Swarm-Based Planning and Control of Robotic Formations

Van Thuyen Ngo

A thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

ARC Centre of Excellence for Autonomous Systems

Faculty of Engineering and Information Technology

University of Technology, Sydney, Australia

August 2008

Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Production Note:
Signature removed prior to publication.

Van Thuyen Ngo

August 2008

Acknowledgements

Firstly, I would like to express my deepest appreciation to my principle supervisor, A/Prof. Quang Ha for his academic supervision of my candidature here at University of Technology, Sydney. He has kindly, critically read through several drafts of this work. I have very much benefited from the discussions with him during this time.

I also would like to express my gratitude to my co-supervisor, Prof Hung Nguyen, for his advice on my academic work as well as his kind support when I have difficulties in my academic life.

I wish to thank Dr Raymond Kwok for sharing his insightful understanding of PSO and initial Matlab coding when I was first introduced to the concept.

Acknowledgements go to Dr Phuoc Huynh for his warm advice and encouragement when I faced the crisis of my life during the time in Sydney. Thanks also go to Marc Gerald Norman for his kind support of accommodation for the last one and a half years, Dr Anh Duy Nguyen with whom I shared accommodation for the first two years of my candidature. They both have provided good advice and helped me get through the most difficulty time in my life. I also wish to thank all of my friends at UTS who have helped me, enriched and made my life more enjoyable. I would like to express my sincerest gratitude to Anya Van Eeuwen and Jo Cunningham-Lang, assistant officers at the Faculty of Engineering, who have provided unconditional support and encouragement. They have truly enriched my life.

This work is supported by the HUT-UTS PhD Student Collaborative Program, funded by the Vietnam Ministry of Education and Training and also by the ARC Centre of Excellence programme, funded by the Australian Research Council (ARC) and the New South Wales State Government.

Most importantly, I would like to dedicate this dissertation to my family. My mother has sacrificed her whole life, bringing me up by herself. She has done everything to keep me in school. No word can express my gratitude to her love and sacrifice. My

wife, Hoai Thu, my three little boys, Quoc Nam, Quoc Viet, and Quoc Quang in Vietnam have given me unworldly love and support throughout my time here in Sydney. I owe my wife the extremely hard time she has had to take care of the three active boys by herself as a full-time working woman.

Contents

List of figures

Abstract

Basic issues with a robotic task that requires multiple mobile robots moving in formations are to assemble at an initial point in the work space for establishing a desired formation, to maintain the formation while moving, to avoid obstacles by occasionally splitting/deforming and then re-establishing the formation, and to change the shape of the formation upon requests to accommodate new tasks or safety conditions. In the literature, those issues have been often addressed separately. This research proposes a generic framework that allows for tackling these issues in an integrated manner in the optimal formation planning and control context.

Within this proposed framework, a leader robot will be assigned and the path for the leader is obtained by utilising a modified A* search together with a vector approach, and then smoothed out to reduce the number of turns and to satisfy the dynamic and kinematic constraints of mobile robots. Next, a reference trajectory is generated for the leader robot. Based on the formation configuration and the workspace environment, desired trajectories for follower robots in the group are obtained. At the lowest level, each robot tracks its own trajectory using a unified tracking controller.

The problem of formation initialisation, in which a group of robots, initially scattering in the workspace, is deployed to get into a desired formation shape, is dealt with by using a Discrete Particle Swarm Optimisation (DPSO) technique incorporated with a behaviour-based strategy. The proposed technique aims to optimally assign desired positions for each robot in the formation by minimisation of a cost function associated with the predefined formation shape. Once each robot has been assigned with a desired position, a search scheme is implemented to obtain a collision free trajectory for each robot to establish the formation.

Towards optimal maintenance of the motion patterns, the path that has been obtained for robots in the group by using the modified A* search, is further adjusted. For this, the Particle Swarm Optimisation (PSO) technique is proposed to minimise a cost function involving global motion of the formation, with the main objective of

preventing unnecessary changes in the follower robot trajectories when avoiding obstacles.

A PSO formation motion planning algorithm is proposed to search for motion commands for each robot. This algorithm can be used to initialise the formation or to navigate the formation to its target. The proposed PSO motion planning method is able to maintain the formation subject to the kinematic and velocity constraints.

Analytical work of the thesis is validated by extensive simulation of multiple differential drive wheeled mobile robots based on their kinematic models. The techniques proposed in this thesis are also experimentally tested, in part, on two Amigo mobile robots.