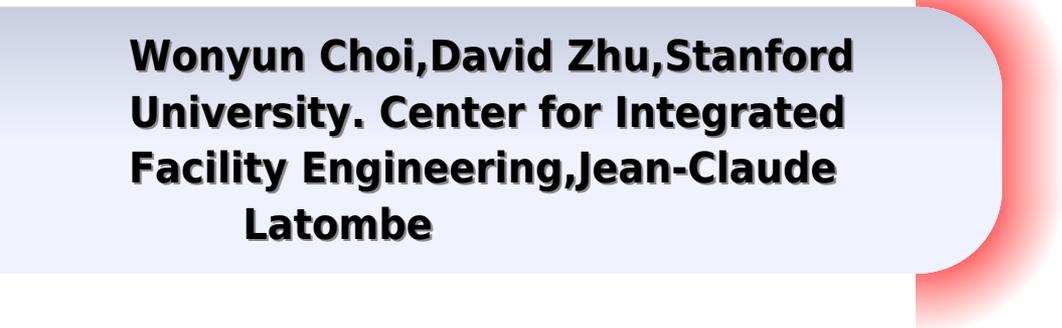


# Complexity Of Robot Motion Planning

**Wonyun Choi, David Zhu, Stanford University. Center for Integrated Facility Engineering, Jean-Claude Latombe**



## Complexity Of Robot Motion Planning:

**The Complexity of Robot Motion Planning** John Canny, 1988 The Complexity of Robot Motion Planning makes original contributions both to robotics and to the analysis of algorithms. In this groundbreaking monograph John Canny resolves long standing problems concerning the complexity of motion planning and for the central problem of finding a collision free path for a jointed robot in the presence of obstacles obtains exponential speedups over existing algorithms by applying high powered new mathematical techniques. Canny's new algorithm for this generalized movers problem, the most studied and basic robot motion planning problem, has a single exponential running time and is polynomial for any given robot. The algorithm has an optimal running time exponent and is based on the notion of roadmaps, one dimensional subsets of the robot's configuration space. In deriving the single exponential bound Canny introduces and reveals the power of two tools that have not been previously used in geometrical algorithms: the generalized multivariable resultant for a system of polynomials and Whitney's notion of stratified sets. He has also developed a novel representation of object orientation based on unnormalized quaternions which reduces the complexity of the algorithms and enhances their practical applicability. After dealing with the movers problem, the book next attacks and derives several lower bounds on extensions of the problem: finding the shortest path among polyhedral obstacles, planning with velocity limits, and compliant motion planning with uncertainty. It introduces a clever technique, path encoding, that allows a proof of NP hardness for the first two problems and then shows that the general form of compliant motion planning, a problem that is the focus of a great deal of recent work in robotics, is non-deterministic exponential time hard. Canny proves this result using a highly original construction. John Canny received his doctorate from MIT and is an assistant professor in the Computer Science Division at the University of California Berkeley. The Complexity of Robot Motion Planning is the winner of the 1987 ACM Doctoral Dissertation Award.

**PLANNING GEOMETRY, AND COMPLEXITY OF ROBOT MOTION (cancelled Out of Print 02/01).** JACOB. SCHWARTZ, 1987 *Planning, Geometry, and Complexity of Robot Motion* Jacob T. Schwartz, Micha Sharir, John E. Hopcroft, 1987 Robotics has come to attract the attention of mathematicians and theoretical computer scientists to a rapidly increasing degree. Initial investigations have shown that robotics is a rich source of deep theoretical problems which range over computational geometry, control theory, and many aspects of physics and whose solutions draw upon methods developed in subjects as diverse as automata theory, algebraic topology, and Fourier analysis.

Robot Motion Planning Jean-Claude Latombe, 2012-12-06 One of the ultimate goals in Robotics is to create autonomous robots. Such robots will accept high level descriptions of tasks and will execute them without further human intervention. The input descriptions will specify what the user wants done rather than how to do it. The robots will be any kind of versatile mechanical device equipped with actuators and sensors under the control of a computing system. Making progress toward autonomous robots is of major practical interest in a wide variety of application domains including manufacturing, construction, waste management, space exploration, undersea work, assistance for the

disabled and medical surgery It is also of great technical interest especially for Computer Science because it raises challenging and rich computational issues from which new concepts of broad usefulness are likely to emerge Developing the technologies necessary for autonomous robots is a formidable undertaking with deep interweaved ramifications in automated reasoning perception and control It raises many important problems One of them motion planning is the central theme of this book It can be loosely stated as follows How can a robot decide what motions to perform in order to achieve goal arrangements of physical objects This capability is eminently necessary since by definition a robot accomplishes tasks by moving in the real world The minimum one would expect from an autonomous robot is the ability to plan its own motions

*Practical Motion Planning in Robotics* Kamal Gupta, Angel P. del Pobil, 1998-10-15 Practical Motion Planning in Robotics Current Approaches and Future Directions Edited by Kamal Gupta Simon Fraser University Burnaby Canada Angel P del Pobil Jaume I University Castellon Spain Designed to bridge the gap between research and industry Practical Motion Planning in Robotics brings theoretical advances to bear on real world applications Capitalizing on recent progress this comprehensive study emphasizes the practical aspects of techniques for collision detection obstacle avoidance path planning and manipulation planning The broad approach spans both model and sensor based motion planning collision detection and geometric complexity and future directions Features include Review of state of the art techniques and coverage of the main issues to be considered in the development of motion planners for use in real applications Focus on gross motion planning for articulated arms enabling robots to perform non contact tasks with relatively high tolerances plus brief consideration of mobile robots The use of efficient algorithms to tackle incremental changes in the environment Illustration of robot motion planning applications in virtual prototyping and the shipbuilding industry Demonstration of efficient path planners combining both local and global planning approaches in conjunction with efficient techniques for collision detection and distance computations International contributions from academia and industry Combining theory and practice this timely book will appeal to academic researchers and practising engineers in the fields of robotic systems mechatronics and computer science

**Reliable Robot Motion Planning** Gregory Paul Heinzinger, 1990 [Algorithms and Data Structures](#) Frank Dehne, 1997-07-23 The book is an introduction to the theory of cubic metaplectic forms on the 3 dimensional hyperbolic space and the author's research on cubic metaplectic forms on special linear and symplectic groups of rank 2 The topics include Kubota and Bass Milnor Serre homomorphisms cubic metaplectic Eisenstein series cubic theta functions Whittaker functions A special method is developed and applied to find Fourier coefficients of the Eisenstein series and cubic theta functions The book is intended for readers with beginning graduate level background interested in further research in the theory of metaplectic forms and in possible applications

**Contingency-tolerant Robot Motion Planning and Control** Wonyun Choi, David Zhu, Stanford University. Center for Integrated Facility Engineering, Jean-Claude Latombe, 1989 **Principles of Robot Motion** Howie Choset, Kevin M. Lynch, Seth Hutchinson, George A. Kantor, Wolfram Burgard, 2005-05-20 A text that

makes the mathematical underpinnings of robot motion accessible and relates low level details of implementation to high level algorithmic concepts Robot motion planning has become a major focus of robotics Research findings can be applied not only to robotics but to planning routes on circuit boards directing digital actors in computer graphics robot assisted surgery and medicine and in novel areas such as drug design and protein folding This text reflects the great advances that have taken place in the last ten years including sensor based planning probabilistic planning localization and mapping and motion planning for dynamic and nonholonomic systems Its presentation makes the mathematical underpinnings of robot motion accessible to students of computer science and engineering relating low level implementation details to high level algorithmic concepts

Proceedings of the 1991 American Control Conference, 1991      **Optimal Motion Planning for Multiple Point Robots in the Plane** Erik Lanny Wynters, 1991      **Robot Motion Planning and Control** Jean-Paul Laumond, 1998 Content Description Includes bibliographical references      **Robotic Control and Nonholonomic Motion Planning** Richard M. Murray, 1990      **Multi-robot Optimal Motion Planning** Guoxiang Zhao, 2022

The recent rapid development of computing communication and sensing technologies triggers the prevalence of multi robot systems Compared to single robot systems multi robot systems are advantageous in three aspects 1 they can accomplish tasks which are beyond the capabilities of single robots 2 they are cheaper and more flexible for certain tasks 3 control scheme of multi robot systems may reveal insights into key issues in social and life sciences Multi robot systems have numerous applications in various areas such as traffic coordination and precision agriculture Robotic motion planning is a fundamental problem where a sequence of controls are identified to steer robots to goal regions subject to geometric and dynamic constraints However the problem is computationally hard even for a single robot The generalized mover s problem is shown to be PSPACE hard in degrees of freedom The optimal motion planning where the aggregate cost along the returned trajectory is minimized is more computationally challenging It is shown that computing the shortest path in  $R^3$  populated with obstacles is NP hard in the number of obstacles Multi robot motion planning is even harder than its single robot counterpart and its worst case computational complexity grows exponentially in the number of robots In this dissertation we aim to study multi robot optimal motion planning and design a set of planners towards scalability and optimality Our research is three fold We first investigate the scenario where a team of robots desire to arrive at their own goal regions as soon as possible The robots are governed by complex dynamics and need to maintain safe distance from static obstacles and other robots The optimality of the solution is characterized by Pareto optimality where the reduction of one robot s travelling time must cause the rise of others A novel numerical algorithm is proposed to identify the Pareto optimal solutions where no robot can unilaterally reduce its traveling time without extending others The consistent approximation of the algorithm in the epigraphical profile sense is guaranteed using set valued numerical analysis Experiments on an indoor multi robot platform and computer simulations show the anytime property of the proposed algorithm i e it is able to quickly return a feasible control policy that

safely steers the robots to their goal regions and it keeps improving policy optimality if more time is given. Then we propose a distributed algorithm to achieve much better scalability. Specifically, the algorithm integrates decoupled optimal feedback planning and distributed conflict resolution to coordinate a fleet of unicycle robots. Each robot independently generates its optimal motions offline and avoids collisions with other objects in online execution. The computational complexity is independent of the robot number. Moreover, each robot's individual planner is optimal and its motion is rarely interfered in exercise, so the algorithm is near optimal. Collision avoidance and finite time arrival at the goal regions are formally guaranteed. A set of simulations are conducted to verify the scalability and near optimality of the proposed algorithm. Lastly, we propose a distributed optimal motion planning algorithm for heterogeneous multi-robot systems and strongly coupled missions to balance scalability and optimality where multiple robots of different dynamics desire to safely reach their respective goal regions with minimal cost. Each robot shares its policy with others in parallel and takes best response with respect to others' policies in a sequential fashion. The proposed algorithm is shown to converge to the optimal value function and the computational complexity is linear with respect to robot number but is much smaller than benchmark. A set of simulations are conducted to verify the scalability and near optimality of the proposed algorithm. *Proceedings of the ... Annual ACM-SIAM Symposium on Discrete Algorithms*, 1996. **Sensing, Intelligence, Motion** Vladimir J.

Lumelsky, 2005-11-28. A leap forward in the field of robotics. Until now, most of the advances in robotics have taken place in structured environments. Scientists and engineers have designed highly sophisticated robots, but most are still only able to cooperate and move in predetermined, planned environments designed specifically for the robots and typically at very high cost. This new book takes robotics to the next level by setting forth the theory and techniques needed to achieve robotic motion in unstructured environments. The ability to move and operate in an arbitrary, unplanned environment will lead to automating a wide range of new robotic tasks, such as patient care, toxic site cleanup, and planetary exploration. The approach that opens the door for robots to handle unstructured tasks is known as Sensing Intelligence Motion (SIM), which draws from research in topology, computational complexity, control theory, and sensing hardware. Using SIM as an underlying foundation, the author's carefully structured presentation is designed to formulate the challenges of sensor-based motion planning and then build a theoretical foundation for sensor-based motion planning strategies. Investigate promising algorithmic strategies for mobile robots and robot arm manipulators in both cases, addressing motion planning for the whole robot body. Compare robot performance to human performance in sensor-based motion planning to gain better insight into the challenges of SIM and help build synergistic human-robot teams for teleoperation tasks. It is both exciting and encouraging to discover that robot performance decisively exceeds human performance in certain tasks requiring spatial reasoning, even when compared to trained operators. Review sensing hardware that is necessary to realize the SIM paradigm. Some 200 illustrations, graphic sketches, and photos are included to clarify key issues, develop and validate motion planning approaches, and demonstrate full

systems in operation As the first book fully devoted to robot motion planning in unstructured environments Sensing Intelligence Motion is a must read for engineers scientists and researchers involved in robotics It will help them migrate robots from highly specialized applications in factories to widespread use in society where autonomous robot motion is needed

Generation of Sensory-based Motion Strategies in the Presence of Uncertainty Jean-Claude Latombe, Stanford University. Center for Integrated Facility Engineering, 1989      **Randomized Single-query Motion Planning in Expansive Spaces** David Hsu, 2000      1989 Symposium Proceedings, Final Edition Stanford University. Center for Integrated Facility Engineering, 1989      AAAI-92, 1992 AAI proceedings describe innovative concepts techniques perspectives and observations that present promising research directions in artificial intelligence The focus of the AAI 92 conference is on the re integration of AI as a diverse but coherent whole Accordingly the traditional list of community based content areas has been replaced by a more neutral set of taxonomies that span the field For example a paper proposing a new epistemology for representing the physical world based on an analysis of human brain structure would be described as representation physical world biological The papers collected here represent significant research contributions to such areas as the principles underlying cognition perception and action in man and machine the design application and evaluation of AI algorithms and systems and the analysis of domains in which AI systems perform

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## **Table of Contents Complexity Of Robot Motion Planning**

1. Understanding the eBook Complexity Of Robot Motion Planning
  - The Rise of Digital Reading Complexity Of Robot Motion Planning
  - Advantages of eBooks Over Traditional Books
2. Identifying Complexity Of Robot Motion Planning
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Complexity Of Robot Motion Planning
  - User-Friendly Interface
4. Exploring eBook Recommendations from Complexity Of Robot Motion Planning
  - Personalized Recommendations
  - Complexity Of Robot Motion Planning User Reviews and Ratings
  - Complexity Of Robot Motion Planning and Bestseller Lists
5. Accessing Complexity Of Robot Motion Planning Free and Paid eBooks
  - Complexity Of Robot Motion Planning Public Domain eBooks
  - Complexity Of Robot Motion Planning eBook Subscription Services

- Complexity Of Robot Motion Planning Budget-Friendly Options
- 6. Navigating Complexity Of Robot Motion Planning eBook Formats
  - ePub, PDF, MOBI, and More
  - Complexity Of Robot Motion Planning Compatibility with Devices
  - Complexity Of Robot Motion Planning Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Complexity Of Robot Motion Planning
  - Highlighting and Note-Taking Complexity Of Robot Motion Planning
  - Interactive Elements Complexity Of Robot Motion Planning
- 8. Staying Engaged with Complexity Of Robot Motion Planning
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Complexity Of Robot Motion Planning
- 9. Balancing eBooks and Physical Books Complexity Of Robot Motion Planning
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Complexity Of Robot Motion Planning
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Complexity Of Robot Motion Planning
  - Setting Reading Goals Complexity Of Robot Motion Planning
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Complexity Of Robot Motion Planning
  - Fact-Checking eBook Content of Complexity Of Robot Motion Planning
  - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
- 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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