Mobile Ad Hoc Robots and Wireless Robotic Systems: Design and Implementation

Raul Aquino Santos
*University of Colima, Mexico*

Omar Lengerke
*University of Colima, Mexico*

Arthur Edwards Block
*University of Colima, Mexico*
Chapter 1
Distributed Multi-Robot Localization ................................................................. 1

Stefano Panzieri, University Roma Tre, Italy
Federica Pascucci, University Roma Tre, Italy
Lorenzo Sciavicco, University Roma Tre, Italy
Roberto Setola, University Campus Bio-Medico, Italy

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.

Chapter 2
Indoor Surveillance Application using Wireless Robots and Sensor Networks: Coordination and Path Planning ................................................................. 19

Anis Koubaa, Al-Imam Mohamed bin Saud University, Saudi Arabia & Polytechnic Institute of Porto (ISEP/IPP), Portugal
Sahar Trigui, National School of Engineering, Tunisia
Imen Chaari, National School of Engineering, Tunisia

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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Local Path-Tracking Strategies for Mobile Robots Using PID Controllers ................................................. 58

Lluis Pacheco, University of Girona, Spain
Ningsu Luo, University of Girona, Spain

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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Mobile/Wireless Robot Navigation ............................................................................................................. 80

Amina Waqar, National University of Computers and Emerging Sciences, Pakistan

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.
Chapter 5
Control Architecture Model in Mobile Robots for the Development of Navigation Routes in Structured Environments

Alejandro Hossian, Universidad Tecnológica Nacional, Argentina
Gustavo Monte, Universidad Tecnológica Nacional, Argentina
Verónica Olivera, Universidad Tecnológica Nacional, Argentina

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.

Chapter 6
A Swarm Robotics Approach to Decontamination

Daniel S. F. Alves, Instituto de Matemática, UFRJ, Brazil
E. Elael M. Soares, Escola Politécnica, UFRJ, Brazil
Guilherme C. Strachan, Escola Politécnica, UFRJ, Brazil
Guilherme P. S. Carvalho, Escola Politécnica, UFRJ, Brazil
Marco F. S. Xaud, Escola Politécnica, UFRJ, Brazil
Marcos V. B. Couto, Escola Politécnica, UFRJ, Brazil
Rafael M. Mendonça, UERJ, Brazil
Renan S. Freitas, Escola Politécnica, UFRJ, Brazil
Thiago M. Santos, Escola Politécnica, UFRJ, Brazil
Vanessa C. F. Gonçalves, UFRJ, Brazil
Luiza M. Mourelle, UERJ, Brazil
Nadia Nedjah, UERJ, Brazil
Fulvio M. G. Francha, UFRJ, Brazil
Nelson Maculan, UFRJ, Brazil
Priscila M. V. Lima, Instituto de Ciências Exactas, UFRRJ, Brazil
Felipe M. G. França, UFRJ, Brazil

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 $G(V,E)$, where $V$ 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 $i \in N$, it 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.
Chapter 7
Path Planning in a Mobile Robot

Diego Alexander Tibaduiza Burgos, Universitat Politècnica de Catalunya, Spain
Maribel Anaya Véjar, Universitat Politècnica de Catalunya, Spain

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.

Chapter 8
An Alternative for Trajectory Tracking in Mobile Robots Applying Differential Flatness

Elkin Yesid Vestín Díaz, Universidad de Boyacá, Colombia
Jules G. Slama, Universidade Federal do Rio de Janeiro, Brazil
Max Suell Dutra, Universidade Federal do Rio de Janeiro, Brazil
Omar Lengerke Pérez, Universidad Autónoma de Bucaramanga, Colombia
Hernán González Acuña, Universidad Autónoma de Bucaramanga, Colombia

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.

Section 2
Wireless Robotic Applications

Chapter 9
A Hierarchically Structured Collective of Coordinating Mobile Robots Supervised by a Single Human

Choon Yue Wong, Nanyang Technological University, Singapore
Gerald Seet, Nanyang Technological University, Singapore
Siang Kok Sim, Nanyang Technological University, Singapore
Wee Ching Pang, Nanyang Technological University, Singapore

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.
Chapter 10
A Mechatronic Description of an Autonomous Underwater Vehicle for Dam Inspection

Driven by the rising demand for underwater operations concerning dam structure monitoring, Hydro-power 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.

Chapter 11
A Virtual Simulator for the Embedded Control System Design for Navigation of Mobile Robots applied in Wheelchairs

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.
Chapter 12
Design of a Mobile Robot to Clean the External Walls of Oil Tanks ........................................ 237
Hernán González Acuña, Universidad Autónoma de Bucaramanga, Colombia
Alfonso Réné Quintero Lara, Universidad Autónoma de Bucaramanga, Colombia
Ricardo Ortiz Guerrero, Universidad Autónoma de Bucaramanga, Colombia
Jairo de Jesús Montes Alvarez, Universidad Autónoma de Bucaramanga, Colombia
Hernando González Acevedo, Universidad Autónoma de Bucaramanga, Colombia
Elkin Yesid Véslin Díaz, 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.

Chapter 13
RobotBASIC: Design, Simulate, and Deploy .................................................. 248
John Blankenship, RobotBASIC, USA
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 on 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.

Chapter 14
Study and Design of an Autonomous Mobile Robot Applied to Underwater Cleaning ............... 258
Laforet Creomar Lima Junior, Federal University of Rio de Janeiro, Brazil
Armando Carlos de Pina Filho, Federal University of Rio de Janeiro, Brazil
Aloísio Carlos de Pina, Federal University of Rio de Janeiro, Brazil

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 customers, 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.
Chapter 15
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Gustavo Ramirez Torres, Siteldi Solutions, Mexico
Pedro Magaña Espinoza, Siteldi Solutions, Mexico
Guillermo Adrián Rodríguez Barragán, Siteldi Solutions, Mexico

With the educational mobile robot Worm-Type Mobile Educational Robot (Robot Móvil Educativo tipo Oruga, or ROMEO, by its Spanish acronym), the authors offer three hierarchical levels of experimental learning, where the operator can develop as far as his/her ability or imagination permits, gaining knowledge about the basics of sensors, communications, and mechanical and robot programming. Due the lack of learning focused on robotics in Mexican educational institutions, the authors present this chapter, where an early stimulation to this topic could trigger curiosity to research that leads to technological advancement. ROMEO is a mobile wireless communication platform with different types of sensors: moisture, brightness, temperature, etc., as well as a compass and accelerometers with similar characteristics to industrial and commercial applications that allow us to experiment with communication algorithms, sampling, and autonomous and semiautonomous navigation.

Chapter 16
Ad Hoc Communications for Wireless Robots in Indoor Environments .............................................. 279

Laura Victoria Escamilla Del Río, University of Colima, Mexico
Juan Michel García Díaz, University of Colima, Mexico

This chapter presents a theoretical and experimental comparison of electromagnetic propagation models for indoor robot communication using mobile ad-hoc IEEE802.11 and IEEE802.15.4. The analysis includes the behavior of the electromagnetic signal using the abovementioned standards in two scenarios, both located inside the building of the College of Telematics of the University of Colima. The results of the propagation of the electromagnetic signals in the two scenarios were then compared with the mathematical model.

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