Advances in Industrial Control

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Control of Multiple Robots Using Vision Sensors

Springer

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Series Editors' Foreword

This series, Advances in Industrial Control, aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline: new theory, new controllers, actuators, sensors, new computer methods, new applications, new design philosophies, and new challenges. Much of this development work resides in industrial reports, feasibility study papers and the reports of advanced collaborative projects. This series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

This *Advances in Industrial Control series monograph Control of Multiple Robots Using Vision Sensors* by Miguel Aranda, Gonzalo López-Nicolás and Carlos Sagüés makes contributions to three areas: robotics, vision sensors with image processing, and automatic control.

Robotics is now an extremely wide-ranging science, and just to categorize its various applications would take a monograph in itself. The Editors' associated series of *Advanced Textbooks in Control and Signal Processing* contains an excellent volume covering all aspects of robotic science entitled Robotics written by Bruno Siciliano, Lorenzo Sciavicco, Luigi Villani, and Giuseppe Oriolo (ISBN 978-1-84628-641-4, 2008). As an indication of just how the field has grown, the Siciliano et al. text is over 650 pages in length. However, the specific objective of the research reported in the current monograph is the coordination and control of robot teams working in 2D and 3D motion. A generic approach is taken with much of the emphasis on geometric robot localization rather than the construction of the robot devices in themselves. Experimental work using a four-wheeled robot from Robosoft (Chap. 3) and a team of four Khepera III robots (Chap. 5) is presented.

The use of vision sensors is another area of technology experiencing significant growth. It is the advent of small, powerful, lightweight cameras allied with many different advanced image-processing algorithms that is driving this growth. Again there is a wide field of applications from rehabilitation devices for the visually impaired and driverless transport through to image processing for security recognition and on to inspection, monitoring, and control applications in industrial

processes. For motion or mobility applications, a key issue is to be able to extract the most important features from complex terrain images to match the demands of the application. In some applications, the information is used in guidance for safe travel; in other more demanding applications it is used for goal-seeking and navigation. The authors of this *Advances in Industrial Control* series monograph are presenting solutions for a far more complex task combining guidance for autonomous robot safe travel, coordination for robot teams, and ultimately localization to achieve goal-seeking objectives.

The final theme in the monograph is the use of automatic control methods to achieve the objectives of guidance; coordination and navigation to target goal locations for a team of autonomous robots integrating information from vision sensors; no mean task. Inevitably the control solution will exploit a hierarchical architecture with high-level supervision and processing instructing low-level actuator commands. Control is likely to be distributed within the hierarchy to help reduce computational loadings on the computing devices used. Finally, there is likely to be a mixture of control actions using mathematical models, for example, in the low-level actuator devices, and at higher levels, mathematical techniques combining "intelligence" and "heuristics" to provide the supervision and navigation needed. These predictions are based on the Editors' experience gained from the application of generic automatic control methods to different industrial applications (this generic character is one of the automatic control's main strengths). The reader will have to read the authors' monograph to see how far these predictions are realized.

Although the use of vision sensors in control applications is an important developing area, the *Advances in Industrial Control* series has had only one prior monograph contribution to this field, namely *Quad Rotorcraft Control* by Luis R. García Carrillo, Alejandro E. Dzul López, Rogelio Lozano, and Claude Pégard (ISBN 978-1-4471-4398-7, 2013). Consequently, the Editors are pleased to welcome this new contribution into the series.

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Preface

Endowing mobile agents with the ability to autonomously navigate an environment is a fundamental research problem in robotics. In particular, systems that consist of multiple autonomous robots moving in coordinated fashion have received tremendous attention recently. Compared with single-robot setups, multirobot systems provide more efficient and robust task completion, and enable behaviors having a higher degree of complexity and sophistication. These properties make them attractive in numerous applications across diverse domains that include manufacturing, transportation, farming, environmental monitoring, or search and rescue missions. Technological advances in computation, sensing, actuation, and communications are continuously enabling new real-world implementations of multirobot control systems. Relevant current challenges in this field concern the development of increasingly reliable, flexible, and scalable systems while taking into account critical aspects such as efficiency of performance and cost per agent.

Autonomous robots rely on sensors to obtain the primary information they need to make decisions. Vision sensors provide abundant information while being widely available, convenient to use, and relatively inexpensive, which has made them a usual choice in many robotic tasks. When dealing with systems that comprise multiple robots, the simplicity and cost advantages associated with the use of cameras become particularly relevant. Still, mobile robot control using vision presents challenges inherent to the very nature of this sensing modality, and faces specific problems when multirobot scenarios are considered.

This book addresses a number of these research issues, presenting solutions that advance the state of the art in the field of vision-based control of multiple robots. We first introduce novel methods for control and navigation of mobile robots using 1D multiple-view models computed from angular visual information obtained with omnidirectional cameras. The relevance of the approaches presented lies in that they overcome field-of-view and robustness limitations, while at the same time providing advantages in terms of accuracy, simplicity, and applicability on real platforms. In addition, we address coordinated motion tasks for multiple robots, exploring different system architectures. In particular, we propose a partially distributed image-based control setup where multiple aerial cameras are used to drive a

team of ground robots to a desired formation, with interesting characteristics regarding simplicity, scalability, and flexibility. Furthermore, we also describe decentralized formation stabilization methods whose significance comes from the fact that they exhibit strong stability properties while relying only on information expressed in the robots' local reference frames and, thereby, being amenable to vision-based implementations. Some of the aspects investigated in the context of these decentralized multirobot control strategies are global convergence guarantees, the presence of time-delays in the communications, or their application to target enclosing tasks.

In this research monograph, we describe in detail the proposed control approaches and formally study their properties. In addition, the performance of the different methodologies is evaluated both in simulation environments and through experiments with real robotic platforms and vision sensors.

This book is primarily aimed at researchers, engineers, and postgraduate students in the areas of robotics, automatic control, and computer vision. The ideas presented can also have links with broader research problems in applied mathematics, industrial control, and artificial intelligence, and be of interest to specialist audiences in those fields. A background in mathematics and engineering at graduate student level is necessary in order to fully understand this book.

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