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Dynamic Coverage and Rendezvous for Mobile Sensor Networks
移動傳感器網絡的動態覆蓋與聚集

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Abstract

Over the last few years, mobile sensor networks have become an area of intense research focus. In contrast to traditional multi-agent networks, a mobile sensor network consists of a large number of mobile sensing devices that are operating with limited capability and resources, and are prone to failures. This thesis will concentrate on two basic problems of mobile sensor networks, that is, coverage and rendezvous.

Coverage control is generally classified into two categories, that is, static coverage and dynamic coverage. In static coverage, the goal is to optimize the locations of sensors to improve the quality of service provided by the mobile sensor network. In dynamic coverage scenario, sensors move in order to sample a given region until every point in that region has been covered with a prescribed coverage level. This thesis will focus on the dynamic coverage problem, especially on developing dynamic coverage control strategies for mobile sensor networks taking into consideration the intrinsic limitations of mobile sensors or complicated deployment environments.

Firstly, adaptive dynamic coverage problem is formulated, where the desired coverage level of each point in the mission domain is dependent on a density function which characterizes the importance of each point in this domain. It is assumed that the density function is not known *a priori* but the sensors can learn the density function from their measurements. Based on a concept of cooperative effective coverage, a decentralized coverage control law and corresponding adaptation law are developed to accomplish the adaptive dynamic coverage task. The proposed coverage algorithm is distributed in the sense that the behavior of each sensor only depends on the information of its neighbors.

Secondly, we address the problem of dynamic coverage control for networked

mobile sensors with double integrator dynamics in an environment with unknown obstacles. The goal is to cover each point in the mission domain but outside the obstacles to a prescribed level. Based on the concept of cooperative effective coverage, a decentralized control strategy is developed to accomplish the dynamic coverage task without collision with the obstacles. Discrete update of the cooperative coverage is also considered to enhance the cooperation of the sensors in the network.

Thirdly, attention is focused on the awareness coverage problem which is another type of dynamic coverage. The problem of adaptive awareness coverage is formulated. We model the mission domain using a density function which characterizes the importance of each point and is unknown *a priori*. Then, the desired awareness coverage level over the mission domain is defined as a non-decreasing differentiable function of the density distribution. A decentralized adaptive control strategy is developed to accomplish the awareness coverage task and learning task simultaneously. The proposed control law is memoryless and can guarantee the achievement of satisfactory awareness coverage of the mission domain in finite time with the approximation error of the density function converging to zero.

Fourthly, persistent awareness coverage control for mobile sensor networks with awareness loss is addressed, where the goal is to cover the mission domain periodically with a finite period and guarantee full awareness coverage of a finite set of points of interest. A closed path for mobile sensors is designed so that the persistent awareness coverage task can be accomplished. The least number of mobile sensors needed for this task is also derived. Furthermore, it is proved that the persistent awareness coverage task can be accomplished for a given network of mobile sensors with a given period of time if there exists a solution to a set of linear inequalities. When awareness loss is not considered, it is shown that the proposed approach guarantees full awareness coverage of the whole mission domain exactly even if only one sensor is deployed.

On the other hand, multi-agent rendezvous, in which a group of mobile agents is required to rendezvous at one point, has been studied extensively. In reality, mobile sensors often possess a limited energy supply and information transmission among

sensors is often intermittent rather than continuous. Therefore, the rendezvous problem for mobile sensor networks under energy constraints and intermittent communication is of great importance in practical applications.

In the final part of this thesis, under an assumption that each sensor can measure its energy storage and exchange the measured energy information with its neighbors periodically, an energy-aware rendezvous protocol is developed which can prevent sensors' energy from dropping below a given lower bound. Moreover, under the proposed protocol the sensors with the least energy among their neighbors are allowed to remain static to conserve energy. A necessary condition and a sufficient condition for mobile sensor networks to achieve rendezvous are also derived . In addition, it is proved that if sensor' energy and the interaction topology satisfy certain conditions, the networked sensors will converge to the location of the sensor with the least energy in the network.

Table of Contents

Abstract i

Acknowledgement iv

List of Figures x

Notations xi

1 Introduction 1

1.1 Background and Literature Review 1

1.2 Thesis Outline and Contributions Overview 6

2 Decentralized Adaptive Dynamic Coverage 10

2.1 Introduction 10

2.2 Problem Statement 12

2.2.1 Cooperative Effective Coverage Model 12

2.2.2 Desired Dynamic Coverage Level 13

2.3 Decentralized Adaptive Control Law for Dynamic Coverage 15

2.3.1 Nominal Control Law 15

2.3.2 Compensation Control Law 18

2.3.3 Overall Control Strategy 20

2.4 Simulation Results 21

2.5 Conclusion 24

3 Dynamic Coverage in Non-convex Environments 25

3.1 Introduction . . . 25
3.2 Problem Statement . . . 27
3.3 Cooperative Effective Coverage . . . 29
3.3.1 Cooperative Effective Coverage . . . 29
3.3.2 Update of Cooperative Effective Coverage . . . 30
3.4 Decentralized Control Law for Dynamic Coverage . . . 31
3.4.1 Nominal Control Law . . . 32
3.4.2 Compensation Control Law . . . 35
3.4.3 Overall Control Strategy . . . 38
3.5 Simulation Results . . . 39
3.6 Conclusion . . . 40

4 Adaptive Awareness Coverage 44

4.1 Introduction . . . 44
4.2 Problem Statement . . . 47
4.2.1 Awareness Coverage Model . . . 47
4.2.2 Desired Awareness Coverage Level . . . 48
4.3 Decentralized Adaptive Control Law for Awareness Coverage . . . 50
4.3.1 Nominal Control Law . . . 51
4.3.2 Perturbation Control Law . . . 55
4.3.3 Overall Control Strategy . . . 57
4.4 Simulation Results . . . 59
4.5 Conclusion . . . 60

5 Persistent Awareness Coverage 62

5.1 Introduction . . . 62
5.2 Problem Statement . . . 64
5.3 Trajectory Planning for Persistent Awareness Coverage . . . 66
5.3.1 Path Planning . . . 66
5.3.2 Speed Control Law . . . 69

5.4 Simulation Results 77
5.5 Conclusion 80

6 Energy-constrained Rendezvous 81
6.1 Introduction 81
6.2 Preliminaries 83
6.3 Energy-aware Rendezvous Protocol 84
6.4 Main Results 87
6.5 Simulation Results 93
6.6 Conclusion 94

7 Concluding Remarks 98

Bibliography 102

Curriculum Vitae 118

List of Figures

2.1 Sensor function M_i with $q_i = (0, 0)$, $G_i = 2$, and r_i=2. 13
2.2 Fleet motion in the plane (start at red dots). 22
2.3 Individual coverage cost function $J_i(t)$. 23
2.4 Approximation error $\delta_i(q_i)$. 23

3.1 Sensor function M_i with $q_i = (0, 0)$, $G_i = 2$, $b_i = 0.1$ and r_i=2. 29
3.2 Fleet motion in the plane (start at red dots). 40
3.3 Global coverage cost function $J(t)$ denoted by the red line and individual coverage cost function $J_i(t)$ for each agent denoted by the blue lines. 41
3.4 Control effort $\|u_i(t)\|$, $i \in S$. 41
3.5 Norm of the velocity $\|v_i(t)\|$, $i \in S$. 42
3.6 (a) Network coverage at $t = 0$. (b) Network coverage at $t = 800$. (c) Network coverage at $t = 1600$. (d) Network coverage at $t = 2400$. . . 43

4.1 Fleet motion in the plane (start at red dots). 60
4.2 Coverage cost function $J_i(t)$. 61
4.3 Approximation error $\delta_i(q_i)$. 61

5.1 Closed path Ω for mobile sensor network. 68
5.2 A mission domain includes 8 points of interest denoted by solid circles. The agents' initial locations are marked with hollow circles. 78
5.3 Time evolution of function $\ln x_0(p) \,/\, x(p, t)$ at the point of interest denoted by red solid circle in figure 5.3. 79

5.4 Awareness coverage cost function $J(t)$ when $\alpha = 0$. 79

6.1 Position trajectories of networked agents under energy-aware rendezvous protocol with $\xi = 1$. 95
6.2 Energy trajectories of networked agents under energy-aware rendezvous protocol with $\xi = 1$. 95
6.3 Position trajectories of networked agents under energy-aware rendezvous protocol with $\xi = 5$. 96
6.4 Energy trajectories of networked agents under energy-aware rendezvous protocol with $\xi = 5$. 96
6.5 Evolution of the cost function V with respect to the threshold ξ. . . . 97

Notations

$\mathbb{Z}$	the set of integer numbers
$\mathbb{R}_{\geq 0}$	the set of nonnegative real numbers
$\mathbb{R}_{+}$	the set of positive real numbers
$\mathbb{R}^n$	n-dimensional Euclidean space
$\mathbb{R}^{m\times n}$	the set of $m \times n$ real matrices
$\lvert \cdot \rvert$	the absolute value
$\lVert \cdot \rVert$	the standard Euclidean norm
$f'(x)$	the derivative of function f at x
$\dot{V}$	the derivative of function V with respect to time t
$P > 0 (\geq 0)$	P being positive (nonnegative)
$P \otimes Q$	Kronecher product of matrices P and Q
A^T	transpose of the matrix A