Chapter 14
Effects of Multi-Robot Team Formations on Distributed Area Coverage

Prithviraj Dasgupta
University of Nebraska at Omaha, USA

Taylor Whipple
University of Nebraska at Omaha, USA

Ke Cheng
University of Nebraska at Omaha, USA

ABSTRACT

This paper examines the problem of distributed coverage of an initially unknown environment using a multi-robot system. Specifically, focus is on a coverage technique for coordinating teams of multiple mobile robots that are deployed and maintained in a certain formation while covering the environment. The technique is analyzed theoretically and experimentally to verify its operation and performance within the Webots robot simulator, as well as on physical robots. Experimental results show that the described coverage technique with robot teams moving in formation can perform comparably with a technique where the robots move individually while covering the environment. The authors also quantify the effect of various parameters of the system, such as the size of the robot teams, the presence of localization, and wheel slip noise, as well as environment related features like the size of the environment and the presence of obstacles and walls on the performance of the area coverage operation.

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INTRODUCTION

Robotic exploration of an unknown environment using a multi-robot system is an important topic within robotics that is relevant in several applications of robotic systems. These applications include automated reconnaissance and surveillance operations, automated inspection of engineering structures, and even domestic applications such as automated lawn mowing and vacuum cleaning. An integral part of robotic exploration is to enable robots to cover an initially unknown environment using a distributed terrain or area coverage algorithm. The coverage algorithm should ensure that every portion of the environment is covered by the coverage sensor or tool of at least one robot. Simultaneously, to ensure that the coverage is efficient, the coverage algorithm should prevent robots from repeatedly covering the same regions that have already been covered by themselves or by other robots. In most of the current multi-robot area coverage techniques, each robot performs and coordinates its motion individually. While individual coverage has shown promising results in many domains, there are a significant number of scenarios for multi-robot exploration such as extra-terrestrial exploration, robotic demining, unmanned search and rescue, etc., where the system can perform more efficiently if multiple robots with different types of sensors or redundant arrays of sensors can remain together as single or multiple cohesive teams (Cassinis, 2000; Chien *et al.*, 2005; De Mot, 2005). For example, in the domain of robotic demining (Bloch, Milisavljevc, & Acheroy, 2007), where autonomous robots are used to detect buried landmines, the incidence of false positive readings from underground landmines can be significantly reduced if robots with different types of sensors such as ground penetrating radar (GPR), IR (infra-red) sensors and metal detectors are able to simultaneously analyze the signals from potential landmines. In such a scenario, it would benefit if robots, each provided with one of these sensors, are able to explore the environment while maneuvering themselves together as a team. Multi-robot formation control techniques provide a suitable mechanism to build teams of robots that maintain and dynamically reconfigure their formation, while avoiding obstacles along their path (Mastellone, Stipanovic, Graunke, Intlekofer, & Spong, 2008; Olfati Saber, 2006; Smith, Egerstedt, & Howard, 2009). However, these techniques are not principally concerned with issues related to area coverage and coverage efficiency. To address this deficit, in this paper, we investigate whether multi-robot formation control techniques and multi-robot area coverage techniques can be integrated effectively to improve the efficiency of the area coverage operation in an unknown environment by maintaining teams of multiple robots.

Recently, miniature robots that have a small footprint size are being used for applications such as automated exploration of engineering structures (Rutishauser, Corell, & Martinoli, 2009; Tache *et al.*, 2009). Similarly, unmanned aerial vehicles (UAVs) and micro-helicopters that have memory and computation capabilities comparable to these mini-robots are being widely used in several domains such as aerial reconnaissance for homeland security, search and rescue following natural disasters, monitoring forest fires, wildlife monitoring, etc. (Anderson *et al.*, 2008). Mini-robots are attractive because they are relatively inexpensive to field and a swarm of several mini-robots can be fielded at a cost comparable to fielding one or a few large robots. A multi-robot system that consists of several mini-robots also improves the robustness of the system. However, coordinating the actions of mini-robots to make them work cooperatively (e.g., move in formation) in a distributed manner becomes a challenging problem. We have approached this problem using a flocking-based technique (Gokce & Sahin, 2009; Balch & Arkin, 1998) to control the movement of robots so that they can move in formation. We have theoretically analyzed our team-formation techniques and identified certain conditions under

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