DEVELOPMENT OF AUTONOMOUS MINIATURE MOBILE ROBOT FOR SWARM APPLICATIONS

By

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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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Biological swarm is a fascinating behavior of nature that has been successfully applied to solve human problems especially for robotics application. The high economical cost and large area required to execute swarm robotics scenarios does not permit experimentation with real robots. Modeling and simulation of mass numbers of these robots are extremely complex and often inaccurate. This research describes the design decision and presents the development of an autonomous miniature mobile robot called AMiR, for swarm robotics research and education. Two criteria for designing a swarm platform are the feasibility of mobile robot as an autonomous system and the amenability of inter-robots behavior in swarm applications. In the design phase, suitable components based on three main principles which are functional ability, low-cost, and local modules were selected. Several common platforms were studied and AMiR prototype was designed. The large number of robots in these systems allows designing of an individual AMiR unit with simple perception and mobile abilities. Hence a large number of robots can be easily and economically feasible to be replicated (around 310 MYR per unit). AMiR has been designed as a complete platform with supporting software development tools for

robotics education and researches. Inter-robot communication is a significant issue in swarm applications. Short range infrared communication was selected to transmit robot's messages. Two different modulation which are amplitude and frequency shift keying techniques were implemented on AMiR and features of each technique were discussed. Additional modules are mounted on top of main board to implement several behaviors inspired from nature. Three different swarm scenarios based on collective behaviors were performed and effective parameters in each behavior were discussed. The experimental results demonstrate the feasibility of using this robot to implement swarm robotic applications.

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

PEMBANGUNAN ROBOT MINIATUR BERGERAK AUTOMATIK UNTUK APLIKASI KAWANAN

Oleh

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Kawanan biologi merupakan satu tabiie' alam yang menarik yang telah digunakan dengan jayanya untuk menyelesaikan masalah manusia terutama dalam bidang aplikasi robotik. Kos yang tinggi serta kawasan yang luas diperlukan untuk melakukan senario kawanan robotik tidak membenarkan eksperimentasi dengan robot sebenar. Manakala model dan simulasi mengunakan bilangan robot yang besar adalah terlalu kompleks dan tidak jitu. Kajian ini menyentuh tentang keputusan rekabentuk dan mempersembahkan pembangunan satu robot miniatur yang berdiri-sendiri dan bergerak dipanggil AMiR, untuk kajian robotik dan pendidikan. Dua perkara penting untuk merekabentuk satu platform kawanan, adalah kemampuan untuk robot bergerak serta berdiri-sendiri dan kemampuan interaksi saling-kelakuan antara robot dalam aplikasi kawanan. Dalam fasa rekabentuk, komponen yang betul dipilih berdasarkan tiga prinsip utama iaitu fungsi, kos yang rendah dan modul tempatan. Beberapa platform yang umum dikaji dan prototaip untuk AMiR direkabentuk. Bilangan robot yang besar membenarkan rekabentuk sebuah unit AMiR menggunakan persepsi mudah dengan kebolehan bergerak. Oleh itu, bilangan

robot yang banyak boleh diadakan serta dengan kos yang rendah memampukan robot dikeluarkan secara besar-besaran (kos untuk satu unit sekitar RM 310). AMiR telah direkabentuk sebagai satu platform yang lengkap dengan sokongan perisian perkakasan rekabentuk komputer untuk kajian robotik dan pendidikan robotik. Komunikasi antara robot merupakan isu yang amat penting dalam aplikasi kawanan. Komunikasi infra-merah jarak dekat dipilh untuk menghantar maklumat dari robot. Dua modulasi yang berbeza iaitu anjakan amplitud dan anjakan frekuensi digunakan AMiR, kelebihan keduanya dibincangkan. Modul tambahan yang diletakan di atas papan utama digunakan untuk melaksanakan beberapa kelakuan kawanan yang di inspirasi daripada alam. Tiga senario kawanan yang berbeza dilaksanakan dan parameter yang berkesan dalan senario tesebut dibincangkan. Keputusan eksperimen menun jukkan bahawa robot ini mampu untuk melaksanakan aplikasi kawanan robotik.

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I certify that a Thesis Examination Committee has met on June 2010 to conduct the final examination of Farshad Arvin on his thesis entitled "Development of Autonomous Miniature Mobile Robot for Swarm Applications" 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 Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

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LIST OF ABBREVIATIONS

AMiR	Autonomous Miniature Robot
PSO	Particle Swarm Optimization
ACO	Ant Colony Optimization
PCB	Printed Circuit Board
DC	Direct Current
PWM	Pulse Width Modulation
IR	Infra Red
B-ASK	Binary Amplitude Shift Keying
B-FSK	Binary Frequency Shift Keying
SPI	Serial Peripheral Interface
MISO	Master Input Slave Output
MOSI	Master Output Slave Input
SCK	Serial Clock
Li-Po	Lithium Polymer
KVL	Kirchhoff's Voltage Law
ISP	In System Programming

CHAPTER 1

INTRODUCTION

Cooperation of multiple robots is an interesting area in the field of robotics. Performing a joint task with interactions among a large number of simple robots could solve a complex problem in real world application. Some problems would not be economic for a single robot even with more capabilities. Furthermore, coordination of multiple robots for solving complex problem can be completed in a short period of time. Study on multi-robots system requires the study on behavior of individual and multiple robots interactions in an environment. There are several configuration of multi-robot systems including controller (centralized or decentralized), homogeneity (identical or nonidentical), and inter-robot communication.

Swarm robotic is a new concept of multi-robotic systems inspired from nature. A large number of simple autonomous mobile robots cooperate together to solve a problem by imitating behavior found in nature. Collective behavior can be obtained by inter-robot interactions. Swarm robotic is a subset of ordinary multi-robotic system defined by the following configuration [1]:

- *Population:* swarm robotic is the study on multiple simple robots which cooperate to solve a problem.

- *Homogeneity:* swarm research concentrate on the study of collective behavior of homogeneous robots. Homogeneity and replicability are two important criteria of swarm robotics.

- *Inefficiency of individual:* defined tasks for swarm robotic are hard to solve by a single robot. Therefore, swarm task should be defined based on: 1) a complex task which could not be solved by an individual robot, or 2) if the problem is solvable by an individual robot, the use of swarm would improve the efficiency to solve the same problem.

- *Perception:* each swarm robot has a limited sensing ability and rely on local communication.

A swarm robotic system has many advantages such as flexibility, cost-efficiency, scalability, robustness, and emergence. The collective behavior in a group of robots emerges from interactions between simple agents, so it has an indirect relationship with behavior of individual robots. Due to this relationship, the result of swarm task can not be predicted before an experiment. A simple modification to an individual robot behavior would results in a significant changes of collective behavior.

Reliability of the robot platform is an important issue for executing swarm robotic scenarios. This thesis will explain the design steps for developing a reliable swarm robotic platform. The platform must be able to imitate swarm behaviors found in nature such as insects, birds, and fish school. It should be designed with compact physical dimension to allow large scale swarm behavior study. A practical mechatronics design is required to simplify replication and ensure platform

homogeneity. The firmware, low-level motion, and perception behavior should be designed to simplify programming of swarm algorithms. Communication of individual robot with its neighbors is another important requirement of the robotic platform. Design of communication system for swarm robotic would ensure reliable task completion. Modularity of swarm robot platform provide flexibility to be used in different swarm applications. Since swarm behaviors usually operate in long term scenarios (approximately 2 hours) [2, 3], low-power consumption in the design is a must.

1.1 Problem Statement

Swarm robotic is difficult to apply with real robots due to the large area required to perform their tasks and also the relatively high economical cost. Along this line, modeling and simulation of mass numbers of these robots encounter with complication and often imprecise. Existing mobile robot platforms were developed for multi purpose robotics, hence they have several limitations such as size, complexity, and cost, in performing swarm applications. Accordingly, to increase researches subjected to swarm robotic, it is essential to design a low-cost and open source platform with locally available components. Thus, a large number of swarm robots can economically be replicated.

1.2 Objectives

The main objectives of this study are:

1. To develop a low-cost autonomous miniature mobile robot
2. To improve the generic model for miniature swarm mobile robot platform

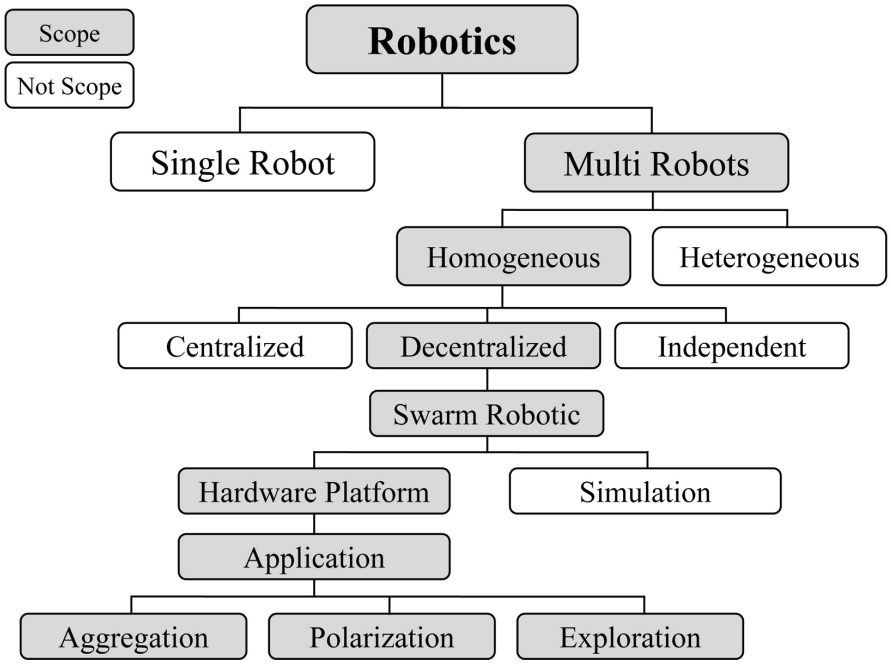

Figure 1.1. Scope of thesis

3. To evaluate the performance of AMiR for collective behavior

The ultimate goal of this study is development of an autonomous miniature mobile robot platform to be used in swarm robotic application. In order to achieve this goal, three specific objectives are accomplished. First objective is designing of a low-cost mobile robot in small size which is acceptable as an autonomous mobile robot. Second objective is evaluation of proposed design in two different levels: 1) reliability of hardware modules as a robotic platform and 2) feasibility of robot as an autonomous machine. In this case, a comparison of present work with other mobile robots is presented. In addition, mathematical models of the modules behavior for proposed robot are described. The last objective is the study of collective behavior of the proposed robot in different swarm scenarios. Individual and collective behavior of the developed robot are compared particularly with other swarm robotic platforms.

1.3 Scope of Work

The following paragraph describe the scope of work based on Figure 1.1:

- Hardware platform:
    1. Limited perception of robots based on swarm robotic definition which requires simple agents.
    2. Inter-robot communication is limited to infrared signal. Other types of wireless data transmission can be adapted by adding additional modules.
    3. There is no feedback sensors from motion due to mechanical configuration and cost reduction.
- Application:
    1. Implementation of 2-dimensional experiments due to the platform design.
    2. Using only light as the behavior clues. In order to use other types of environmental configurations such as odor and audio can be adopted by adding additional modules.
    3. Due to limitation of resources, six robot platforms are made and scalable experiments are performed using these platforms. However significant changes in swarm behavior has been observed.

1.4 Organization of Thesis

This thesis is organized in five chapters. Chapter 2 is a survey of related works on swarm systems. A brief introduction of swarm intelligence and inspired

behaviors are presented. Then swarm robotics definition and its applications are explained. Several existing platforms which are utilized in swarm researches are introduced. Chapter 3 explains methodology of this research which is organized in two parts, development of robot and defining swarm behavior of robots. First part describes architecture and hardware components of robot. This part includes mechanical design, main board, kinematic, sensory system, communication, power, and extension modules. Second part includes implementation of three swarm scenarios to prove the feasibility of developed robot. There are three swarm scenarios which are honeybee aggregation, polarization, and exploration. Various effective parameters in all collective behaviors are extracted and the influence of these parameters on the collective behaviors, are discussed. Chapter 4 presents results of hardware system and analyzes the collective behaviors. In this chapter, amenability of developed functions for motion, sensory system, communication, and power consumption are tested. Finally results of implemented swarm behaviors and analyzing of effective parameters are discussed. Chapter 5 concludes this work with summary in relation to the objectives.

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