Planning Algorithms Motion Planning

Motion planning is defined as the problem of finding a valid path taking a robot (or any movable object) from a given start configuration to a goal configuration in an environment. While motion planning has its roots in robotics, it now finds application in many other areas of scientific computing such as protein folding, drug design, virtual prototyping, computer-aided design (CAD), and computer animation. These new areas test the limits of the best sequential planners available, motivating the need for methods that can exploit parallel processing. This dissertation focuses on the design and implementation of a generic and scalable framework for parallelizing motion planning algorithms. In particular, we focus on sampling-based motion planning algorithms which are considered to be the state-of-the-art. Our work covers the two broad classes of sampling-based motion planning algorithms--the graph-based and the tree-based methods. Central to our approach is the subdivision of the planning space into regions. These regions represent sub- problems that can be processed in parallel. Solutions to the sub-problems are later combined to form a solution to the entire problem. By subdividing the planning space and restricting the locality of connection attempts to adjacent regions, we reduce the work and inter-processor communication associated with nearest neighbor calculation, a critical bottleneck for scalability in existing parallel motion planning methods. We also describe how load balancing strategies can be applied in complex environments. We present experimental results that scale to thousands of processors on different massively parallel machines for a range of motion planning problems. The electronic version of this dissertation is accessible from http://hdl.handle.net/1969.1/152806

This chapter introduces two kinds of motion path planning algorithms for mobile robots or unmanned ground vehicles (UGV). First, we present an approach of trajectory planning for UGV or mobile robot under the existence of moving obstacles by using improved artificial potential field method. Then, we propose an I-RRT* algorithm for motion planning, which combines the environment with obstacle constraints, vehicle constraints, and kinematic constraints. All the simulation results and the experiments show that two kinds of algorithm are effective for practical use.

Robotic motion planning, which concerns the computation of paths and controls that drive an autonomous agent from one configuration to another, is quickly becoming a vitally important field of research as its applications diversify and become increasingly public. Many algorithms have been proposed to deal with this central problem; sampling-based approaches like the Rapidly-exploring Random Tree (RRT) and Probabilistic Roadmap Method (PRM) planners are among the most successful. Still, these algorithms are not fully understood and suffer from pathologically poorly-performing instances resulting from the contributions of random sampling and qualitative obstacle features like narrow passages. The large means and variances that result from these issues continue to motivate the development of new algorithms and adaptations to increase consistency and to allow more difficult problems to be solved. This research examines these performance issues with a focus on the Rapidly-exploring Random Tree (RRT) planner. Fundamental analysis establishes that the interaction of its Voronoi bias with particular obstacle features can compromise its efficacy and illustrates the types of distributions on its performance that result. It further provides guidance on the types of problems amenable to solutions by the algorithm and on the use of its alternative EXTEND and CONNECT heuristics and step size parameter. Observations from this analysis prompt an investigation of the use of restart strategies to manage issues of both scaling in computation and exploratory missteps. In turn, their impact provides a foundation for the introduction of a novel algorithm, the Path-length Annexed Random Tree (PART) planner, that directs its exploration on a local basis. This algorithm and its environment-adaptive successor, the Adaptive PART (APART) planner, demonstrate competitive performance on instructive examples and dramatic improvements on difficult benchmarks, while also supplementing their utility with the output of a connected roadmap.

This thesis addresses the development and implementation of algorithms for unmanned air vehicles (UAVs). With advances in technology, it is relatively easy to manufacture and operate UAVs that are particularly useful for dull, dirty and dangerous operations. The success of such autonomous missions depends heavily on the planning algorithms used. A key consideration in the thesis is the path planning problem for single and multiple UAV systems in obstacle rich environments in the presence of uncertainty. Recently, rapidly-exploring random trees (RRTs) have been applied to find feasible trajectories quickly in complex motion planning problems. We use RRTs to construct trees of kinematically feasible trajectories made of waypaths, and feasibility is evaluated by checking for collisions with the predicted trajectories. When there are uncertainties acting on the system, we can identify probabilistic feasible paths by growing trees of state distributions and ensuring that the probability of constraint violation is below a pre-defined value. In addition to this, a guidance law is designed combining a pursuit law with a line-of-sight law, to track the path generated by the path planner with minimum deviation. In the penultimate chapter, an application is presented where a multi-UAV system captures a more capable target by forming a target centred formation around it. The approach combines a consensus algorithm with a controller to develop a robust distributed control law for formation control. Under certain conditions, it is shown that a set of UAVs can form a target centred formation even when target information is not known. The effectiveness of this algorithm is demonstrated using numerical results. In the appendix, a decentralised scheme is described for target tracking using consensus theory in conjunction with a data fusion algorithm which guarantees perfect fault detection and isolation. This scheme was developed by the Leicester team. As part of this thesis the theoretical algorithm was tested experimentally on a set of real robots.

During the last decades, improved sensor and hardware technologies as well as new methods and algorithms have made self-driving vehicles a realistic possibility in the near future. At the same time, there has been a growing demand within the transportation sector to increase efficiency and to reduce the environmental impact related to transportation of people and goods. Therefore, many leading automotive and technology companies have turned their attention towards developing advanced driver assistance systems and self-driving vehicles. Autonomous vehicles are expected to have their first big impact in closed environments, such as mines, harbors, loading and offloading sites. In such areas, the legal requirements are less restrictive and the surrounding environment is more controlled and predictable compared to urban areas. Expected positive outcomes include increased productivity and safety, reduced emissions and the possibility to relieve the human from performing complex or dangerous tasks. Within these sites, tractor-trailer vehicles are frequently used for transportation. These vehicles are composed of several interconnected vehicle segments, and are therefore large, complex and unstable while reversing. This thesis addresses the problem of designing efficient motion planning and feedback control techniques for such systems. The contributions of this thesis are within the area of motion planning and feedback control for long tractor-trailer combinations operating at low-speeds in closed and unstructured environments. It includes development of motion planning and feedback control frameworks, structured design tools for guaranteeing closed-loop stability and experimental validation of the proposed solutions through simulations, lab and field experiments. Even though the primary application in this work is tractor-trailer vehicles, many of the proposed approaches can with some adjustments also be used for other systems, such as drones and ships. The developed sampling-based motion planning algorithms are based upon the probabilistic closed-loop rapidly exploring random tree (CL-RRT) algorithm and the deterministic lattice-based motion planning algorithm. It is also proposed to use numerical optimal control offline for precomputing libraries of optimized maneuvers as well as during online planning in the form of a warm-started optimization step. To follow the motion plan, several predictive path-following control approaches are proposed with different computational complexity and performance. Common for these approaches are that they use a path-following error model of the vehicle for future predictions and are tailored to operate in series with a motion planner that computes feasible paths. The design strategies for the path-following approaches include linear quadratic (LQ) control and several advanced model predictive control (MPC) techniques to account for physical and sensing limitations. To strengthen the practical value of the developed techniques, several of the proposed approaches have been implemented and successfully demonstrated in field experiments on a full-scale test platform. To estimate the vehicle states needed for control, a novel nonlinear observer is evaluated on the full-scale test vehicle. It is designed to only utilize information from sensors that are mounted on the tractor, making the system independent of any sensor mounted on the trailer. Under de senaste årtiondena har utvecklingen av sensor- och hårdvaruteknik gått i en snabb takt, samtidigt som nya metoder och algoritmer har introducerats. Samtidigt ställs det stora krav på transportsektorn att öka effektiviteten och minska miljöpåverkan vid transporter av både människor och varor. Som en följd av detta har många ledande fordonstillverkare och teknikföretag börjat satsat på att utveckla avancerade förarstödsystem och självkörande fordon. Även forskningen inom autonoma fordon har under de senaste årtiondena kraftig ökat då en rad tekniska problem återstår att lösas. Förarlösa fordon förväntas få sitt första stora genombrott i slutna miljöer, såsom gruvor, hamnar, lastnings- och lossningsplatser. I sådana områden är lagstiftningen mindre hård jämfört med stadsområden och omgivningen är mer kontrollerad och förutsägbar. Några av de förväntade positiva effekterna är ökad produktivitet och säkerhet, minskade utsläpp och möjligheten att avlasta människor från att utföra svåra eller farliga uppgifter. Inom dessa platser används ofta lastbilar med olika släpvagnskombinationer för att transportera material. En sådan fordonskombination är uppbyggd av flera ihopkopplade moduler och är således utmanande att backa då systemet är instabilt. Detta gör det svårt att utforma ramverk för att styra sådana

system vid exempelvis autonom backning. Självkörande fordon är mycket komplexa system som består av en rad olika komponenter vilka är designade för att lösa separata delproblem. Två viktiga komponenter i ett självkörande fordon är dels rörelseplaneraren som har i uppgift att planera hur fordonet ska röra sig för att på ett säkert sätt nå ett överordnat mål, och dels den banföljande regulatorn vars uppgift är att se till att den planerade manövern faktiskt utförs i praktiken trots störningar och modellfel. I denna avhandling presenteras flera olika algoritmer för att planera och utföra komplexa manövrar för lastbilar med olika typer av släpvagnskombinationer. De presenterade algoritmerna är avsedda att användas som avancerade förarstödsystem eller som komponenter i ett helt autonomt system. Även om den primära applikationen i denna avhandling är lastbilar med släp, kan många av de förslagna algoritmerna även användas för en rad andra system, så som drönare och båtar. Experimentell validering är viktigt för att motivera att en föreslagen algoritm är användbar i praktiken. I denna avhandling har flera av de föreslagna planerings- och reglerstrategierna implementerats på en småskalig testplattform och utvärderats i en kontrollerad labbmiljö. Utöver detta har även flera av de föreslagna ramverken implementerats och utvärderats i fältexperiment på en fullskalig test-plattform som har utvecklats i samarbete med Scania CV. Här utvärderas även en ny metod för att skatta släpvagnens beteende genom att endast utnyttja information från sensorer monterade på lastbilen, vilket gör det föreslagna ramverket oberoende av sensorer monterade på släpvagnen.
In this chapter, we present one of the most crucial branches in motion planning: search-based planning and replanning algorithms. This research branch involves two key points: first, representing traverse environment information as discrete graph form, in particular, occupancy grid cost map at arbitrary resolution, and, second, path planning algorithms calculate paths on these graphs from start to goal by propagating cost associated with each vertex in graph. The chapter will guide researcher through the foundation of motion planning concept, the history of search-based path planning and then focus on the evolution of state-of-the-art incremental, heuristic, anytime algorithm families that are currently applied on practical robot rover. The comparison experiment between algorithm families is demonstrated in terms of performance and optimality. The future of search-based path planning and motion planning in general is also discussed.
The main charter of this contract is the implementation and experimentation with motion planning algorithms that emphasize the exact combinatorial and purely geometric approach. Motion planning is considered to be one of the major research areas in robotics, and is one of the main stages in the design and implementation of autonomous intelligent systems, which is an important long-range goal in robotics research. Motion planning is one of the basic capabilities that such a system must possess. In purely geometric terms, the simplest version of the problem can be stated as follows. The system is given complete information about the geometry of the environment in which it is to operate (and of its own structure), and has to process it so that, when commanded to move from its current position to some target position, it can determine whether it can do so without colliding with any of the obstacles around it, and if so plan (and execute) such a motion. These are many variants of the problem. A few of those are: motion planning in environments that are only partially known to the system, compliant motion planning that allows contact with obstacles, which might be unavoidable due to measurement errors, optimal motion planning, motion planning with

kino-dynamic constraints, and motion planning amidst moving obstacles. Still, even the simplest, static, and purely geometric version stated above is far from being simple, and poses serious challenges in the design of efficient and robust algorithms.
This monograph discusses issues related to estimation, control, and motion planning for mobile robots operating in rough terrain, with particular attention to planetary exploration rovers. Rough terrain robotics is becoming increasingly important in space exploration, and industrial applications. However, most current motion planning and control algorithms are not well suited to rough terrain mobility, since they do not consider the physical characteristics of the rover and its environment. Specific addressed topics are: wheel terrain interaction modeling, including terrain parameter estimation and wheel terrain contact angle estimation; rough terrain motion planning; articulated suspension control; and traction control. Simulation and experimental results are presented that show that the desribed algorithms lead to improved mobility for robotic systems in rough terrain.
Autonomous robots will soon play a significant role in various domains, such as search-and-rescue, agriculture farms, homes, offices, transportation, and medical surgery, where fast, safe, and optimal response to different situations will be critical. However, to do so, these robots need fast algorithms to plan their motion sequences in real-time with limited perception and battery life. The field of motion planning and control addresses this challenge of coordinating robot motions and enabling them to interact with their environments for performing various challenging tasks under constraints. Planning algorithms for robot control have a long history ranging from methods with complete to probabilistically complete worst-case theoretical guarantees. However, despite having deep roots in artificial intelligence and robotics, these methods tend to be computationally inefficient in high-dimensional problems. On the other hand, machine learning advancements have led toward systems that can directly perform complex decision-making from raw sensory information. This thesis introduces a new class of planning methods called Neural Motion Planners that emerged from the cross-fertilization of classical motion planning and machine learning techniques. These methods can achieve unprecedented speed and robustness in planning robot motion sequences in complex, cluttered, and partially observable environments. They exhibit worst-case theoretical guarantees and solve a broad range of motion planning problems under geometric collision-avoidance, kinodynamic, non-holonomic, and hard kinematic manifold constraints. Another challenge towards deploying robots into our natural world is the tedious process of defining objective functions for underlying motion planners and transferring and composing their motion skills into new skills for a combinatorial outburst in robot's skillset for solving unseen practical problems. To address these challenges, this thesis introduces novel methods, i.e., variational inverse reinforcement learning and compositional reinforcement learning approaches. These methods learn unknown constraint functions and their motion skills directly from expert demonstrations for NMPs and compose them into new complex skills for solving more complicated problems across different domains. Finally, this thesis also presents a model-free neural task planning algorithm that works with never-before-seen objects and generalizes to real world environments. It generates task plans for underlying motion planning and control approaches and solves challenging rearrangement tasks in unknown environments.
This report presents automatic motion planning algorithms for robotic manipulators performing a variety of tasks. Given a task and a robot manipulator equipped with a tool in its hand, the motion planners compute robot motions to complete the task while respecting manipulator kinematic constraints and avoiding collisions with objects in the robot's work space. To handle the high complexity of the motion planning problem, a sophisticated search strategy called SANDROS is developed and used to solve many variations of the motion planning problem. To facilitate systematic development of motion planning algorithms, robotic tasks are classified into three categories according to the dimension of the manifold the robot tool has to travel:

visit-point (0 dimensional), trace-curve (1 dimensional) and cover-surface (2 dimensional) tasks. The motion planner for a particular dimension is used as a sub-module by the motion planner for the next-higher dimension. This hierarchy of motion planners has led to a set of compact and systematic algorithms that can plan robot motions for many types of robotic operations. In addition, an algorithm is developed that determines the optimal robot-base configuration for minimum cycle time. The SANDROS search paradigm is complete in that it finds a solution path if one exists, up to a user specified resolution. Although its worst-case time complexity is exponential in the degrees of freedom of the manipulator, its average performance is commensurate with the complexity of the solution path. Since solution paths for most of motion planning problems consist of a few monotone segments, the motion planners based on SANDROS search strategy show approximately two-orders of magnitude improvements over existing complete algorithms.

Computer Science Workbench is a monograph series which will provide you with an in-depth working knowledge of current developments in computer technology. Every volume in this series will deal with a topic of importance in computer science and elaborate on how you yourself can build systems related to the main theme. You will be able to develop a variety of systems, including computer software tools, computer graphics, computer animation, database management systems, and computer-aided design and manufacturing systems. Computer Science Workbench represents an important new contribution in the field of practical computer technology. TOSIYASU L. KUNII To my parents Kenjiro and Nori Fujimura Preface Motion planning is an area in robotics that has received much attention recently. Much of the past research focuses on static environments - various methods have been developed and their characteristics have been well investigated. Although it is essential for autonomous intelligent robots to be able to navigate within dynamic worlds, the problem of motion planning in dynamic domains is relatively little understood compared with static problems.

Excerpt from On-Line Motion Planning: Case of a Planar Rod Task planning algorithms and strategies make up an important area of robotics research. Of great importance is the area of robot motion planning, sometimes also known as trajectory planning or collision avoidance. Simply stated, the problem is to navigate a mobile robot or robot arm manipulator through an environment from some initial position to some target position. About the Publisher Forgotten Books publishes hundreds of thousands of rare and classic books. Find more at www.forgottenbooks.com This book is a reproduction of an important historical work. Forgotten Books uses state-of-the-art technology to digitally reconstruct the work, preserving the original format whilst repairing imperfections present in the aged copy. In rare cases, an imperfection in the original, such as a blemish or missing page, may be replicated in our edition. We do, however, repair the vast majority of imperfections successfully; any imperfections that remain are intentionally left to preserve the state of such historical works.

Robots that can actively change morphology offer many advantages over fixed shape, or monolithic, robots: flexibility, increased maneuverability and modularity. So called self-reconfiguring systems (SRS) are endowed with a shape changing ability enabled by an active connection mechanism. This mechanism allows a mechanical link to be engaged or disengaged between two neighboring robotic subunits. Through utilization of embedded joints to change the geometry plus the connection mechanism to change the topology of the kinematics, a collection of robotic subunits can drastically alter the overall kinematics. Thus, an SRS is a large robot comprised of many small cooperating robots that is able to change its morphology on demand. By design, such a system has many and variable degrees of freedom (DOF). To gain the benefits of self-reconfiguration, the process of morphological change needs to be controlled in response to the environment. This is a motion planning problem in a high dimensional configuration space. This problem is complex because each subunit only has a few internal DOFs, and each subunit's range of motion depends on the state of its connected

neighbors. Together with the high dimensionality, the problem may initially appear to be intractable, because as the number of subunits grow, the state space expands combinatorially. However, there is hope. If individual robotic subunits are identical, then there will exist some form of regularity in the resulting state space of the conglomerate. If this regularity can be exploited, then there may exist tractable motion planning algorithms for self-reconfiguring system. Existing approaches in the literature have been successful in developing algorithms for specific SRSs. However, it is not possible to transfer one motion planning algorithm onto another system. SRSs share a similar form of regularity, so one might hope that a tool from mathematical literature would identify the common properties that are exploitable for motion planning. So, while there exists a number of algorithms for certain subsets of possible SRS instantiations, there is no general motion planning methodology applicable to all SRSs. In this thesis, firstly, the best existing general motion planning techniques were evaluated to the SRS motion planning problem. Greedy search, simulated annealing, rapidly exploring random trees and probabilistic roadmap planning were found not to scale well, requiring exponential computation time, as the number of subunits in the SRS increased. The planners performance was limited by the availability of a good general purpose heuristic. There does not currently exist a heuristic which can accurately guide a path through the search space toward a far away goal configuration. Secondly, it is shown that a computationally efficient reconfiguration algorithms do exist by development of an efficient motion planning algorithm for an exemplary SRS, the Claytronics formulation of the Hexagonal Metamorphic Robot (HMR). The developed algorithm was able to solve a randomly generated shape-to-shape planning task for the SRS in near linear time as the number of units in the configuration grew. Configurations containing 20,000 units were solvable in under ten seconds on modest computational hardware. The key to the success of the approach was discovering a subspace of the motion planning space that corresponded with configurations with high mobility. Plans could be discovered in this sub-space much more readily because the risk of the search entering a blind alley was greatly reduced. Thirdly, in order to extract general conclusions, the efficient subspace, and other efficient subspaces utilized in other works, are analyzed using graph theoretic methods. The high mobility is observable as an increase in the state space's Cheeger constant, which can be estimated with a local sampling procedure. Furthermore, state spaces associated with an efficient motion planning algorithm are well ordered by the graph minor relation. These qualitative observations are discoverable by machine without human intervention, and could be useful components in development of a general purpose SRS motion planner compiler.
Offers a theoretical and practical guide to the communication and navigation of autonomous mobile robots and multi-robot systems This book covers the methods and algorithms for the navigation, motion planning, and control of mobile robots acting individually and in groups. It addresses methods of positioning in global and local coordinates systems, off-line and on-line path-planning, sensing and sensors fusion, algorithms of obstacle avoidance, swarming techniques and cooperative behavior. The book includes ready-to-use algorithms, numerical examples and simulations, which can be directly implemented in both simple and advanced mobile robots, and is accompanied by a website hosting codes, videos, and PowerPoint slides Autonomous Mobile Robots and Multi-Robot Systems: Motion-Planning, Communication and Swarming consists of four main parts. The first looks at the models and algorithms of navigation and motion planning in global coordinates systems with complete information about the robot’s location and velocity. The second part considers the motion of the robots in the potential field, which is defined by the environmental states of the robot's expectations and knowledge. The robot's motion in the unknown environments and the corresponding tasks of environment mapping using sensed information is covered in the third part. The fourth part deals with the multi-robot systems and swarm dynamics in two and three dimensions. Provides a self-contained, theoretical guide to understanding mobile robot control and navigation

Features implementable algorithms, numerical examples, and simulations Includes coverage of models of motion in global and local coordinates systems with and without direct communication between the robots Supplemented by a companion website offering codes, videos, and PowerPoint slides Autonomous Mobile Robots and Multi-Robot Systems: Motion-Planning, Communication and Swarming is an excellent tool for researchers, lecturers, senior undergraduate and graduate students, and engineers dealing with mobile robots and related issues.

Planning algorithms are impacting technical disciplines and industries around the world, including robotics, computer-aided design, manufacturing, computer graphics, aerospace applications, drug design, and protein folding. Written for computer scientists and engineers with interests in artificial intelligence, robotics, or control theory, this is the only book on this topic that tightly integrates a vast body of literature from several fields into a coherent source for teaching and reference in a wide variety of applications. Difficult mathematical material is explained through hundreds of examples and illustrations.

Planning algorithms are impacting technical disciplines and industries around the world, including robotics, computer-aided design, manufacturing, computer graphics, aerospace applications, drug design, and protein folding. This coherent and comprehensive book unifies material from several sources, including robotics, control theory, artificial intelligence, and algorithms. The treatment is centered on robot motion planning, but integrates material on planning in discrete spaces. A major part of the book is devoted to planning under uncertainty, including decision theory, Markov decision processes, and information spaces, which are the 'configuration spaces' of all sensor-based planning problems. The last part of the book delves into planning under differential constraints that arise when automating the motions of virtually any mechanical system. This text and reference is intended for students, engineers, and researchers in robotics, artificial intelligence, and control theory as well as computer graphics, algorithms, and computational biology.

The Complexity of Robot Motion Planning makes original contributions both to roboticsand to the analysis of algorithms. In this groundbreaking monograph John Canny resolveslong-standing problems concerning the complexity of motion planning and, for the central problem offinding a collision free path for a jointed robot in the presence of obstacles, obtains exponentialspeedups over existing algorithms by applying high-powered new mathematical techniques.Canny's newalgorithm for this "generalized movers' problem," the most-studied and basic robot motion planningproblem, has a single exponential running time, and is polynomial for any given robot. The algorithmhas an optimal running time exponent and is based on the notion of roadmaps - one-dimensionalsubsets of the robot's configuration space. In deriving the single exponential bound, Cannyintroduces and reveals the power of two tools that have not been previously used in geometricalgorithms: the generalized (multivariable) resultant for a system of polynomials and Whitney'snotion of stratified sets. He has also developed a novel representation of object orientation basedon unnormalized quaternions which reduces the complexity of the algorithms and enhances theirpractical applicability.After dealing with the movers' problem, the book next attacks and derivesseveral lower bounds on extensions of the problem: finding the shortest path among polyhedralobstacles, planning with velocity limits, and compliant motion planning with uncertainty. Itintroduces a clever technique, "path encoding," that allows a proof of NP-hardness for the first twoproblems and then shows that the general form of compliant motion planning, a problem that is thefocus of a great deal of recent work in robotics, is non-deterministic exponential time hard. Cannyproves this result using a highly original construction.John Canny received his doctorate from MITAnd 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 DoctoralDissertation Award.

Written by Ron Alterovitz and Ken Goldberg, this monograph combines ideas from robotics, physically-based modeling, and operations research to develop new motion planning and optimization algorithms for image-guided medical procedures.

Motion planning is one of the most critical tasks in robotics, as it is one of the few critical functions for robot autonomy. This component requires fast computations and generalization to different environments for problems such as collision avoidance. Deep learning, as a new fast-growing field, offers great advances in computational speed and generalization. It has shown success in computer vision and reinforcement learning, which is closely related to motion planning. In this thesis, we will investigate the combination of learning and motion planning methods. Specifically, we separately consider individual components of motion planning tasks. By combining the proposed learning-based methods for each component, we can obtain an integrated end-to-end learning-based motion planning algorithm. We show experimental results for each component. In general, our learning-based methods showed high computational speed with generalization in several motion planning tasks.

From ships and airplanes to robots and space vehicles…it's all here: how to design the safest and most efficient path trajectories possible. Optimized-Motion Planning is the first handbook to the practical specifics of motion planning that gives design engineers hands-on guidance for solving real motion planning problems in a 3-dimensional space. Complete with a disk of software programs, this unique guide allows users to design, test, and implement possible solutions, useful in a host of contexts, especially tool path planning. The nucleus of the book consists of several motion planning algorithms (with sample programs for the different algorithms on disk), which have been designed to: Provide optimized solutions for a wide range of problems, including motion planning for multibody systems in 3-dimensional space Automatically comply with given dynamic constraints Progress logically from a simple case of a point moving between polygons in 2-dimensional space to the more complex cases of nonpoint objects moving between 3-dimensional obstacles Optimized-Motion Planning is a practical, complete, and fascinating introduction to designing the safest trajectories for the vehicles that support our way of life as well as a guidebook to one of the new technological imperatives of the coming century.

The book includes topics, such as: path planning, avoiding obstacles, following the path, go-to-goal control, localization, and visual-based motion control. The theoretical concepts are illustrated with a developed control architecture with soft computing and artificial intelligence methods. The proposed vision-based motion control strategy involves three stages. The first stage consists of the overhead camera calibration and the configuration of the working environment. The second stage consists of a path planning strategy using several traditional path planning algorithms and proposed planning algorithm. The third stage consists of the path tracking process using previously developed Gauss and Decision Tree control approaches and the proposed Type-1 and Type-2 controllers. Two kinematic structures are utilized to acquire the input values of controllers. These are Triangle Shape-Based Controller Design, which was previously developed and Distance-Based Triangle Structure that is used for the first time in conducted experiments. Four different control algorithms, Type-1 fuzzy logic, Type-2 Fuzzy Logic, Decision Tree Control, and Gaussian Control have been used in overall system design. The developed system includes several modules that simplify characterizing the motion control of the robot and ensure that it maintains a safe distance without colliding with any obstacles on the way to the target. The topics of the book are extremely relevant in many areas of research, as well as in education in courses in computer science, electrical and mechanical engineering and in mathematics at the graduate and undergraduate levels.

The book Advanced Path Planning for Mobile Entities provides a platform for practicing researchers, academics, PhD students, and other scientists to design, analyze, evaluate, process, and implement diversiform issues of path planning, including algorithms for multipath and mobile planning and path planning for mobile robots. The nine chapters of the book demonstrate capabilities of advanced path planning for mobile entities to solve scientific and engineering problems with varied degree of complexity.

Optimized-Motion PlanningTheory and ImplementationWiley-Interscience

The dominant theme of this book is to introduce the different path planning methods and present some of the most appropriate ones for robotic routing; methods that are capable of running on a variety of robots and are resistant to disturbances; being real-time, being autonomous, and the ability to identify high risk areas and risk management are the other features that will be mentioned in the introduction of the methods. The introduction of the profound significance of the robots and delineation of the navigation and routing theme is provided in the first chapter of the book. The second chapter is concerned with the subject of routing in unknown environments. In the first part of this chapter, the family of bug algorithms including are described. In the following, several conventional methods are submitted. The last part of this chapter is dedicated to the introduction of two recently developed routing methods. In Chapter 3, routing is reviewed in the known environment in which the robot either utilizes the created maps by extraneous sources or makes use of the sensor in order to prepare the maps from the local environment. The robot path planning relying on the robot vision sensors and applicable computing hardware are concentrated in the fourth chapter. The first part of this chapter deals with routing methods supported mapping capabilities. The second part manages the routing dependent on vision sensor typically known as the best sensor within the routing subject. The movement of two-dimensional robots with two or three degrees of freedom is analyzed within the third part of this chapter. In Chapter 5, the performance of a few of the foremost important routing methods initiating from the second to fourth chapters is conferred regarding the implementation in various environments. The first part of this chapter is engaged in the implementation of the algorithms Bug1, Bug2, and Distbug on the pioneering robot. In the second part, a theoretical technique is planned to boost the robot's performance in line with obstacle collision avoidance. This method, underlying the tangential escape, seeks to proceed the robot through various obstacles with curved corners. In the third and fourth parts of this chapter, path planning in different environments is preceded in the absence and the presence of danger space. Accordingly, four approaches, named artificial fuzzy potential field, linguistic technique, Markov decision making processes, and fuzzy Markov decision making have been proposed in two following parts and enforced on the Nao humanoid robot.

Key Elements for Motion Planning Algorithms.

This book addresses the need in the field for a comprehensive review of motion planning algorithms and hybrid control methodologies for complex legged robots. Introducing a multidisciplinary systems engineering approach for tackling many challenges posed by legged locomotion, the book provides engineering detail including hybrid models for planar and 3D legged robots, as well as hybrid control schemes for asymptotically stabilizing periodic orbits in these closed-loop systems. Complete with downloadable MATLAB code of the control algorithms and schemes used in the book, this book is an invaluable guide to the latest developments and future trends in dynamical legged locomotion.

"This book provides a comprehensive presentation of issues and challenges faced by researchers and practicing engineers in motion planning and hybrid control of dynamical legged locomotion. The major features range from offline and online motion planning algorithms to generate desired feasible periodic walking and running motions and tow-level control schemes, including within-stride feedback laws, continuous time update laws and event-based update laws, to asymptotically stabilize the generated desired periodic orbits. This book describes the current state of the art and future directions across all domains of dynamical legged locomotion so that readers can extend proposed motion planning algorithms and control methodologies to other types of planar and 3D legged robots"--

The common theme of this dissertation is sampling-based motion planning with the two key contributions being in the area of replanning and spatial load balancing for robotic systems. Here, we begin by recalling two sampling-based motion planners: the asymptotically optimal rapidly-exploring random tree (RRT*), and the asymptotically optimal probabilistic roadmap (PRM*). We also provide a brief background on collision cones and the Distributed Reactive Collision Avoidance (DRCA) algorithm. The next four chapters detail novel contributions for motion replanning in environments with unexpected static obstacles, for multi-agent collision avoidance, and spatial load balancing. First, we show improved performance of the RRT* when using the proposed Grandparent-Connection (GP) or Focused-Refinement (FR) algorithms. Next, the Goal Tree algorithm for replanning with unexpected static obstacles is detailed and proven to be asymptotically optimal. A multi-agent collision avoidance problem in obstacle environments is approached via the RRT*, leading to the novel Sampling-Based Collision Avoidance (SBCA) algorithm. The SBCA algorithm is proven to guarantee collision free trajectories for all of the agents, even when subject to uncertainties in the knowledge of the other agents' positions and velocities. Given that a solution exists, we prove that livelocks and deadlock will lead to the cost to the goal being decreased. We introduce a new deconfliction maneuver that decreases the cost-to-come at each step. This new maneuver removes the possibility of livelocks and allows a result to be formed that proves convergence to the goal configurations. Finally, we present a limited range Graph-based Spatial Load Balancing (GSLB) algorithm which fairly divides a non-convex space among multiple agents that are subject to differential constraints and have a limited travel distance. The GSLB is proven to converge to a solution when maximizing the area covered by the agents. The analysis for each of the above mentioned algorithms is confirmed in simulations.

During the last decades, motion planning for autonomous systems has become an important area of research. The high interest is not the least due to the development of systems such as self-driving cars, unmanned aerial vehicles and robotic manipulators. The objective in optimal motion planning problems is to find feasible motion plans that also optimize a performance measure. From a control perspective, the problem is an instance of an optimal control problem. This thesis addresses optimal motion planning problems for complex dynamical systems that operate in unstructured environments, where no prior reference such as road-lane information is available. Some example scenarios are autonomous docking of vessels in harbors and autonomous parking of self-driving tractor-trailer vehicles at loading sites. The focus is to develop optimal motion planning algorithms that can reliably be applied to these types of problems. This is achieved by combining recent ideas from automatic control, numerical optimization and robotics. The first contribution is a systematic approach for computing local solutions to motion planning problems in challenging unstructured environments. The solutions are computed by combining homotopy methods and direct optimal control techniques. The general principle is to define a homotopy that transforms, or preferably relaxes, the original problem to an easily solved problem. The approach is demonstrated in motion planning problems in 2D and 3D environments, where the presented method outperforms a state-of-the-art asymptotically optimal motion planner based on random sampling. The second contribution is an optimization-based framework for automatic generation of motion primitives for lattice-based motion planners. Given a family of systems, the user only needs to specify which principle types of motions that are relevant for the considered system family. Based on the selected principle motions and a selected system instance, the framework computes a library of motion primitives by simultaneously optimizing the motions and the terminal states. The final contribution of this thesis is a motion planning framework that combines the strengths of sampling-based planners with direct optimal control in a novel way. The sampling-based planner is applied to the problem in a first step using a discretized search space, where the system dynamics and objective function are chosen to coincide with those used in a second step based on optimal control. This combination ensures that the sampling-based motion planner provides a feasible motion plan which is highly suitable as warm-start to the optimal control step. Furthermore, the second step is modified such that it also can be applied in a receding-horizon fashion, where the proposed combination of methods is used to provide theoretical guarantees in terms of recursive feasibility, worst-case objective function value and convergence to the terminal state. The proposed motion planning framework is successfully applied to several problems in challenging unstructured environments for tractor-trailer vehicles. The framework is also applied and tailored for maritime navigation for vessels in archipelagos and harbors, where it is able to compute energy-efficient trajectories which complies with the international regulations for preventing collisions at sea.

Algorithms are a fundamental component of robotic systems: they control or reason about motion and perception in the physical world. They receive input from noisy sensors, consider geometric and physical constraints, and operate on the world through imprecise actuators. The design and analysis of robot algorithms therefore raises a unique combination of questions in control theory, computational and differential geometry, and computer science. This book contains the proceedings from the 2006 Workshop on the Algorithmic Foundations of Robotics. This biannual workshop is a highly selective meeting of leading researchers in the field of algorithmic issues related to robotics. The 32 papers in this book span a wide variety of topics: from fundamental motion planning algorithms to applications in medicine and biology, but they have in common a foundation in the algorithmic problems of robotic systems.

State of the art sample-based path planning algorithms, such as the Rapidly-exploring Random Tree (RRT), have proven to be effective in path planning for systems subject to complex kinematic and geometric constraints. The performance of these algorithms, however, degrade as the dimension of the system increases. Furthermore, sample-based planners rely on distance metrics which do not work well when the system has differential constraints. Such constraints are particularly challenging in systems with non-holonomic and underactuated dynamics. This thesis develops two intelligent sampling strategies to help guide the search process. To reduce sensitivity to dimension, sampling can be done in a low-dimensional task space rather than in the high-dimensional state space. Altering the sampling strategy in this way creates a Voronoi Bias in task space, which helps to guide the search, while the RRT continues to verify trajectory feasibility in the full state space. Fast path planning is demonstrated using this approach on a 1500-link manipulator. To enable task-space biasing for underactuated systems, a hierarchical task space controller is developed by utilizing partial feedback linearization. Another sampling strategy is also presented, where the local reachability of the tree is approximated, and used to bias the search, for systems subject to differential constraints. Reachability guidance is shown to improve search performance of the RRT by an order of magnitude when planning on a pendulum and non-holonomic car. The ideas of task-space biasing and reachability guidance are then combined for demonstration of a motion planning algorithm implemented on LittleDog, a quadruped robot. The motion planning algorithm successfully planned bounding trajectories over extremely rough terrain. Robotics is an ever-expanding field and intelligent planning continues to play a major role. Given that the intention of mobile robots is to carry out tasks independent from human aid, robot intelligence is needed to make and plan out decisions based on various sensors. Planning is the fundamental activity that implements this intelligence into the mobile robots to complete such tasks. Understanding problems, challenges, and solutions to path planning and how it fits in is important to the realm of robotics. Intelligent Planning for Mobile Robotics: Algorithmic Approaches presents content coverage on the basics of artificial intelligence, search problems, and soft computing approaches. This collection of research provides insight on both robotics and basic algorithms and could serve as a reference book for courses related to robotics, special topics in AI, planning, applied soft computing, applied AI, and applied evolutionary computing. It is an ideal choice for research students, scholars, and professors alike.