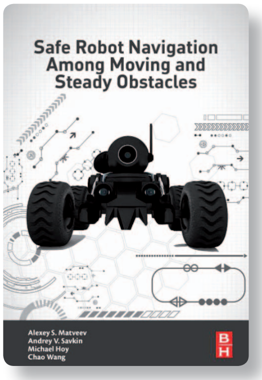
IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Scott R. Ploen, Hong Yue, or Hesuan Hu, the associate editors for books reviews.



Butterworth-Heinemann, 2016, ISBN: 9780128037300, 358 pages, US$130.

Safe Robot Navigation Among Moving and Steady Obstacles

by ALEXEY S. MATVEEV, ANDREY V. SAVKIN, MICHAEL HOY, and CHAO WANG

Reviewed by Changliu Liu

Although great progress has been made in robotics in recent years, many challenges still exist regarding real-time robot navigation in dynamic uncertain environments. Example scenarios of interest include navigation of unmanned aerial or ground vehicles in civil tasks such as search and rescue, surveillance, and inspection or navigation of self-driving vehicles in future transportation systems. To operate safely in a populated environment, a robot needs to react efficiently to hazardous situations and avoid any possible collisions. In practice, the challenges to achieve safe and efficient navigation come from limitations in sensing, communication, and computational power as well as limited mobility for the robot.

Due to increasing demands for such technology to be applied in different social sectors, robot navigation continues to be an active research area. Other surveys of this area can be found in [2]–[5]. Although it is hard, and maybe impossible, to build a unified method to solve all navigation problems, various methods are proposed to solve certain subproblems. The planning methods can be divided into two groups depending on their planning horizons, namely the global planner (or the long-term planner) and the local planner (or the short-term planner).

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Global planners try to build a comprehensive model of the environment to find the best trajectory to accomplish the navigation task. Three kinds of global planners are widely used: optimization based (including model predictive control), search based (including A* or D* graph search), and sampling based (including the family of rapidly exploring random-tree algorithms). If the environment is previously known without any uncertainty, the global planner is capable of finding the globally optimal trajectory. However, in practice, it is computationally expensive to build the model of the environment given a limited sensing ability.

Local planners try to plan only a few steps into the near future based on the limited knowledge of the environment obtained by current sensory data. Such planners require less computational power and are good choices for robots with limited sensing abilities. An extreme case of a local planner is the reactive controller, where the planning horizon reduces to one. There are usually closed-form solutions for a reactive controller, such as a direct mapping from the sensory data to the control, which can greatly relieve the computational burden. Existing reactive methods include virtual force field, potential field, and a family of biologically inspired methods. However, since it only regulates the motion locally, a local planner is sensitive to local optima; for example, it is possible for the robot to get stuck in some location and not reach the target. Thus, global convergence to the target needs to be addressed when designing a local planner. However, it is very hard to guarantee global convergence for local planners in general since the system under consideration is nonlinear (because the robot motion is nonholonomic), time varying (because the obstacles in the system are moving and deforming), and stochastic (because the information about the environment is limited).

Safe Robot Navigation Among Moving and Steady Obstacles presents navigation solutions in the regime of reactive controllers that take into account the limitations in sensing and computation abilities as well as the nonholonomic motion of the robot in environments cluttered with moving and static obstacles. Since the objective of the navigation can be divided into target reaching and collision avoidance, the reactive controllers are designed as switching controllers between the two modes. The resulting system exhibits sliding-mode behavior [1]. The major contribution of the book lies in the justification of the global convergence of the system using the proposed controllers via rigorous mathematical analysis under certain assumptions about the geometry of the problem.

The organization of the book is problem oriented rather than technique oriented, and every chapter is self-contained. Starting from Chapter 4, each chapter deals with one navigation problem. In those chapters, models of the problems are discussed, control strategies are proposed, theoretical guarantees on collision avoidance and global convergence of the proposed control strategies are proved, and simulation or experimentation results are shown. The book covers navigation problems in static and dynamic environments, from global information to local information, and from a single robot to multiple robots chapter by chapter.

Chapters 1–3 provide readers with the background of the navigation problems. Chapter 1, "Introduction," presents the challenges that are faced by robot navigation in dynamic uncertain environments and the advantages of using sliding-mode control methods in reactive planners. Chapter 2, "Fundamentals of Sliding Mode Control," reviews a few basic concepts and facts of classic sliding-mode control theory, which serve as the mathematical tools in analyzing the switching reactive control laws in the following chapters. Chapter 3, "Survey of Algorithms for Safe Navigation of Mobile Robots in Complex Environments," documents methods related to navigation of unmanned vehicles. The purpose of these chapters is to familiarize the readers with the problems and the research in this field.

Chapters 4–7 discuss navigation algorithms for a single robot in a static environment. Chapter 4, "Shortest Path Algorithm for Navigation of Wheeled Mobile Robots Among Steady Obstacles," considers the problem of global shortest-path planning in a known environment. The problem is solved using a tangent graph, which shows that such an optimal path is composed of straight lines in the free space and boundary curves for the obstacles. This naturally divides the navigation into two kinds of motions, straight movement in the free space and motion for boundary following. Based on this observation, the authors propose a reactive randomized algorithm for robot navigation in an unknown environment, which switches between the two kinds of motions. Chapter 5, "Reactive Navigation of Wheeled Robots for Border Patrolling," presents the method for boundary following with limited sensing abilities. Boundary following can be used for collision avoidance during target reaching. Meanwhile, boundary following is important by itself because it is the main task in border patrolling. Reactive sliding-mode control laws are proposed to drive the robot to a prespecified distance from the boundary and maintain the distance. Mathematically rigorous analysis of the proposed control laws is performed in the framework of the sliding-mode control theory. Chapters 6 and 7, "Safe Navigation to a Target in Unknown Cluttered Static Environments Based on Border Patrolling Algorithms" and "Algorithm for Reactive Navigation of Nonholonomic Robots in Maze-Like Environments," respectively, present the reactive control strategies for target reaching under different static environments. Cluttered environments are considered in Chapter 6 while maze-like environments are considered in Chapter 7. The proposed navigation strategies combine the target-reaching mode (motions straight to the target) and the collision-avoidance mode (bypassing obstacles at close range with the aid of border-patrolling algorithms). A set of rules regulating switches between these two modes is presented. The authors then discuss the requirements on the obstacle geometries for the proposed strategies to deliver theoretical guarantees on collision avoidance and global convergence.

Chapters 8–11 discuss navigation algorithms for a single robot in a dynamic environment. Chapter 8, "Biologically Inspired Algorithm for Safe Navigation of a Wheeled Robot Among Moving Obstacles," presents a simple biologically inspired strategy for safe navigation of a Dubins-car-like robot in a dynamic environment where the obstacles have translational movements. Chapter 9, "Reactive Navigation Among Moving and Deforming Obstacles: Problems of Border Patrolling and Avoiding Collisions," presents a sliding-mode-based strategy for navigation and guidance of a unicycle-like robot. It is then applied to the problems of patrolling the border of a moving and deforming domain and reaching a target through a dynamic environment cluttered with moving and deforming obstacles. Chapter 10, "Seeking a Path Through the Crowd: Robot Navigation Among Unknowingly Moving Obstacles Based on an Integrated Representation of the Environment," presents a reactive algorithm for the collision-free navigation of a nonholonomic robot in unknown complex dynamic environments with moving obstacles. Under the proposed navigation algorithm, the robot is able to seek a short path through a crowd of moving or steady obstacles, instead of avoiding the crowd as a whole, like some other navigation algorithms do. Chapter 11, "A Globally Converging Reactive Algorithm for Robot Navigation in Scenes Densely Cluttered with Moving and Deforming Obstacles," introduces and examines a purely reactive algorithm to navigate a planar mobile robot in densely cluttered environments with unpredictably moving and deforming obstacles.

Chapter 12, "Safe Cooperative Navigation of Multiple Wheeled Robots in Unknown Steady Environments with Obstacles," discusses navigation algorithms for multiple robots in a static environment. It presents a decentralized, cooperative, reactive, and model predictive control-based collision-avoidance scheme that plans short-term paths in the part of the environment that is currently sensed. Simulations and real-world testing in various scenarios are employed to validate the algorithms.

The objective of this book is to present recent advancements in the area of robot navigation in dynamic uncertain environments, and it focuses on local planners, especially reactive controllers using switching control laws. The authors provide a rigorous mathematical analysis of the collision-avoidance behavior and global convergence behavior of the proposed control laws, which are sometimes missing in other books. The book can be a reference for experienced researchers in both academia and industry. The materials in the presentation are self-contained, and the only prerequisite is undergraduate-level mathematics. Some basic experience in programming and robotics is enough for interested readers to implement the proposed algorithms directly from the text. The readers can also refer to some easily accessible references to further pursue the relevant topics of interest. The proposed methods have their own limitations, such as requirements on high sampling frequency and restrictions on the obstacle geometry, but these do not limit the entire book's value and significance.

REVIEWER INFORMATION

Changliu Liu (changliuliu@berkeley.edu) received a B.S. degree in mechanical engineering and a B.S. degree in economics from Tsinghua University, Beijing, China, in 2012 and an M.S. degree in mechanical engineering and an M.A. degree in mathematics from University of California at Berkeley, in 2014 and 2016, respectively. She is currently working toward her Ph.D. degree in the Department of Mechanical Engineering, University of California at Berkeley. Her research interests include optimal control and optimization, multiagent system and game theory, machine learning and artificial intelligence, and control and decision theories for human-machine systems. She was the recipient of the Chinese National Scholarship in 2010, the Berkeley fellowship in 2012, and the finalist of the Best Student Paper from the ASME DSC Division in 2014.

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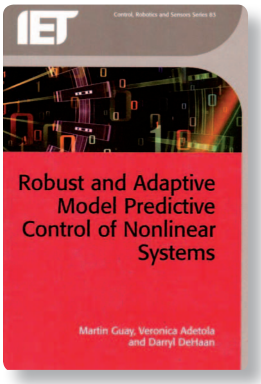

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Robust and Adaptive Model Predictive Control of Nonlinear Systems

by MARTIN GUAY, VERONICA ADELTOLA, and DARRYL DEHAAN

Reviewed by Baocang Ding

Robust and Adaptive Model Predictive Control of Nonlinear Systems is not about fundamental knowledge of model predictive control (MPC) but a deep study of nonlinear adaptive robust MPC. Traditionally, when MPC is used in complex industrial processes (such as a refinery or chemical plant), it is in a hierarchical structure [1]. Real-time optimization (RTO) is used to give ideal/desired steady-state values of a part of the manipulated variables (MVs; in this book, u) and controlled variables (CVs; in this book, x). These values are provided to the MPC, which typically has two layers, steady-state target (setpoint) calculation and target tracking (tracking control). An adaptive mechanism is reflected in this hierarchical structure by the integration of a disturbance model (see [2]). In this case, the disturbance is artificial, being used as a real-time estimate of the prediction error caused by the model-plant mismatch. The mismatch considered in this book includes model parametric uncertainties and unmodeled disturbances.

It is intrinsically difficult to analyze the closed-loop stability of this hierarchical MPC since it is a complex, multiperiod, multiobjective system with a multilayered model and multilayered optimization. Table 1 lists the complexities inherent in studying the closed-loop stability of hierarchical MPC. In academic studies of MPC, systematic closed-loop stability results are achieved only for the cases with single-objective, single-layered models and single-layered optimization (see, for example, [3] and [4])—points 1, 2, and 3 in Table 1 are rarely achieved with guaranteed stability. Furthermore, in the literature, only limited results exist with guaranteed stability for adaptive MPC; this fact is also revealed in this book. Due to the state of art on points 1–3, using an adaptive mechanism with disturbance models

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