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Parallel and Distributed Map Merging and Localization

Algorithms, Tools and Strategies for Robotic Networks

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Preface

The increasing interest in multi-robot systems is motivated by the wealth of possibilities offered by teams of robots cooperatively performing collective tasks. In these scenarios, distributed strategies attract a high attention, especially in applications which are inherently distributed in space, time, or functionality. These distributed schemes not only reduce the completion time of the task due to the parallel operation, but also present a natural robustness to failures due to the redundancy. In addition to the classical issues associated to the operation of individual robots, these scenarios introduce novel challenges specific to communications and coordination of the members of the robot team.

In this book, we analyze a particular problem of high interest in these scenarios: distributed map merging and localization. It allows the robots to acquire the knowledge of their surrounding needed for carrying out other coordinated tasks. We identify the main issues associated to this problem, and we present at each chapter different distributed strategies for solving them.

The explanation of this problem serves us as a tool for discussing topics which are classical in these scenarios and for introducing the reader to several multi-robot concepts. Thus, this book has several purposes. First, to give a complete solution to the distributed map merging and localization problem, which can be implemented in a multi-robot platform. Second, to provide the reader with the necessary tools for proposing new solutions to the multi-robot perception problem, or for addressing other interesting topics related to multi-robot scenarios. And third, to attract the attention to multi-robot systems and distributed strategies.

The authors have been working in different topics related to robotics perception and control. In this book they analyze distributed algorithms for perception in localization and map merging. The authors believe that this is an interesting topic, and that there are still many challenges that remain to be addressed in order to achieve the final aim of having a complete availability of these systems in the life of human beings.

This book can be of interest to the robotics and control communities, to post-graduate students and researchers, and, in general, to anyone interested in multi-robot systems. We do not make any assumption about the background needed to read the book. However, the basic understanding on mathematics of a graduate student is necessary. It is very difficult to give a fully self-contained material and, although we have introduced as many explanations and demonstrations as we could, we give references which can be studied if needed.

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Chapter 1
Introduction

Abstract The increasing interest in multi-robot systems is motivated by the wealth of possibilities offered by teams of robots cooperatively performing collective tasks. This chapter introduces the multi-robot map merging and localization problem, and makes a revision of the state of the art in the topics involved. The last section in this chapter contains the book organization and explains the way in which the authors have focused the study.

Keywords Networked robots · Distributed systems · Parallel computation · Limited communication · Multi-robot perception · Localization · Data association · Map merging

1.1 Motivation

The increasing interest in multi-robot applications is motivated by the wealth of possibilities offered by teams of robots cooperatively performing collective tasks. The efficiency and robustness of these teams go beyond what individual robots can do. In these scenarios, distributed strategies attract a high attention, especially in applications which are inherently distributed in space, time or functionality. These distributed schemes do not only reduce the completion time of the task due to the parallel operation, but also present a natural robustness to failures due to the redundancy. In addition to the classical issues associated to the operation of individual robots, these scenarios introduce novel challenges specific to communications and coordination of the members of the robot team. Several distributed algorithms are based on behaviors observed in nature. It has been observed that certain groups of animals are capable of deploying over a given region, assuming a specified pattern, achieving rendezvous at a common point, or jointly initiating motion or changing direction in a synchronized way (Fig. 1.1).[1] Species achieve synchronized behavior, with limited

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[1] The images in Fig. 1.1 have been obtained from the following sources. Figure 1.1 (left): https://commons.wikimedia.org/wiki/File:Grus_grus_flocks.jpg; Andreas Trepte, http://www.photo-natur.de. Figure 1.1 (right): https://commons.wikimedia.org/wiki/File:IRobot_Create_team.jpg; Jiuguang Wang; A team of iRobot Create robots at the Georgia Institute of Technology.

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Fig. 1.1 Examples of pattern formation observed in animals and of multi-robot teams

sensing or communication between individuals, and without apparently following the instructions of a group leader. Robotic researchers have intensively investigated on coordination strategies for multi-robot systems (Fig. 1.1) capable of imitating these collective behaviors. In particular, it is worth mentioning the following strategies: rendezvous, which consists of the robots getting together at a certain location; deployment or coverage, which consists of deploying the robot team over the region of interest, and agreement, which consists of reaching consensus upon the value of some variable. Agreement has a special interest and recently it has been shown that several multi-robot strategies, including pattern formation and rendezvous, can be transformed into an agreement problem.

Our research is focused on distributed applications for perception tasks. Perception is of high importance in robotics, since almost all robotic applications require the robot team to interact with the environment. Then, if a robot is not able to obtain an environmental representation from others, or an a priori representation is not available, it must have perception capabilities to sense its surroundings. Perception has been long studied for single robot systems and a lot of research has been carried out in the fields of localization, map building, and exploration. Among the different sensors that can be used to perceive the environment, visual perception using conventional or omnidirectional cameras has been broadly used because of its interesting properties (Fig. 1.2).

While the first kind of cameras (Fig. 1.3) are widely known and used in any area, omnidirectional devices are very popular in robotic applications. These cameras are able to capture visual information within 360° around the robot due to the use of an hyperbolic mirror (Fig. 1.4). Cameras provide bearing-only information through the projection of landmarks which are in the scene. In order to recover the position of these landmarks in the world, multiple observations taken from different positions must be combined. The manipulation of bearing data is an important issue in robotics. Compared with information extracted from other sensors, such as lasers, bearing information is complicated to use. However, the multiple benefits of using cameras

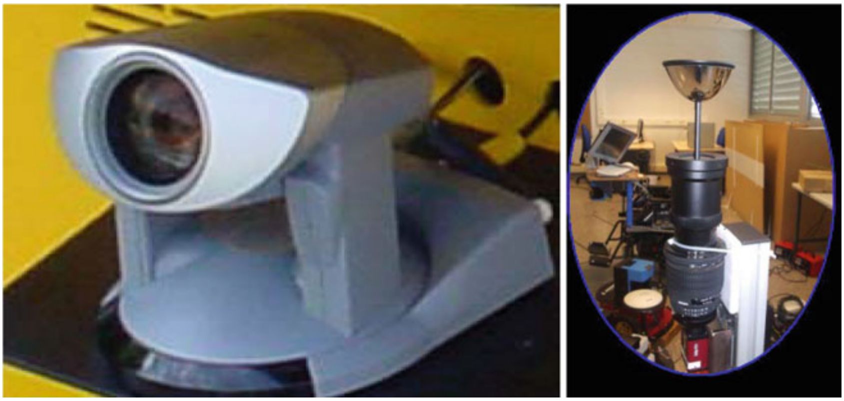

Fig. 1.2 Examples of conventional (*left*) and omnidirectional cameras (*right*)

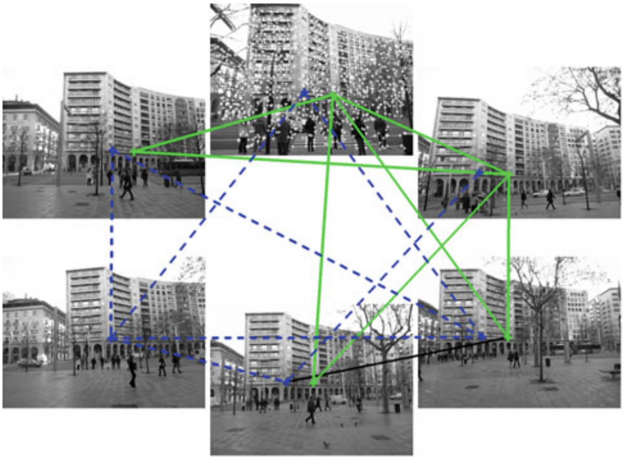

Fig. 1.3 Examples of images taken by a team of six robots moving in formation equipped with a conventional camera. Crosses are features extracted from the images and lines between images represent features matches

Fig. 1.4 Examples of omnidirectional images. Crosses are features extracted form the images, and lines between images represent features matches

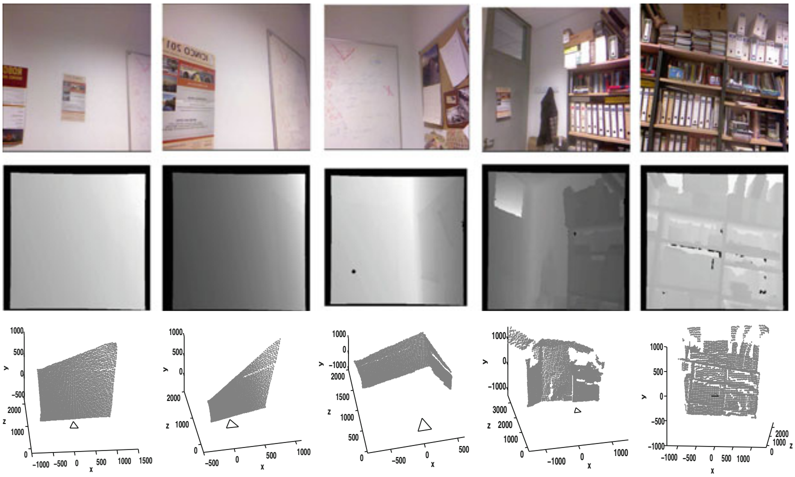

Fig. 1.5 An example of the images obtained with the RGB-D sensor

have motivated the interest in the researchers. These benefits include the property that cameras are able to sense quite distant features, so that the sensing is not restricted to a limited range. An additional kind of cameras of high interest are RGB-D devices. They provide both regular RGB (Fig. 1.5, first row) and depth image information (Fig. 1.5, second row). Thus, it is possible to compute the landmark 3D position from a single image (Fig. 1.5, third row).

Robots sense the environment and combine the bearing data to build representations of their surroundings in the form of stochastic maps. Each individual robot perceives the portion of the environment where it is operating. In order to make decisions in a coordinated way, the robots must merge their local observations into a global map. We can distinguish between centralized and distributed approaches. Centralized strategies, where a central node compiles all the information from other robots, performs the computations, and propagates the processed information or decisions to the other nodes, have several drawbacks. The whole system can fail if the central node fails, leader selection algorithms may be needed, and communication of all agents with the central system may be required. On the other hand, distributed systems are naturally more robust to individual failures since all robots play the same role. They also consider more realistic situations where agents cannot communicate with all other robots at every time instant, but instead they exchange data only with a limited number of other robots, e.g., agents within a specific distance. These situations can be best modeled using communication graphs, where nodes are the agents and edges represent communication capabilities between the robots. Additionally, since agents are moving, the topology of the graph may vary along the time, given rise to switching topologies. We analyze map merging and localization solutions for robotic systems with range limited communication, and where the