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Mobile Ad Hoc Robots and Wireless Robotic Systems

Design and Implementation

Raul Aquino Santos, Omar Lengerke & Arthur Edwards Block

Mobile Ad Hoc Robots and Wireless Robotic Systems:

Design and Implementation

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Information Science
REFERENCE

Managing Director: Lindsay Johnston
Editorial Director: Joel Gamon
Book Production Manager: Jennifer Romanchak
Publishing Systems Analyst: Adrienne Freeland
Assistant Acquisitions Editor: Kayla Wolfe
Typesetter: Nicole Sparano
Cover Design: Nick Newcomer

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Mobile ad hoc robots and wireless robotic systems: design and implementation / Raul Aquino Santos, Omar Lengerke, and Arthur Edwards Block, editors.
pages cm
Includes bibliographical references and index.
Summary: "This book introduces robotic theories, wireless technologies and routing applications involved in the development of mobile ad hoc robots"-- Provided by publisher.
ISBN 978-1-4666-2658-4 (hardcover) -- ISBN 978-1-4666-2689-8 (ebook) -- ISBN (invalid) 978-1-4666-2720-8 (print & perpetual access) 1. Mobile robots. 2. Ad hoc networks (Computer networks) I. Aquino Santos, Raul, 1965- II. Lengerke, Omar, 1975- III. Block, Arthur Edwards, 1957-
TJ211.415.M59 2013
629.8'932--dc23
2012029182

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

All work contributed to this book is new, previously-unpublished material. The views expressed in this book are those of the authors, but not necessarily of the publisher.

Preface

It was Leonardo da Vinci (1452-1519) who first studied robotics in great depth. His great ability to project and develop mechanisms intended to reproduce natural characteristics he was interested in are published in his notebooks, *Codex Atlanticus*, Ms.B, Ms.I, today in the museum of science of Florence, Italy, and in private collections like the *Codex Leicester*, belonging to Bill Gates, the founder of Microsoft (Rosheim, 2006). The first robots were truly complex, automatic pieces of art capable of carrying out repetitive tasks. These robots gave rise to today's fixed-base, manipulating arms, widely used in industry (e.g. car-making industry). Mobile robots were developed recently, and their main feature is their guided, semi-autonomous, or fully autonomous motion capability.

The evolution of mobile robots has contributed to a number of solutions in the area of robot control. For example, the distributed control of robots requires wireless communication networks connecting the robots to other devices in their surroundings. This book intends to, among other things, provide examples of solutions related to the distributed control of mobile robots. Wifi and Bluetooth technologies are examples of such networks. Ad Hoc networks can be readily installed in a setting to offer coverage of a wide region by using a great number of nodes. Besides offering communication for the robots, a sensor network can aid their motion and location, as well as enhance their sensing capability. This book presents different platforms and studies that permit the integration of Ad Hoc networks into mobile robot applications with the goal of providing control of and communication among mobile robots through wireless technologies.

The last decade's fast advance in technology made mobility a reality. Each day witnesses the appearance of mobile and portable devices with ever-larger storage and processing capabilities. Likewise, wireless communication technologies have also been developed, searching for optimal relation of energy-unit-transmitted data. Perhaps the greatest advances have been in the area of wireless sensor networks.

Wireless Sensor Networks (WSNs) are made up of devices traditionally known as sensor nodes. These nodes are compact, autonomous, possess limited storage capacity, sense physical characteristics in their environment, and employ Radio Frequency (RF) signals over short distances, thus facilitating communication (usually Ad Hoc). Mobile robots are computerized mechanisms capable of moving and reacting to their surroundings by means of a combination of direction and operation established through a trajectory, defined plan, or action transmitted in real time. Sensor-led information measures both the robot's internal status and its surroundings. Mobile robots are classified based on the application type or locomotion type. Limbed robots can move across more irregular terrain than wheeled robots, but they demand more energy and are also slower (Pfeiffer, et al., 1998). Robot mobility can also be airborne, as is the case with robots used in aerial rescue, surveillance, and space exploration (Kaestner, et al., 2006). Some robots move quickly on the soil or on service lines (ducts, wiring, etc.) while others use magnetic levitation, which requires especially prepared surfaces. Lastly, there are sub-aquatic robots, which share stability problems with their space counterparts.

Mobile robotics is among the great variety of areas presently using wireless sensor networks. The combined use of these technologies is quite interesting from the perspective that they supplement each other. Mobile robots can be equipped with nodes and they can be interpreted as mobile nodes as part of a sensor network, or as they are utilized as a communication channel between isolated networks. On the other hand, a sensor network can be seen as an extension of the sensing and communication capabilities of mobile robots. There is, for example, extensive literature exploring two of the abovementioned characteristics.

The study of mobile robot location and control stands as an interesting challenge, given their great mobility and the constant topology changes characteristic of Ad Hoc Mobile Networks (MANET). These features call for efficient communications regarding the agent's individual status and rapid algorithms capable of calculating the relative positions of the systems involved.

Wireless mobile networks are communication systems where those stations constituting mobile nodes communicate by means of links (radio). These network types can be classified into two kinds: networks with infrastructure and Ad Hoc networks, or without infrastructure. The main feature of Ad Hoc networks is that they do not have any type of previously established infrastructure. Therefore, this kind of network can be quickly constructed, either in complex surroundings, or wherever previous installation of an infrastructure is difficult. In Ad Hoc networks, the nodes are responsible for carrying out those functions previously carried out by the access point; then, each network node becomes a router responsible for sending, forwarding, or receiving the messages with other nodes that must communicate among themselves to reach any defined area. Given that nodes can move randomly and dynamically, thus altering the topology of the network, the routing protocols used in Ad Hoc networks must be adaptive and capable of finding routes in this rapidly changing scenario.

Substantial work in the area of Ad Hoc networks has been presented in the last few years. The characteristic feature of these types of networks is the use of radio channels to promote communication between their nodes and the absence of fixed devices centralizing network communication, meaning that two nodes can communicate directly once they are within each other's transmission area. Whenever two nodes are quite distant from each other, intermediate nodes in the network can participate as intermediaries in this communication, carrying out routing functions of the messages between origin and destination nodes.

Several protocols have already been proposed in the literature to guarantee the routing of messages between all of the network nodes and enhance communication efficiency. Examples include DSDV (Perkins & Bhagwat, 1994), DSR (Johnson & Maltz, 1996), TORA (Park & Corson, 1997), and AODV (Perkins & Royer, 1999). These features allow nodes to move within a given area, dynamically altering the network topology while maintaining connectivity. All of this expands the number of possible applications of Ad Hoc networks.

The vision of Leonardo da Vinci is quickly becoming a reality. Robots can now emulate many natural movements in many areas of endeavor, and their application is sure to grow in the future as technology evolves and makes further advances possible. Robots and their intercommunication will one day make human life more enjoyable, productive, safer, and more entertaining. *Mobile Ad Hoc Robots and Wireless Robotic Systems: Design and Implementation* is a book whose objective is to present state-of-the-art work being done in the area of robotics and communications so that its readers can one day advance science and technology to our ultimate goal: produce robotic systems that can one day encompass every aspect of our lives, thus freeing the human species to advance in many other fields of endeavor.

Acknowledgment

Raul Aquino Santos would like to thank his wife, Tania, for her deep love and for giving him a wonderful family and his lovely daughters, Tania Iritzi and Dafne, for providing him with many years of happiness. In addition, he would like to thank his parents, Teodoro and Herlinda, for offering him the opportunity to study and to believe in God. Finally, he wants to thank his brother, Carlos, and his sisters, Teresa and Leticia, for their support.

Omar Lengerke would like to thank his wife, Magda. This book would not have been possible without her support and encouragement. Words cannot express his gratitude to Editor Prof. Aquino for his professional advice and assistance in polishing this manuscript. Special thanks to the researchers for their invaluable assistance in producing this volume.

Arthur Edwards Block would like to endlessly thank his wife, Marilú, for selflessly dedicating her life to making his life worth living. He would like to thank her for giving him the most precious children, Elisa and David, and for always firmly standing beside him. Thank you for walking life's path with him.

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In this chapter, the design of a completely decentralized and distributed multi-robot localization algorithm is presented. The issue is approached using an Interlaced Extended Kalman Filter (IEKF) algorithm. The proposed solution allows the dynamic correction of the position computed by any single robot through information shared during the random rendezvous of robots. The agents are supposed to carry short-range antennas to enable data communication when they have a "visual" contact. The information exchange is limited to the pose variables and the associated covariance matrix. The algorithm combines the robustness of a full-state EKF with the effortlessness of its interlaced implementation. The proposed unsupervised method provides great flexibility by using exteroceptive sensors, even if it does not guarantee the same position estimate accuracy for each agent. However, it can be effective in case of connectivity loss among team robots. Moreover, it does not need synchronization between agents.

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Mobile robots and Wireless Sensor Networks (WSNs) are enabling technologies of ubiquitous and pervasive applications. Surveillance is one typical example of such applications for which the literature proposes several solutions using mobile robots and/or WSNs. However, robotics and WSNs have mostly been considered as separate research fields, and little work has investigated the marriage of these two technologies. In this chapter, the authors propose an indoor surveillance application, SURV-TRACK, which controls a team of multiple cooperative robots supported by a WSN infrastructure. They propose a system model for SURV-TRACK to demonstrate how robots and WSNs can complement each other to efficiently accomplish the surveillance task in a distributed manner. Furthermore, the authors investigate two typical underlying problems: (1) Multi-Robot Task Allocation (MRTA) for target tracking and capturing and (2) robot path planning. The novelty of the solutions lies in incorporating a WSN in the problems' models. The authors believe that this work advances the literature by demonstrating a concrete ubiquitous application that couples robotic and WSNs and proposes new solutions for path planning and MRTA problems.

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Accurate path following is an important mobile robot research topic. In many cases, radio controlled robots are not able to work properly due to the lack of a good communication system. This problem can cause many difficulties when robot positioning is regarded. In this context, gaining automatic abilities becomes essential to achieving a major number of mission successes. This chapter presents a suitable control methodology used to achieve accurate path following and positioning of nonholonomic robots by using PID controllers. An important goal is to present the obtained experimental results by using the available mobile robot platform that consists of a differential driven one.

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Sensor-based localization has been found to be one of the most preliminary issues in the world of Mobile/Wireless Robotics. One can easily track a mobile robot using a Kalman Filter, which uses a Phase Locked Loop for tracing via averaging the values. Tracking has now become very easy, but one wants to proceed to navigation. The reason behind this is that tracking does not help one determine where one is going. One would like to use a more precise "Navigation" like Monte Carlo Localization. It is a more efficient and precise way than a feedback loop because the feedback loops are more sensitive to noise, making one modify the external loop filter according to the variation in the processing. In this case, the robot updates its belief in the form of a probability density function (pdf). The supposition is considered to be one meter square. This probability density function expands over the entire supposition. A door in a wall can be identified as peak/rise in the probability function or the belief of the robot. The mobile updates a window of 1 meter square (area depends on the sensors) as its belief. One starts with a uniform probability density function, and then the sensors update it. The authors use Monte Carlo Localization for updating the belief, which is an efficient method and requires less space. It is an efficient method because it can be applied to continuous data input, unlike the feedback loop. It requires less space. The robot does not need to store the map and, hence, can delete the previous belief without any hesitation.

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Robotic navigation applies to multiple disciplines and industrial environments. Coupled with the application of Artificial Intelligence (AI) with intelligent technologies, it has become significant in the field of cognitive robotics. The capacity of reaction of a robot in unexpected situations is one of the main qualities needed to function effectively in the environment where it should operate, indicating its degree of autonomy. This leads to improved performance in structured environments with obstacles identified by evaluating the performance of the reactive paradigm under the application of the technology of neural networks with supervised learning. The methodology implemented a simulation environment to train different robot trajectories and analyze its behavior in navigation and performance in the operation phase, highlighting the characteristics of the trajectories of training used and its operating environment, the scope and limitations of paradigm applied, and future research.

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Many interesting and difficult practical problems need to be tackled in the areas of firefighting, biological and/or chemical decontamination, tactical and/or rescue searches, and Web spamming, among others. These problems, however, can be mapped onto the graph decontamination problem, also called the graph search problem. Once the target space is mapped onto a graph $G(N,E)$, where N is the set of G nodes and E the set of G edges, one initially considers all nodes in N to be contaminated. When a guard, i.e., a decontaminating agent, is placed in a node $i \in N$, i becomes (clean and) guarded. In case such a guard leaves node i, it can only be guaranteed that i will remain clean if all its neighboring nodes are either clean or clean and guarded. The graph decontamination/search problem consists of determining a sequence of guard movements, requiring the minimum number of guards needed for the decontamination of G. This chapter presents a novel swarm robotics approach to firefighting, a conflagration in a hypothetical apartment ground floor. The mechanism has been successfully simulated on the Webots platform, depicting a firefighting swarm of e-puck robots.

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This chapter presents the development and implementation of three approaches that contribute to solving the mobile robot path planning problems in dynamic and static environments. The algorithms include some items regarding the implementation of on-line and off-line situations in an environment with static and mobile obstacles. A first technique involves the use of genetic algorithms where a fitness function and the emulation of the natural evolution are used to find a free-collision path. The second and third techniques consider the use of potential fields for path planning using two different ways. Brief descriptions of the techniques and experimental setup used to test the algorithms are also included. Finally, the results applying the algorithms using different obstacle configurations are included.

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One solution for trajectory tracking in a non-holonomic vehicle, like a mobile robot, is proposed in this chapter. Using the boundary values, a desired route is converted into a polynomial using a point-to-point algorithm. With the properties of Differential Flatness, the system is driven along this route, finding the necessary input values so that the system can perform the desired movement.

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Using a Single-Human Multiple-Robot System (SHMRS) to deploy rescue robots in Urban Search and Rescue (USAR) can induce high levels of cognitive workload and poor situation awareness. Yet, the provision of autonomous coordination between robots to alleviate cognitive workload and promote situation awareness must be made with careful management of limited robot computational and communication resources. Therefore, a technique for autonomous coordination using a hierarchically structured collective of robots has been devised to address these concerns. The technique calls for an Apex robot to perform most of the computation required for coordination, allowing Subordinate robots to be simpler computationally and to communicate with only the Apex robot instead of with many robots. This method has been integrated into a physical implementation of the SHMRS. As such, this chapter also presents practical components of the SHMRS including the robots used, the control station, and the graphical user interface.

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Driven by the rising demand for underwater operations concerning dam structure monitoring, Hydropower Plant (HPP), reservoir, and lake ecosystem inspection, and mining and oil exploration, underwater robotics applications are increasing rapidly. The increase in exploration, prospecting, monitoring, and security in lakes, rivers, and the sea in commercial applications has led large companies and research centers to invest underwater vehicle development. The purpose of this work is to present the design of an Autonomous Underwater Vehicle (AUV), focusing efforts on dimensioning structural elements and machinery and elaborating the sensory part, which includes navigation sensors and environmental conditions sensors. The integration of these sensors in an intelligent platform provides a satisfactory control of the vehicle, allowing the movement of the submarine on the three spatial axes. Because of the satisfactory fast response of the sensors, one can determine the acceleration and inclination as well as the attitude in relation to the trajectory instantaneously taken. This vehicle will be able to monitor the physical integrity of dams, making acquisition and storage of environmental parameters such as temperature, dissolved oxygen, pH, and conductivity, as well as document images of the biota from reservoir lake HPPs, with minimal cost, high availability, and low dependence on a skilled workforce to operate it.

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This chapter presents a virtual environment implementation for embedded design, simulation, and conception of supervision and control systems for mobile robots, which are capable of operating and adapting to different environments and conditions. The purpose of this virtual system is to facilitate the development of embedded architecture systems, emphasizing the implementation of tools that allow the simulation of the kinematic, dynamic, and control conditions, in real time monitoring of all important system points. To achieve this, an open control architecture is proposed, integrating the two main techniques of robotic control implementation at the hardware level: systems microprocessors and reconfigurable hardware devices. The utilization of a hierarchic and open architecture, distributing the diverse actions of control in increasing levels of complexity and the use of resources of reconfigurable computation are made in a virtual simulator for mobile robots. The validation of this environment is made in a nonholonomic mobile robot and in a wheelchair; both of them used an embedded control rapid prototyping technique for the best navigation strategy implementation. After being tested and validated in the simulator, the control system is programmed in the control board memory of the mobile robot or wheelchair. Thus, the use of time and material is optimized, first validating the entire model virtually and then operating the physical implementation of the navigation system.

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Elkin Yesid Veslin Diaz, Universidad de Boyacá, Colombia

This chapter describes a Mechatronics Design methodology applied to the design of a mobile robot to climb vertical surfaces. The first part of this chapter reviews different ways to adhere to vertical surfaces and shows some examples developed by different research groups. The second part presents the stages of Mechatronics design methodology used in the design, including mechanical design, electronics design, and control design. These stages describe the most important topics for optimally successful design. The final part provides results that were obtained in the design process and construction of the robot. Finally, the conclusions of this research work are presented.

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Samuel Mishal, RobotBASIC, USA

Unlike most chapters in this book, this chapter does not introduce new methods or algorithms related to robotic navigation systems. Instead, it provides an overview of a simulation tool that, in some situations, can be useful for quickly evaluating the overall appropriateness of a wide variety of alternatives before focusing more advanced development activities on a chosen design. In addition, since the tool described herein is totally free, it can be used to help students and others new to robotics understand the value of utilizing a design-simulate-deploy approach to developing robotic behaviors. Robot Simulators can emulate nearly all aspects of a robot's functionality. Unfortunately, many programming environments that support simulation have steep learning curves and are difficult to use because of their ability to handle complex attributes such as 3D renderings and bearing friction. Fortunately, there are many situations where advanced attributes are unnecessary. When the primary goal is to quickly test the feasibility of a variety of algorithms for robotic behaviors, RobotBASIC provides an easy-to-use, economical alternative to more complex systems without sacrificing the features necessary to implement a complete design-simulate-deploy cycle. RobotBASIC's ability to simulate a variety of sensors makes it easy to quickly test the performance of various configurations in an assortment of environments. Once algorithm development is complete, the same programs used during the simulation phase of development can immediately control a real robot.

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The chapter describes the stages of an autonomous mobile robot project, in this case, an underwater cleaning robot. First, the authors analyze the products already available for costumers, mainly focusing on the tasks they can perform (instead of the systems they use), in order to define the requirements of their project. Then, they build some models, based in the literature available. Based on them, the authors dimension the parts and systems by evaluating the results of these models. Finally, the authors use all information gathered to create a prototype, modeled with a CAE system.