

Chapter 10

Multi-Robot Swarm for Cooperative Scalar Field Mapping

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ABSTRACT

In this chapter, autonomous mobile robots are deployed to measure an unknown scalar field and build its map. The development of a cooperative sensing and control method is presented for multi-robot swarming to build the scalar field map. The proposed method consists of two parts. First, the development of a distributed sensor fusion algorithm is obtained by integrating two different distributed consensus filters to achieve cooperative sensing among robots. This fusion algorithm has two phases. In the first phase, the weighted average consensus filter is developed which allows each robot to find an estimate of the value of the scalar field. In the second phase, the average consensus filter is used to allow each robot to find a confidence of the estimate. The final estimate of the value of the scalar field is iteratively updated during the movement of the robot via a weighted average protocol. Second, the distributed control algorithm is developed to control the mobile robots to form a network and cover the field. Experimental results are provided to demonstrate the proposed algorithms.

INTRODUCTION

Multi-robot collaboration/swarm has broad applications including target tracking (La and Sheng, 2009) search and rescue operations, and environmental monitoring (Zhang and Leonard, 2010), etc. In recent years, missions that require the mapping of a scalar field become prominent. Measuring and exploring an unknown field of interest has attracted much attention of environmental scientists and control engineers (Cortes, 2009 and Choi et al., 2010). There are numerous applications including environmental monitoring (Lynch et al., 2008) and oil spill and toxic-chemical plume tracing (Tanner et al., 2009 and Zarzhitsky et al., 2010). Because the scalar field is often distributed across a large area, we need many robots to cover the field (La et al., 2015). Hence mobile robot network (MRN) is an ideal candidate for such missions.

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In order to create the map of a scalar field, the MRN should be able to achieve cooperative sensing among robots in a distributed manner (La and Sheng, 2013). Development of a novel cooperative sensing algorithm based on distributed estimation and control algorithms for MRNs is very challenging, especially in noisy environments (La and Sheng, 2013). The estimation and control have to be performed in each robot using only local information, while as a whole the network should exhibit collective intelligence and achieve a global goal (Cognetti et al., 2014). In a resource-constrained multi-robot system, the communication range and sensing range of each robot are small compared to the size of the surveillance region (La et al., 2015). Hence, robots cannot accomplish the mission without an effective cooperative control. Therefore, this book chapter aims to present a cooperative sensing scheme to address both estimation and motion control problems to build the map of an unknown scalar field. Our idea is to combine distributed estimation and motion control to allow mobile robots to obtain the estimates of the field during their movements.

The organization of this chapter is as follows. The next section represents system modeling including multi-robot model, scalar field model and robot measurement model. In Section “Cooperative Sensing”, the cooperative sensing among robots is presented. Section “Cooperative Control” presents cooperative control for multi-robot to cover the scalar field. The experimental results of the scalar field mapping is presented in Section “Experiment Results for Scalar Field Mapping”. Finally, the conclusions are given in Section “Conclusions”.

SYSTEM MODELING

In this section we present the models of multi-robot system, scalar field, and sensor measurement of each robot.

Multi-Robot System Model

Consider a dynamic graph G consisting of a vertex set $\mathfrak{V} = \{1, 2, \dots, n\}$ and an edge set $E \subseteq \{(i, j) : i, j \in \mathfrak{V}, j \neq i\}$. In this graph each vertex denotes a mobile robot, and each edge denotes the communication link between robots.

Let $\mathbf{p}_i \in \mathcal{R}^2$ be the position of robot i , and $d_{ij}(t) = \|\mathbf{p}_j - \mathbf{p}_i\|$ be the Euclidean distance. During the movement of the robots, the relative distance between them may change, hence the neighbors of robot also change. Therefore, a neighborhood set of robot i at time step t can be defined as:

$$N_i(t) = \{j \in \mathfrak{V} : d_{ij}(t) \leq r, j \neq i\}, \quad (1)$$

where r is a robot sensing range.

Consider n mobile robots moving in a two dimensional space and each robot with its dynamic as:

$$\dot{\mathbf{p}}_i = \mathbf{v}_i, i \in \{1, \dots, n\}, \quad (2)$$

where $\mathbf{v}_i \in \mathcal{R}^2$ is the velocity vectors of robot i , respectively. The control input of robot i is

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