Mobile Robots Navigation

Mobile Robots Navigation

Edited by

Alejandra Barrera

In-Tech
intechweb.org

Published by In-Teh

In-Teh
Olajnica 19/2, 32000 Vukovar, Croatia

www.intechweb.org
Additional copies can be obtained from:
publication@intechweb.org

First published March 2010
Printed in India

Technical Editor: Goran Bajac
Cover designed by Dino Smrekar

Mobile Robots Navigation,
Edited by Alejandra Barrera

p. cm.
ISBN 978-953-307-076-6

Preface

Mobile robots navigation includes different interrelated activities: (i) perception, as obtaining and interpreting sensory information; (ii) exploration, as the strategy that guides the robot to select the next direction to go; (iii) mapping, involving the construction of a spatial representation by using the sensory information perceived; (iv) localization, as the strategy to estimate the robot position within the spatial map; (v) path planning, as the strategy to find a path towards a goal location being optimal or not; and (vi) path execution, where motor actions are determined and adapted to environmental changes.

The book addresses those activities by integrating results from the research work of several authors all over the world. Research cases are documented in 32 chapters organized within 7 categories next described.

Sensory perception

The accurate perception of sensory information by the robot is critical to support the correct construction of spatial representations to be exploited with navigational purposes. Different types of sensor devices are introduced in this part of the book together with interpretation methods of the acquired sensory information. Specifically, Chapter 1 presents the design of a sensor combining omni-directional and stereoscopic vision to facilitate the 3D reconstruction of the environment.

Chapter 2 describes the prototype of an optical azimuth angular sensor based on infrared linear polarization to compute the robot's position while navigating within an indoor arena.

Chapter 3 depicts the design of a stereoscopic vision module for a wheeled robot, where left and right images from the same scene are captured, and one of two appearance-based pixel descriptors for surface ground extraction are employed, luminance or Hue, depending on the environment particular characteristics. This vision module also detects obstacle edges and provides the reconstruction of the scene based on the stereo image analysis.

Chapter 4 presents a sensor setup for a 3D scanner to promote a fast 3D perception of those regions in the robot's vicinity that are relevant for collision avoidance. The acquired 3D data is projected into the XY-plane in which the robot is moving and used to construct and update egocentric 2.5D maps storing either the coordinates of closest obstacles or environmental structures.

Closing this first part of the book, Chapter 5 depicts a sensor fusion technique where perceived data are optimized and fully used to build navigation rules.

Robot localization

In order to perform successful navigation through any given environment, robots need to localize themselves within the corresponding spatial representation. A proper localization allows the robot to exploit the map to plan a trajectory to navigate towards a goal destination. In the second part of the book, four chapters address the problem of robot localization from visual perception. In particular, Chapter 6 describes a localization algorithm using information from a monocular camera and relying on separate estimations of rotation and translation to provide an uncertainty feedback for both motion components while the robot navigates in outdoor environments.

Chapter 7 proposes a self-localization method using a single visual image, where the relationship between artificial or natural landmarks and known global reference points is identified by a parallel projection model.

Chapter 8 presents computer simulations of robot heading and position estimation by using a single vision sensor system to complement the encoders' function during robot motion.

By means of experiments with a robotic wheelchair, Chapter 9 demonstrates the localization ability within a topological map built by using only an omni-directional camera, where environmental locations are recognized by identifying natural landmarks in the scene.

Path planning

Several chapters focus on discussing path planning algorithms within static and dynamic environments, and two of them deal with multiple robots. In this way, Chapter 10 presents a path planning algorithm based on the use of a neural network to build up a collision penalty function. Results from simulations show proper obstacle avoidance in both static and dynamic arenas.

Chapter 11 proposes a path planning algorithm avoiding obstacles by classifying them according to their size to decide the next robot navigation action. The algorithm starts by considering the shortest path, which is then expanded on either side spreading out by considering the obstacles type and proximity.

In the context of indoor semi-structured environments full of corridors connecting offices and laboratories, Chapter 12 compares several approaches developed for door identification based on handle recognition, where doors are defined as goals for the robot during the path planning process. The chapter describes a two-step multi-classifier that combines region detection and feature extraction to increase the computational efficiency of the object recognition procedure.

In the context of planetary exploration vehicles, Chapter 13 describes a path planning and navigation system based on the recognition of occluded areas in a local map. Experimental results show the performance of a vehicle navigating through an irregular rocky terrain by perceiving its environment, determining the next sensing position that maximizes the non-occluded region within each local map, and executing the local path generated.

Chapter 14 presents a robotic architecture based on the integration of diverse computation and communication processes to support the path planning and navigation of service robots.

Applied to the flock traffic navigation context, Chapter 15 introduces an algorithm capable of planning paths for multiple agents on partially known and changing environments.

Chapter 16 studies the problem of path planning and navigation of robot formations in static environments, where a formation is defined, composed and repaired according to a proposed mereological method.

Obstacle avoidance

One of the basic capabilities that mobile robots need to exhibit in navigating within any given environment is obstacle detection and avoidance. This part of the book is dedicated to review diverse mechanisms to deal with obstacles, being static and/or dynamic, implemented on robots with different purposes, from service robots in domestic or office-like environments to car-like vehicles in outdoors arenas. Specifically, Chapter 17 proposes an approach to reactive obstacle avoidance for service robots by using the concept of artificial protection field, which is understood as a dynamic geometrical neighborhood of the robot and a set of situation assessment rules that determine if the robot needs to evade an object not present in its map when its path was planned.

Chapter 18 describes a hierarchical action-control method for omni-directional mobile robots to achieve a smooth obstacle avoidance ensuring safety in the presence of moving obstacles including humans.

Chapter 19 presents a contour-following controller to allow a wheeled robot to follow discontinuous walls contours. This controller is integrated by a standard wall-following controller and two complementary controllers to avoid collisions and find lost contours.

Chapter 20 introduces a fuzzy decision-making method to control the motion of car-like vehicles in dynamic environments showing their ability to park in spatial configurations with different placement of static obstacles, to run with the presence of dynamic obstacles, and to achieve a final target from a given arbitrary initial position.

Chapter 21 presents a qualitative vision-based method to follow a path avoiding obstacles.

Analysis of navigational behavior

A correct evaluation of the navigational behavior of a mobile robotic system is required prior its use solving real tasks in real-life scenarios. This part of the book stresses the importance of employing qualitative and quantitative measures to analyze the robot performance. From diverse perspectives, five chapters provide analysis metrics and/or results from comparative analysis of existing methods to assess different behavioral aspects, from positioning underwater vehicles to transmitting video signals from tele-operated robots.

From an information theory perspective, Chapter 22 studies the robot learning performance in terms of the diversity of information available during training. Authors employ motivational measures and entropy-based environmental measures to analyze the outcome of several robotic navigation experiments.

Chapter 23 focuses on the study of positioning as a navigation problem where GPS reception is limited or non-existent in the case of autonomous underwater vehicles that are forced to use deadreckoning in between GPS sightings in order to navigate accurately. Authors provide an analysis of different position estimators aiming at allowing vehicle designers to improve performance and efficiency, as well as reduce vehicle instrumentation costs.

Chapter 24 provides results from analyzing several performance metrics to contrast mobile robots navigation algorithms including safety, dimension and smoothness of the planned trajectory.

Chapter 25 analyses the performance of different codecs in transmitting video signals from a teleoperated mobile robot. Results are shown from robot tests in an indoor scenario.

With an aim at supporting educational and research activities, in Chapter 26, authors provide a virtual environment to develop mobile robot systems including tools to simulate kinematics, dynamics and control conditions, and monitor in real time the robot performance during navigation tasks.

Inspiration from nature

Research cycles involving living organisms' studies, computational modeling, and robotic experimentation, have inspired for many years the understanding of the underlying physiology and psychology of biological systems while also inspiring new robotic architectures and applications. This part of the book describes two different studies that have taken inspiration from nature to design and implement robotic systems exhibiting navigational capabilities, from visual perception and map building to place recognition and goal-directed behavior. Firstly, Chapter 27 presents a computational system-level model of rat spatial cognition relating rat learning and memory processes by interaction of different brain structures to endow a mobile robot with skills associated to global and relative positioning in space, integration of the traveled path, use of kinesthetic and visual cues during orientation, generation of topological-metric spatial representation of the unknown environment, management of rewards, learning and unlearning of goal locations, navigation towards the goal from any given departure location, and on-line adaptation of the cognitive map to changes in the physical configuration of the environment. From a biological perspective, this work aims at providing to neurobiologists/neuroethologists a technological platform to test with robots biological experiments whose results can predict rodents' spatial behavior.

Secondly, Chapter 28 proposes an approach inspired after developmental psychology and some findings in neuroscience that allows a robot to use motor representations for learning a complex task through imitation. This framework relies on development, understood as the process where the robot acquires sophisticated capabilities over time as a sequence of simpler learning steps. At the first level, the robot learns about sensory-motor coordination. Then, motor actions are identified based on lower level, raw signals. Finally, these motor actions are stored in a topological map and retrieved during navigation.

Navigation applications

The book concludes by introducing different contexts and real scenarios where mobile robots have been employed to solve diverse navigational tasks.

Presenting successful results along four testing years, Chapter 29 provides a mechatronic description of an autonomous robot for agricultural tasks in greenhouses emphasizing the use of specialized sensors during the development of control strategies of plants spraying and robot navigation.

A sociological application is introduced in Chapter 30, consisting on providing electric-powered wheelchairs able to predict and avoid risky situations and navigate safely through congested areas and confined spaces in the public transportation environment. Authors propose a high-level architecture that facilitates terrain surveillance and intelligence gathering through laser sensors implanted in the wheelchair in order to anticipate accidents by identifying obstacles and unusual patters of movement.

Chapter 31 describes the communication, sensory, and artificial intelligence systems implemented on the CAESAR (Contractible Arms Elevating Search And Rescue) robot, which supplies rescuers with critical information about the environment, such as gas detection, before they enter and risk their lives in unstable conditions.

Finally, another monitoring system is depicted by Chapter 32. A mobile robot being controlled by this system is able to perform a measuring task of physical variables, such as high temperatures being potentially hazardous for humans, while navigating within a known environment by following a predefined path.

The successful research cases included in this book demonstrate the progress of devices, systems, models and architectures in supporting the navigational behavior of mobile robots while performing tasks within several contexts. With no doubt, the overview of the state of the art provided by the book may be a good starting point to acquire knowledge of intelligent mobile robotics.

Alejandra Barrera
Mexico's Autonomous Technological Institute (ITAM)
Mexico

Contents

1

A 3D Omnidirectional Sensor For Mobile Robot Applications

Rémi Boutteau, Xavier Savatier, Jean-Yves Ertaud and Bélahcène Mazari
Institut de Recherche en Systèmes Electroniques Embarqués (IRSEEM)
France

1. Introduction

In most of the missions a mobile robot has to achieve – intervention in hostile environments, preparation of military intervention, mapping, etc – two main tasks have to be completed: navigation and 3D environment perception. Therefore, vision based solutions have been widely used in autonomous robotics because they provide a large amount of information useful for detection, tracking, pattern recognition and scene understanding. Nevertheless, the main limitations of this kind of system are the limited field of view and the loss of the depth perception.
A 360-degree field of view offers many advantages for navigation such as easiest motion estimation using specific properties on optical flow (Mouaddib, 2005) and more robust feature extraction and tracking. The interest for omnidirectional vision has therefore been growing up significantly over the past few years and several methods are being explored to obtain a panoramic image: rotating cameras (Benosman & Devars, 1998), muti-camera systems and catadioptric sensors (Baker & Nayar, 1999). Catadioptric sensors, i.e. the combination of a camera and a mirror with revolution shape, are nevertheless the only system that can provide a panoramic image instantaneously without moving parts, and are thus well-adapted for mobile robot applications.
The depth perception can be retrieved using a set of images taken from at least two different viewpoints either by moving the camera or by using several cameras at different positions.
The use of the camera motion to recover the geometrical structure of the scene and the camera's positions is known as Structure From Motion (SFM). Excellent results have been obtained during the last years with SFM approaches (Pollefeys et al., 2004; Nister, 2001), but with off-line algorithms that need to process all the images simultaneous. SFM is consequently not well-adapted to the exploration of an unknown environment because the robot needs to build the map and to localize itself in this map during its world exploration.
The in-line approach, known as SLAM (Simultaneous Localization and Mapping), is one of the most active research areas in robotics since it can provide a real autonomy to a mobile robot. Some interesting results have been obtained in the last few years but principally to build 2D maps of indoor environments using laser range-finders. A survey of these algorithms can be found in the tutorials of Durrant-Whyte and Bailey (Durrant-Whyte & Bailey, 2006; Bailey & Durrant-Whyte, 2006).

Vision-based SLAM algorithms are generally dedicated to monocular systems which are cheaper, less bulky, and easier to implement than stereoscopic ones. Stereoscopic systems have, however, the advantage to work in dynamic environments since they can grab simultaneously two images. Calibration of the stereoscopic sensor enables, moreover, to recover the Euclidean structure of the scene which is not always possible with only one camera.
In this chapter, we propose the design of an omnidirectional stereoscopic system dedicated to mobile robot applications, and a complete scheme for localization and 3D reconstruction. This chapter is organized as follows. Section 2 describes our 3D omnidirectional sensor. Section 3 is dedicated to the modelling and the calibration of the sensor. Our main contribution, a Simultaneous Localization and Mapping algorithm for an omnidirectional stereoscopic sensor, is then presented in section 4. The results of the experimental evaluation of each step, from calibration to SLAM, are then exposed in section 5. Finally, conclusions and future works are presented section 6.

2. System overview

2.1 Sensor description

Among all possible configurations of central catadioptric sensors described by Nayar and Baker (Baker & Nayar, 1999), the combination of a hyperbolic mirror and a camera is preferable for the sake of compactness since a parabolic mirror needs a bulky telecentric lens.
Although it is possible to reconstruct the environment with only one camera, a stereoscopic sensor can produce a 3D reconstruction instantaneously (without displacement) and will give better results in dynamic scenes. For these reasons, we developed a stereoscopic system dedicated to mobile robot applications using two catadioptric sensors as shown in Figure 1.

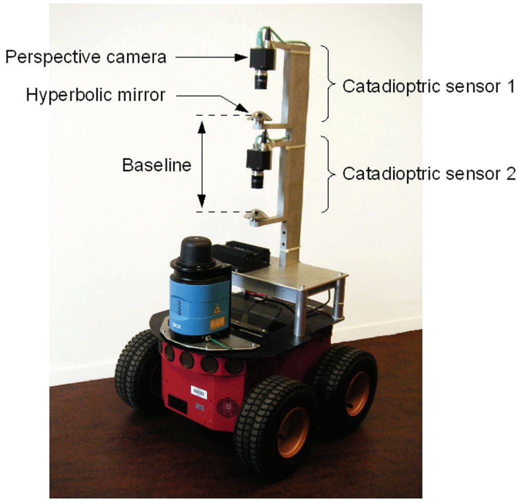

Fig. 1. View of our catadioptric stereovision sensor mounted on a Pioneer robot. Baseline is around 20cm for indoor environments and can be extended for outdoor environments. The overall height of the sensor is 40cm.

2.2 Imposing the Single-Viewpoint (SVP) Constraint

The formation of images with catadioptric sensors is based on the Single-Viewpoint theory (Baker & Nayer, 1999). The respect of the SVP constraint permits the generation of geometrically correct perspective images. In the case of a hyperbolic mirror, the optical center of the camera has to coincide with the second focus **F'** of the hyperbola located at a distance of *2e* from the mirror focus as illustrated in Figure 2. The eccentricity *e* is a parameter of the mirror given by the manufacturer.

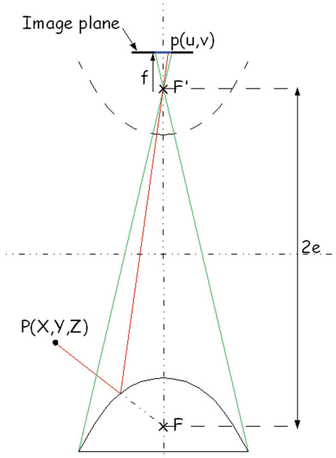

Fig. 2. Image formation with a hyperbolic mirror. The camera center has to be located at *2e* from the mirror focus to respect the SVP constraint.

A key step in designing a catadioptric sensor is to respect this constraint as much as possible. To achieve this, we first calibrate our camera with a standard calibration tool to determine the central point and the focal length. Knowing the parameters of both the mirror and the camera, the image of the mirror on the image plane can be easily predicted if the SVP constraint is respected as illustrated in Figure 2. The expected mirror boundaries are superposed on the image and the mirror has then to be moved manually to fit this estimation as shown in Figure 3.

Fig. 3. Adjustment of the mirror position to respect the SVP constraint. The mirror border has to fit the estimation (green circle).