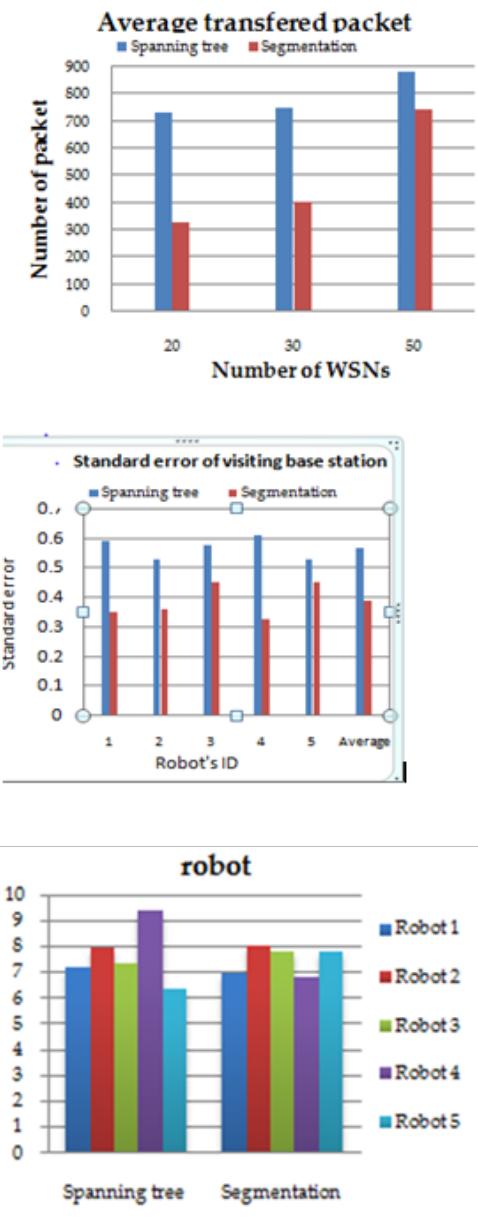


Figure 7 Visiting base station analysis.

Conclusion

In this paper, we propose a multi robots system for harvesting WSNS data in a structured environment with unknown obstacle and dumping data into a base station. For implementing this system we use mobile robot as mobile relays or Mrs. We design an exploration algorithm for searching WSN's nodes without any positioning device. The input of environment to the robots is only the radius from the centre of terrain. We use swarm robots which have positioning device for doing harvesting task in this system.

Swarm robots are used in this system also equipped with wireless connection between themselves. The exploration algorithm is an online model which is updated by robots through the wireless connection. Swarm robots in this work have 360 degree range sensor for determining obstacle in environment. One factor in segmentation strategy that reduces the total time is dividing tasks between swarm robots in balanced way. And another factor is exploring whole environment in balanced manner. For examining this algorithm we use player/stage simulator for implementing this algorithm. We test the algorithm in 3 situations with different numbers of nodes in terrain. For each setting we test the algorithm in 50 iterations. For qualifying energy consumption we also describe some parameter in simulation to provide energy consumption behaviour. The results show the efficiency in terms of time and energy. Simulations results show in environment with sparse deploying of WSNs, he proposed mixed algorithm have more efficiency than spanning tree algorithm. Also segmentation strategy has efficiency toward solely spanning tree in impact terrain. For future work, we may work on dividing strategy. As in this work we have geometric shape terrain, in the future work swarms robots should be able to divide an area without geometric shape to different segments. Furthermore another method that will be added is using some MRs as connection chain to the base station for providing local station for dumping data.

Acknowledgements

None.

Conflict of interest

The author declares no conflict of interest.

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