UNIVERSITI PUTRA MALAYSIA

WIRELESS SENSOR NODES DEPLOYMENT USING MULTI-ROBOT BASED ON IMPROVED SPANNING TREE ALGORITHM

REZA AREZOUMAND

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By

REZA AREZOUMAND

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

July 2015

Dedicated to

My father, mother for their support through my study

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
in fulfilment of the requirement for the degree of Master of Science

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July 2015

Chairman: Syamsiah Mashohor , PhD
Faculty: Engineering

A wireless sensor network is a network consisting of a large number of sensor nodes deployed in a region to fulfil the demanding task of sensing. By merging wireless sensor nodes with mobile robots, the performance of wireless sensor network applications may be improved. Coverage and connectivity are the two parameters of a wireless sensor network. Stochastic node deployment or random node deployment may cause holes in sensing coverage and existing redundant nodes in the area. On the other hand, precise deployment of nodes in large area is very time consuming and even impossible in hazardous environment. One of the solutions to this problem is by using mobile robots with concern on exploration algorithm for mobile robot. In this thesis an autonomous deployment method for wireless sensor nodes is proposed via multi-robot system which robots are considered as nodes carrier. Developing an exploration algorithm based on spanning tree is the main contribution. The exploration algorithm should perform fast localization of sensor nodes in energy efficient manner. Employing a multi-robot system and path planning with spanning tree algorithm is a strategy for speeding up sensor node deployment. An improvement of this technique in deployment of nodes is the use of an obstacle avoidance mechanism without concern on shape and size of obstacle. The deployment task in this thesis is simulated on Player/Stage environment and the results were compared with other algorithms like obstacle-free and power-efficient (OFPE) which is modified to multi-robot (MR-OFPE) for deploying nodes. Using the proposed method, the results demonstrated an improvement in energy efficiency up to 40%, while deploying time is reduced about 28% compared to MR-OFPE. By deploying these nodes, the sensing coverage is enhanced about 8% compared to MR-OFPE. This research shows that a multi-robot system can optimize time and energy in robots while improving the application of a wireless sensor network.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENEMPATAN NOD PENDERIA SECARA WAYARLES MENGGUNAKAN PELBAGAI ROBOT BERASASKAN ALGORITMA PEPOHON RENTANG YANG DITAMBAHBAIK

Oleh

REZA AREZOUMAND

Julai 2015

Pengerusi: Syamsiah Mashohor, PhD
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Rangkaian penderia wayarles merupakan satu rangkaian sejumlah besar nod penderia yang dipasang di sesuatu kawasan bagi melaksanakan tugas penderiaan yang diperlukan. Penggabungan nod penderia wayarles bersama robot mudah alih dapat meningkatkan prestasi aplikasi rangkaian penderia wayarles. Liputan dan penyambungan adalah dua fungsi asas bagi rangkaian penderia wayarles. Penggunaan nod stokastik atau penempatan rawak akan mengakibatkan beberapa ruang di dalam kawasan liputan penderiaan dan kawasan nod berlebihan sedia ada tidak dapat dideria. Di samping itu, penempatan nod secara tepat di dalam kawasan yang luas sangat memakan masa, malahan mustahil untuk dilaksanakan di persekitaran yang merbahaya.

Salah satu penyelesaian bagi masalah ini adalah dengan menggunakan algoritma penerokaan bagi robot mudah alih. Dalam tesis ini, satu kaedah penempatan berautonomi bagi nod pengesan wayarles telah dicadangkan melalui sistem beberapa robot di mana robot-robot tersebut dianggap sebagai pembawa nod. Pembangunan algoritma penerokaan berdasarkan kaedah pepohon rentang merupakan sumbangan utama dan algoritma penerokaan ini dapat menempatkan nod pengesan dengan pantas dan cekap tenaga.

Penggunaan sistem beberapa robot dan perancangan laluan dengan algoritma pepohon rentang adalah strategi untuk mempercepat proses penempatan nod pengesan.

Penambahbaikan terbaru bagi teknik penempatan nod ini adalah ia mempunyai mekanisma untuk mengelak halangan tanpa mengambil kira saiz atau bentuk halangan tersebut.
Dalam tesis ini, simulasi penempatan nod telah dibuat pada persekitaran "*Player/Stage"* dan keputusannya dibandingkan dengan strategi lain seperti *obstacle-free and power-efficient* (OFPE) yang telah diubahsuai kepada bererapa robot OFPE (MR-OFPE) bagi pemasangan nod.

Jika dibandingkan dengan MR-OFPE, keputusan bagi kaedah yang dicadangkan menunjukkan peningkatan bagi kecekapan penggunaan tenaga sebanyak 40% dan masa bagi penempatan nod sebanyak dikurangkan 28%. Dengan pemasangan nod-nod tersebut, kawasan liputan pengesanan telah

ditambah baik kepada **8%** berbanding MR-OFPE. Kajian ini menunjukkan sistem beberapa robot dapat mengoptimumkan penggunaan masa dan tenaga bagi robot di samping meningkatkan penggunaan rangkaian penderia wayarles.

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I certify that a Thesis Examination Committee has met on (July 2015) to conduct the final examination of (Reza Arezoumand) on his thesis entitled ("WIRELESS SENSOR NODES DEPLOYMENT USING MULTI-ROBOT BASED ON IMPROVED SPANNING TREE ALGORITHM") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master of Science.
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

WSN	Wireless sensor network
SLAM	Simultaneous Localization and Mapping
MWSN	Mobile Wireless Sensor Node
ROI	Region of Interest
CH	Cluster Head
CA	Coverage Accuracy
SR	Sensing Coverage
ER	Effective Ratio
MANET	Mobile Ad-hoc Network
NRS	Networked Robotic System
GPS	Global Positioning System
3D-NDT	Three-Dimensional Normal Distributions Transform
COMCL	Constraint rules Optimized Monte Carlo Localization
CCP	Coverage path Planning
STC	Spanning Tree Coverage
S-MSTC	Simultaneous Multi Spanning Tree Coverage
M-STC	Multi-robot spanning tree coverage
ES-MSTC	Extended Simultaneous Multi-robot Spanning Tree Coverage
UAV	Unmanned Aerial Vehicle
RSSI	Received Signal Strength Indication
LRV	Last Recently Visited
OFPE	Obstacle-Free and Power-Efficient deployment
ORRD	Obstacle-Resistant Deployment
MR-OFPE	Multi-robot Obstacle-Free and Power-Efficient deployment
MR-ORRD	Multi-robot Obstacle-Resistant Deployment

OD Optimal Distance

CHAPTER 1

INTRODUCTION

1.1 An overview

A wireless sensor network (WSN) refers to number of devices which contain a sensor along with radio transmitter for communication with other devices. A processing unit is also attached as a bridge between transmitter and sensor for online and offline processing of data. Common applications of WSN consist of a number of nodes which usually provide a system for measuring parameters like temperature. These applications include monitoring tasks like measuring temperature in forest for detecting fire and other applications like disaster-relief application, healthcare and industrial application. The type of WSN in an application is also related to the type of operational environment or region of interest. Operational environments may include harsh environments such as battlefields, or normal areas such as urban areas. Depending on the type of environment, methods for using WSNs differ. These methods include several topologies for module networking, or other methods for deployment, transferring data, collecting data, clustering, and using mobile elements. These methods have resulted in a broad area of research that began long ago and will continue in future research.

For applying WSN in different types of environments like harsh environment, a WSN is not sufficient. Other tools are needed to assist WSN to improve flexibility to interact with the environments. Using mobile elements in the wireless sensor network is a new vision in this area. Mobile elements like autonomous robots can provide more flexibility and capability for WSN system. For example, mobile elements application may enable nodes with the ability to change their position relevant to variation in environment. In addition, mobile nodes such as carrier-based robots can change the position of nodes for satisfying system requirements.

Indeed, another area that autonomous robots can be used is deployment of sensor nodes. Autonomous mobile robots have the ability to improve preciseness and reliability in deployment. In precise deployment, WSNs should be placed at an exact point. In terms of deployment methods, two kinds of coverage are more concerned one is related to sensing range of sensor attached to the node, and the other is the radio transmitting range of WSN. Sensor range is an area covered by the sensor which can detect the proposed parameters such as temperature or moisture. Radio coverage describes a region which a node can communicate with other nodes, sink or any other target point for transferring data. Both types of coverage require a deployment strategy, which can be done by autonomous robot as a carrier of WSN, which places them in suitable suggested locations.

For these types of applications, an autonomous multi-robot can be used. A Multi-robot system can give a better result instead of using single robot. For example, one advantage of using the multi-robot system is covering a big area very fast by increasing the total number of robots used. Furthermore, the multi-

robot system provides an alternative in the case of failure of a robot. However, a multi-robot system has some issues like task allocation between robots that must be in a balanced and distributed in an efficient way. Communication issue is a basic requirement for task allocation, and last but not least is the energy concern as autonomous robots use limited source of energy. For most applications of autonomous robots, mobile robots need to have an exploration method for designing simultaneous localization and mapping (SLAM) algorithm to work in unknown environments.

Exploration algorithms should be comparable a team of mobile robots or a multi-robot system. This algorithm should have an ability to divide exploration tasks between robots in an efficient way. Efficiency for an exploration algorithm refers to minimum time and energy in path planning and communication. Figure 1.1 shows an overview of work on this thesis. The biggest circle shows the area for using robots, with the problem for this area in the middle circles and the main objective at the center, which is the exploration algorithm.

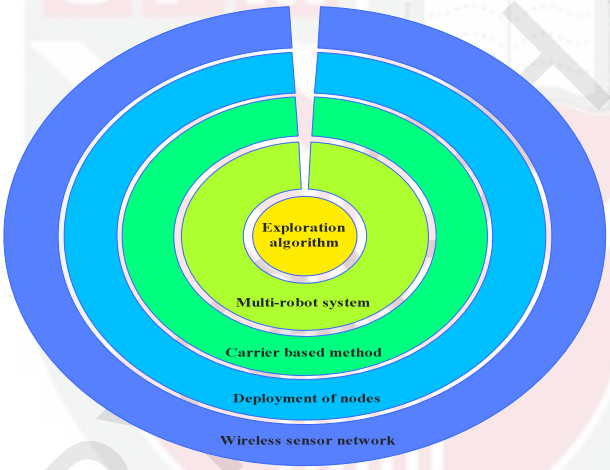

Figure 1.1. The scope of work

1.2 Application

Ability and flexibility for a wireless sensor network are in great demand for many applications. WSN is kind of sensor equipped with other devices. The main purpose of using WSN is measuring and monitoring some condition in different environment [1]. Some applications are described in the following sections.

1.2.1 Security and military

In this type of application, the main measuring parameter is the existence of human or other objects like heavily-armoured military vehicles or any other moving devices. In such applications, using redundant nodes is very common

as some of the nodes can be miss by enemy's actions or because of harshness of environment [2].

1.2.2 Monitoring and alarming tasks

Several tasks require analysis of the environment with respect to several parameters, for example, air pollution measuring in urban area or soil erosion and humidity in agricultural field and habitat monitoring for study on habitat [3]. Quick alert from firing in forest is very important for a firefighter to control it in initial stage. Deploying WSN in a forest is the way to prevent spreading fire in the forests. Figure 1.2 shows a fire detection system with WSN carried on animals in the forest, in which sensors send monitoring data to an access point for fire watching [4].

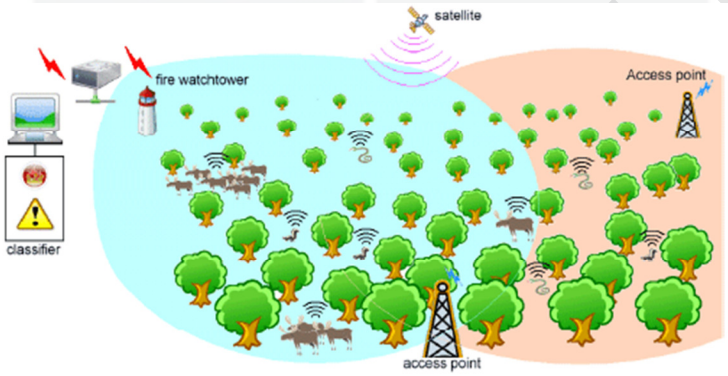

Figure 1.2. WSN for fire detection in forest [4]

1.2.3 Disaster relief system

In some cases when a disaster happen, there is need to monitor unreachable places. For example, a nuclear disaster is very dangerous for humans or any living creature if they are in proximity with the power plant. So, using WSN can be very helpful in such a condition like sensing radiation area. Finding human bodies in a fire disaster is another application for WSN in which usually a mobile node is used. Figure 1.3 demonstrates a system consists of WSN to detect eruption in active and hazardous volcanoes. In this application, an array of special wireless sensors were deployed in hillside in far distance from the aperture on the upper flanks of the volcano [4, 5].

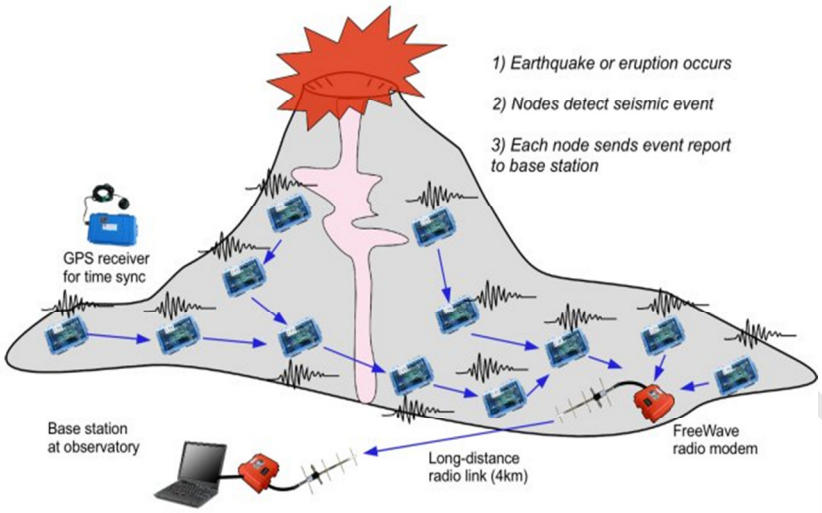

Figure 1.3. WSN for earthquake detection [5]

1.2.4 Healthcare

Wireless sensors have market potential in health care and pharmaceutical. For example, in some cases people can use WSN as health care assistance. One example is athletic performance monitoring which in this case a specialist can use WSN for measuring some biological parameter during the athletic exercise for improving their performance. Another case is home assistance in personal care, such as monitoring weight and analysis in a personal computer or determining blood sugar levels for diabetic patients. Figure 1.4 shows a health care system for monitoring heart beat and the rate of motion, which was done by a sensor installed on WSN and carried by user and the data passed by a WSN structure to an end user or doctor for analysis and alerting [2, 6, 7].

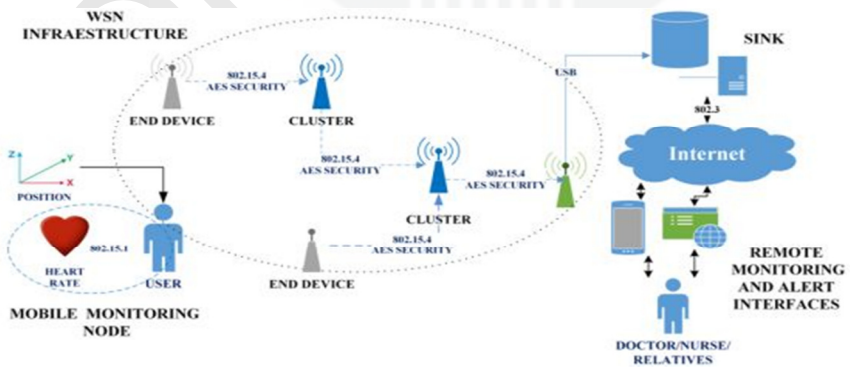

Figure 1.4. Home care monitoring system [6]

1.2.5 Industrial application

Wireless sensor networks can be seen in variety of cases in industrial application like coal mines, oil drilling, and nuclear plants. For instance, WSN can be used for monitoring sewage in outfalls of nuclear plant. In advanced manufacturing, WSN can be used for Industrial safety like monitoring tools to reduce accidents. Warehouse management is another application in industry, as WSN can be used for monitoring temperature or humidity and other parameters that should be monitored in warehouses or even checking smart tags for finding their location. Figure 1.5 shows an industrial example of deploying WSN for detecting vibration in motors to detect any problems in semiconductor fabrication plant [8].

Figure 1.5. Deploying sensor node for analysing vibration [8]

1.3 Open problem in WSN

Improving the performance of a wireless sensor network is vast area, as different categories of electronic devices are used in WSN. Researches can improve variety of parameters related to each category. Issues in WSN can be solved by different methods or in different manners, either in software or hardware.

1.3.1 Energy performance

Usually a WSN runs with a limited source of energy. A common source of energy is a battery [9]. As most of the applications have to use portable and limited source of energy, researchers try to find the best methods for saving the energy. Reducing the energy consumption of a WSN increases its capability. In this area, two subjects are important. The first one is scheduling the process time in WSN for maintaining the CPU more in sleep or idle mode instead of running. The second subject is managing the packet transferring, this area consists of a variety of protocols and algorithms and also is more concerned in WSN as the highest energy consumer in WSN is a radio transmitter module [10].

1.3.2 Low Cost

In all application, especially large-scale WSN system, the cost plays an important role. High-performance algorithms and topology for networking and implementation of WSN are important challenges for researchers in this area. Using fewer nodes within the system is an alternative to reduce cost as maintenance and administration of fewer nodes have huge effect on the total cost. Using high energy performance topology is another operative on cost. With the WSN systems that have minimum energy usage, money can be saved on replacing battery or increasing the total life time on the system.

1.3.3 Flexibility and mobility

Flexibility in WSNs improves their adapting capacity. Conditions of using WSNs can be different, so improving flexibility of WSN helps to use them more easily in any type of environments. For example, several applications of WSN need to add some nodes randomly, and network topology should provide flexibility to do that. The location of nodes is another issue which concern of the ability of the node to move. If changing the position of nodes is available then sensing coverage can be improved by changing the position of sensor nodes. One type of WSN that can change their position is Mobile Wireless Sensor Network (MWSN). MWSN is built into a WSN on one mobile object like a robot.

1.3.4 Mobile elements in WSN

Mobile element is new era in the wireless sensor network. With mobile elements, applications can cover some deficiency in the wireless system. Mobile elements can be used in a different manner. Mobile node is one of them. By using mobile nodes WSN can have a sophisticated and flexible system from coverage and networking standpoints. Mobile collectors and mobile sink are another kind of mobile element which is helpful in transferring data in situations which requires more nodes for making connection between nodes and base stations or any users. For deploying and placing WSNs, mobile robots can be used. Using autonomous mobile robot offers benefits in terms of cost and precision. Indeed mobile robots are a solution for maintenance and replacing corrupted nodes.

1.4 Robotic view

A mobile element in WSN system needs a mobile actor. A robot as autonomous mobile element can play this role. For better performance in robotic task multi-robot systems can be utilized. Using group mobile robots instead of a single robot provides more advantages in terms of time.

1.4.1 Robot exploration

For all tasks that a robot needs to follow a path or explore the environment, the robot needs an exploration algorithm. In some environment without map the robot needs simultaneous localization and mapping (SLAM) algorithm [11]. These types of algorithms use some methods based on sensors to create a map and also to find several target spot in the map. Frontier based algorithm are one of the common types of SLAM, which in the algorithm robot follows a path by finding optimal direction.

1.4.2 Multi robot system

Multi-robot system is a team of autonomous mobile robots which fulfill a task by distributing the task between each other. The idea of using the multi-robot system instead of the single robot refers to benefit of group working. The main advantage of a multi-robot system is reducing completion time, as teamwork finishes the task faster. Although using the multi-robot systems have two main challenges for any application, these challenges are communication among robots and how the robots divide tasks among themselves.

Combining multi-robot system with wireless communication can satisfy some issue in WSN applications. Using these robots for servicing and deploying wireless node is one of them.

1.5 Problem statement

Wireless sensor network (WSN) can be used in different types of applications, but before using WSN for an application, WSN nodes should be placed on the application environment. This placement or namely deployment cannot be done randomly in several applications. In application with full sensing coverage, establishing nodes based on random deployment is difficult due to existence of coverage hole in random deployment, and even impossible if nodes deployments are sparse [12, 13]. Random deployment causes many issues so deployment should be done based on certain parameters which take into consideration time to deploy, location to deploy and method to deploy.

Efficiency in minimum number of nodes and ideal place for deployment are very important. Several applications like disaster-relief applications need an emergency response, so deployment time becomes crucial in these types of applications. Furthermore, if the environment through the application or region of interest (ROI) is dangerous for human this causes another problem, which mean how to deploy the nodes, by what method and tools? Or what to do when environment has an unknown terrain and obstacles? Due to these criteria,

deployment method is more concerned to improve the efficiency of WSN. Figure 1.6 shows an overview of common issues in the WSN deployment.

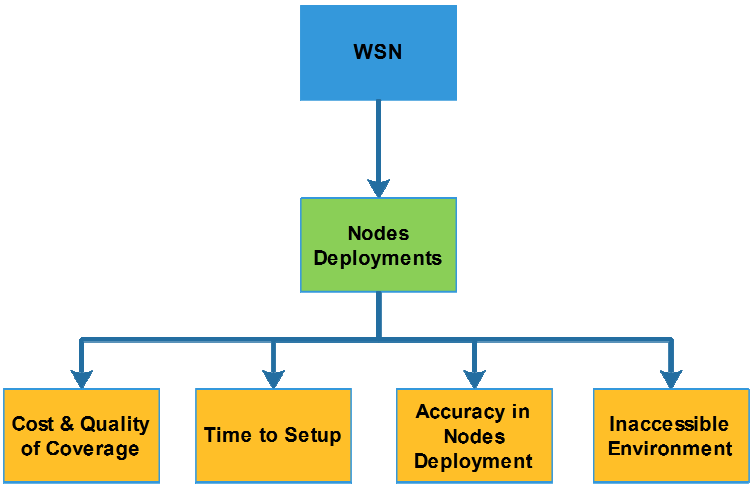

Figure 1.6. Issues in deploying nodes of WSN

To answer the aforementioned questions, various research and works has been done, for dealing with structured deployment rather than random deployment. A method named grid-based deployment has suggested to provide coverage and connectivity together behind the deployment [14]. For applying grid-based deployment by mobile robot, a path-planning strategy is needed. With regards to problems such as inaccessible environments, the mobile robot seems to be a smart solution and for dealing with time constrained applications, the multi-robot system is a logical option.

Path-planning is important issue that should be concerned in a multi-robot system. Efficiency in mobile robot mostly related to the path-planning algorithm. Path-planning needs to be designed in an efficient manner. However, the path-planning algorithm should be compatible with multi-robot system as the main aim in this work is using multi robot system.

Due to problems and solutions in this area, the methods presented in this thesis compared to previous works is to design a path planning algorithm for grid-based deployment using multi-robot system. The path planning algorithm should be efficient in time and energy. The deployment algorithm should have coverage accuracy to deal with connectivity and coverage issue.

1.6 Objectives

The aim of this thesis is to design an autonomous system for efficient deployment of a wireless sensor network in an unknown environment with the multi-robot system.

1. To design and develop spanning tree exploration using multi-robot system for grid-based deployment in WSN.

2. To analyse and benchmark performance result of the proposed algorithms compare to others methods.

3. To enhance the proposed spanning tree with wall follower for obstacle avoidance capability.

1.7 Contribution

Exploration method is the main parameter for a mobile robot to map and localize an environment. Indeed the importance of the exploration algorithm is much higher in the autonomous multi-robot system. Multi-robot system should do the mapping and localization task together as a team work. In this thesis an efficient terrain coverage algorithm designed for a multi-robot system to improve mapping and localization for deployment. As in some application of WSN nodes should be deployed in a structured manner rather than randomly deployment so a multi-robot system with the efficient exploration algorithm can do it in fast and accurate way. Grid-based deployment is a common method in structured deployment, requiring an effective exploration algorithm to provide coverage accuracy (CA) for sensor range of each node to run through the multi-robot system. Besides accuracy in placing nodes, the mapping strategy in an exploration algorithm should be capable of dealing with an unknown environment in terms of obstacles. An enhanced spanning-tree algorithm for deployment can deal with obstacles in environment along with localizing a place for deploying nodes in an accurate way to maximize sensing coverage (SR) beside the exploration algorithm can handle multi-robot system to do the deployment task as a team work. Exploration algorithms improve due to characteristics and requirements of the application. The main requirement of deployment application is providing suitable coverage quality beyond the minimum number of nodes, namely effective ratio (ER).

1.8 Thesis outline

Chapter 2 will discuss the literature review related to the work, deployment of WSN, and mobile elements. Several works related to multi-robot system and exploration algorithm come next in this chapter. In addition, some literature about networking and coverage in WSN has been added to this chapter too.

Chapter 3 is the methodology of the proposed method. Section in chapter three consists of designing multi-robot system and deployment model then implementing exploration algorithms for deploying wireless nodes besides communication and task allocation methods.

Chapter 4 will discuss the results of the proposed method for deploying wireless nodes. The main content of this chapter discusses time, energy, and coverage accuracy.

Chapters 5 will summarize the project and discuss future works.

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