Chapter 39
Experimental Validation of Distributed Cooperative Control of Multiple Mobile Robots via Local Information Exchange

Gregory A Bock
Bradley University, USA

Ryan T Hendrickson
Bradley University, USA

Jared Allen Lamkin
Bradley University, USA

Brittany Dhall
Bradley University, USA

Jing Wang
Bradley University, USA

In Soo Ahn
Bradley University, USA

ABSTRACT

In this paper, we present the experimental testing results of distributed cooperative control algorithms for multiple mobile robots with limited sensing/communication capacity and kinematic constraints. Rendezvous and formation control problems are considered, respectively. To deal with the inherent kinematic constraints with robot model, the input/output linearization via feedback is used to convert the nonlinear robot model into a linear one, and then the distributed cooperative control algorithms are designed via local information exchange among robots. Extensive experiments using Quanser's QBot2 mobile robot platforms are conducted to validate the effectiveness of the proposed distributed cooperative control algorithms. Specifically, the robot's onboard Kinect vision sensor is applied to solve the localization problem, and the information exchange is done through an ad-hoc peer-to-peer wireless TCP/IP connection among neighboring robots. Collision avoidance problem is also addressed based on the utilization of fuzzy logic rules.

DOI: 10.4018/978-1-7998-1754-3.ch039

INTRODUCTION

Distributed control of multiple mobile robots has received a great deal of attention in recent years. This growing area of research finds its inspiration from different systems that exist in nature. There are many examples of such systems as a flock of birds or a swarm of insects. A salient feature of such systems is that the individuals in the system can share information with their neighbors locally and through which the global behaviors of the overall system may be achieved. Numerous applications exist in the use of multiple mobile robots. For instance, this can be found in a variety of military missions such as surveillance and reconnaissance, or search and rescue, and in civilian applications such as environmental sensing and monitoring, and cooperative transportation (Qu, 2009; Red & Beard, 2008).

The design of distributed control for multiple robots is challenging because interactions among robots are often local, directional and intermittent due to limited sensing/communication capabilities of individual robots. Thorough study has been done addressing this challenge by assuming simple linear models for robots (Ren & Beard, 2008; Qu, 2009; Bullo et al., 2009; Saber et al., 2007). For instance, formation control of multi-robots was studied in (Desai et al., 1998; Leonard & Fiorelli, 2001) under a fixed sensing and communication structure among robots. For time varying sensing and communication, the neighboring control rule was proposed in (Vicsek et al., 1995) and rigorously proved in (Jadbabaie et al., 2003). It was shown that all systems in the group converge to the same value if the underlying undirected sensing communication topologies among systems are connected. More complicated sensing and communication topologies were studied in (Ren & Beard, 2005; Lin et al., 2004; Saber et al., 2007; Qu et al., 2008; Wang et al., 2006). By explicitly considering robot dynamics, a discontinuous control was proposed in (Dimarogonal & Kyriakopoulos, 2007) and stability was analyzed using nonsmooth Lyapunov theory. Time-varying controls were designed and analyzed using average theory in (Lin et al., 2005). A number of experimental results have been reported recently, which deal with multi-robot coordination (Marshall et al., 2006), leader-follower flocking (Gu & Wang, 2009), formation control (Antonelli et al., 2009; Reyes & Tanner, 2015), and containment control for multiple vehicles (Cao et al., 2011).

In this paper, we aim to experimentally validate a set of simple yet efficient distributed control algorithms for multiple mobile robots by explicitly addressing several practical issues associated with robot model constraints, localization, and collision avoidance. Both rendezvous and formation control problems are addressed. In particular, the input/output linearization via feedback is used to convert the nonlinear robot model into a linear one, and accordingly the design of distributed control algorithms is made tractable. Three QBot2 robots from Quanser Inc. are used in the experiments. Each QBot2 is equipped with a Microsoft Kinect RGB camera and depth sensor, wheel encoders, and communication channels. Unlike many of existing experiments designed for testing cooperative control algorithms for multiple robots reported in the literature (Antonelli et al., 2009; Cao et al., 2011; Gu & Wang, 2009; Marshall et al., 2006; Reyes & Tanner, 2015), in which a centralized system such as high-speed camera is usually utilized for robot localization, in our experiments, we completely rely on local information exchange among robots. For each robot, its current position with respect to its local coordinate frame can be measured using wheel encoders. The image acquired by its Kinect sensor is used for global localization by converting the initial position of the robot in its local coordinate frame into a global coordinate frame. The position data are then communicated with neighboring robots via an ad-hoc peer-to-peer wireless TCP/IP connection for execution of distributed control rules. In the implementation of distributed control algorithms, collision avoidance is further addressed using fuzzy logic rules. A preliminary version