Robot Motion Control and Planning

Lecture 1 – Introduction and Logistics

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Introduction

- ## What is a robot?
  - First defined by Czech writer Karel Čapek in his play R.U.R. (Rossum's Universal Robots) in 1920.

- ## Many alternative definitions but common features:
  - Should be able to "move" (i.e. do physical work)
  - Should be programmable
  - "Intelligence" and autonomy are optional but desirable

- ## Our motivation:
  - Programming motion is a tricky problem to define and usually very difficult to solve!

# A Little History: Search Based AI

- Blocks World and STRIPS action planning (1960s)
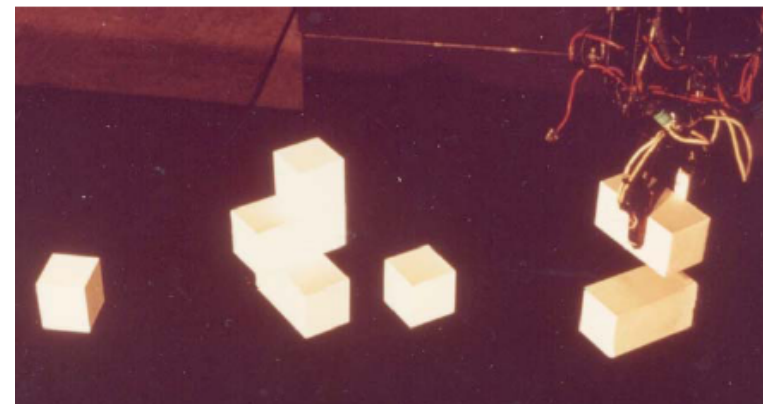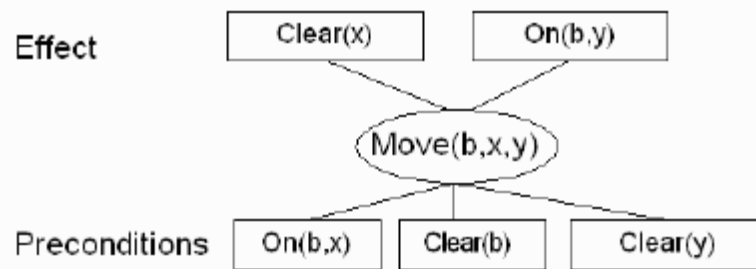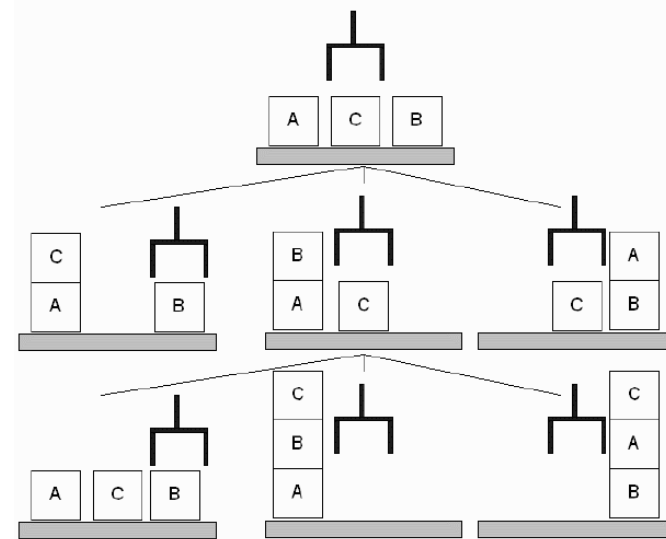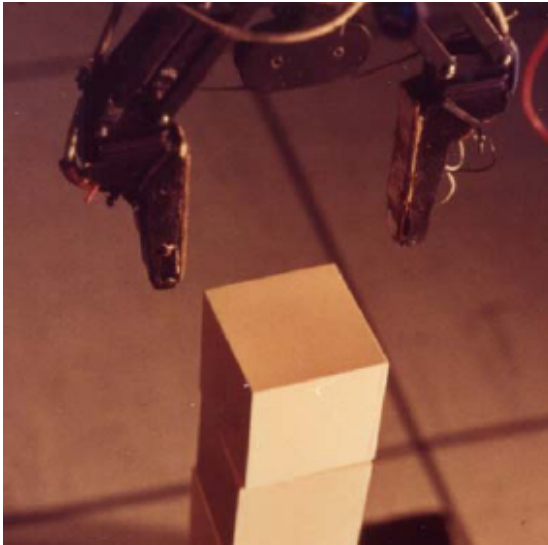
A Little History: Search Based AI

- Shakey the Robot **(SRI, 1966 – 1972)**
  - Triangulating range-finder for sensing obstacles
  - STRIPS based A* planner for navigating to a goal
  - Wireless radio and video camera

- Makes many not-so-realistic assumptions about the robot and its environment (more on this later)
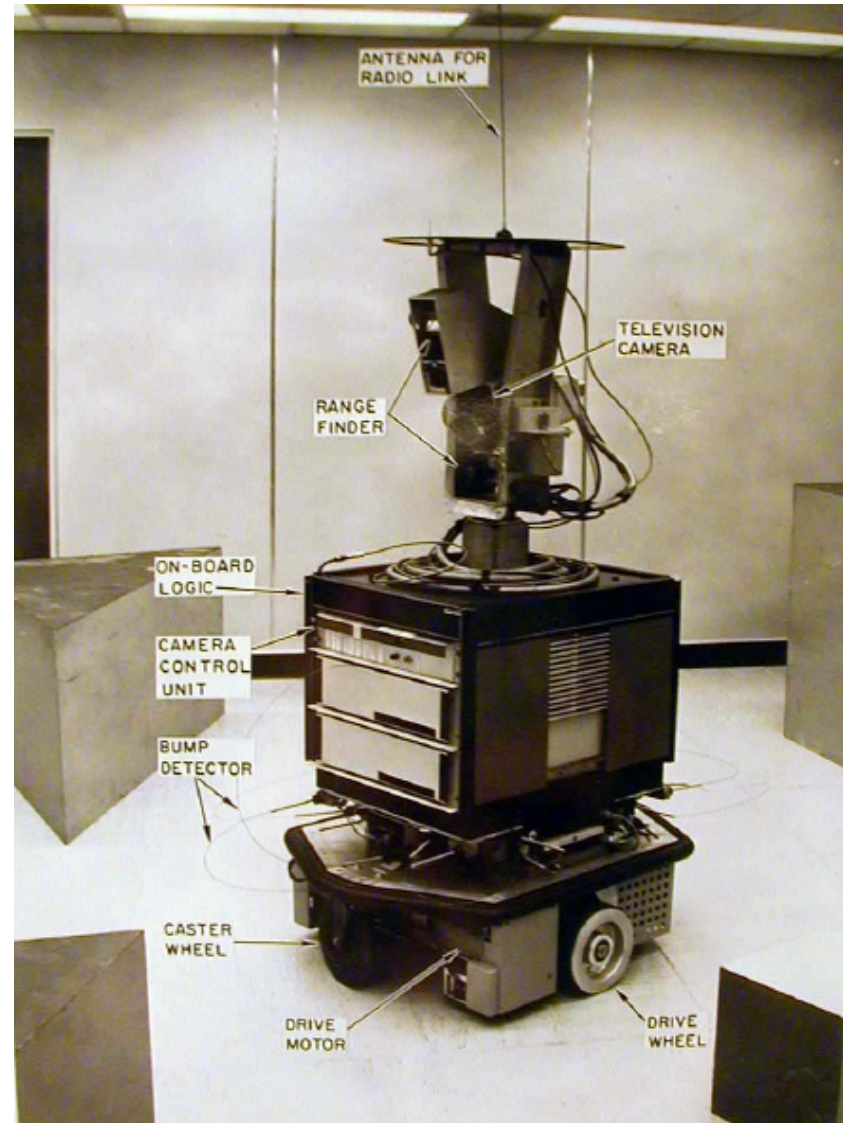
Motion Planning and Control

- ## Motion planning:
  - Where should I go and what motions should I go through?
  - Is this just a search problem? Why? Why not?

- ## Motion control:
  - How do I perform the desired motions?
  - What's the difference from planning?
  - Is this yet another search?

- ## Do these need to be separate?
  - Do you always plan first and then act?

Live Motion Planning Experiments

- Person 1 walks through some obstacles
- Person 1, looking at Person 2, directs Person 2 through obstacles
- Person 1, looking at Person 2 with eyes closed, directs Person 2 through obstacles
- Person 1, looking at a map and not Person 2, whose eyes are still closed, directs Person 2 through obstacles
- Person 1, looking at an object and Person 2, whose eyes are closed, directs Person 2 to grab an obstacle
- How do we do the last experiment with a map?

What did we assume?

- Perfect sensors?
  - What information is available?
  - Uncertainty?

- Perfect control?
  - What controls are available?
  - Uncertainty?

- Perfect thinking?
  - Knowledge of the world? Complete?
  - Processing the world? Everything?

- What else?

Trends in Robotics/Motion Planning

<u>Classical Robotics (mid-70's)</u>
- exact models
- no sensing necessary

<u>Reactive Paradigm (mid-80's)</u>
- no models
- relies heavily on good sensing

<u>Hybrids (since 90's)</u>
- model based at higher levels
- reactive at lower levels

**<u>Probabilistic Robotics (since mid-90's)</u>**
- seamless integration of models and sensing
- inaccurate models, inaccurate sensors

Mathematical rigor

Symbol	Meaning
$\exists$	there exists
$\forall$	for all
∞	infinity
$\in$	element
$\notin$	not in
s.t.	such that
$\mathbb{R}$	real numbers
$\mathbb{R}^m$	m-dimensioned real numbers
$\cup$	union
$\cap$	intersection
$\backslash$	set difference
$\Rightarrow$	implies. $p \to q$ is p implies q
$\Leftarrow$	implies. $q \to p$ is q implies p
$\Longleftrightarrow$	if and only if
S^1	a circle
∇	gradient
D	differential or distance to closest obstacle (depending on context)
d_i	distance to obstacle i in either the workspace or configuration space (depending on context)
$d(x, y)$	distance between the two points x and y
Null	null space

J	Jacobian
Γ	Christoffel symbol
RM	roadmap
$\mathcal{W}$	workspace
$\mathcal{Q}$	configuration space
$\mathcal{Q}_{free}$	free space
$x(k)$	state at time k
$\|x\|$	norm of x
$\subseteq$	subset of
$\subset$	strict subset of
$cl(A)$	closure of A
T^n	n-dimensional torus
S^n	n-dimensional sphere in $\mathbb{R}^{n+1}$
$SO(n)$	special orthogonal group
$SE(n)$	special Euclidean group
$B_\epsilon(q)$	open ball of radius ϵ centered at q
Df	differential of f
∇f	gradient of f
∇	affine connection
$\nabla_{Y_1} Y_2$	covariant derivative of Y_2 with respect to Y_1
C^0	continuous
C^n	n times differentiable
$\langle x, y \rangle$	inner product of x and y
$\mathcal{I}$	identity matrix
atan2(y, x)	returns angle to (x, y) in the plane in range $[-\pi, \pi)$
$T_x \mathcal{M}$	tangent space of $\mathcal{M}$ at x
$T\mathcal{M}$	tangent bundle of $\mathcal{M}$
$[f, g]$	Lie bracket of vector fields f, g
$\overline{\text{Lie}}(\mathcal{G})$	the Lie algebra of a set of vector fields $\mathcal{G}$
$\overline{\mathcal{D}}$	involutive closure of the distribution $\mathcal{D}$
$\mathcal{U}_\pm$	control set positively spanning $\mathbb{R}^m$
$\mathcal{U}_+$	control set spanning $\mathbb{R}^m$
$\langle Y_1 : Y_2 \rangle$	the symmetric product of vector fields Y_1 and Y_2

Example of a World (and Robot)

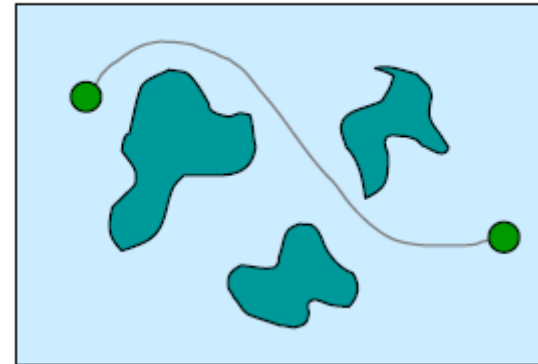Free Space

Obstacles

Robot

x,y
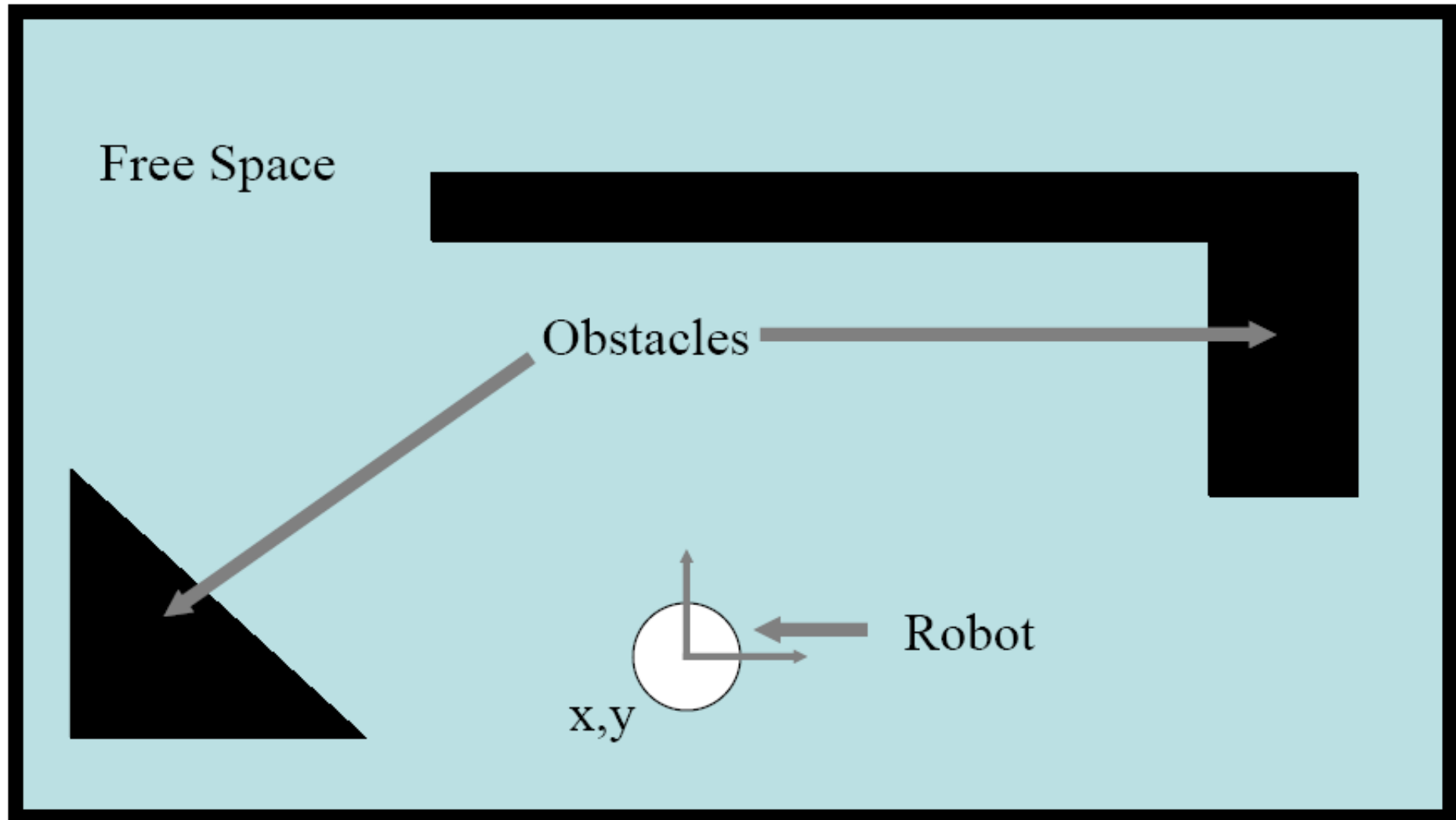
Example: Basic Path Planning

Problem Statement:

Compute a continuous sequence of collision-free robot configurations connecting the initial and goal configurations.
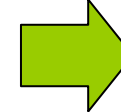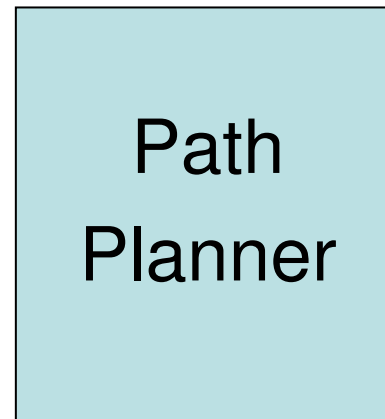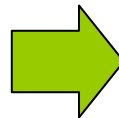
2D EXAMPLE:

Geometry of environment

Geometry and kinematics of the robot

Initial and goal configurations

Path Planner

Collision-free path

Motion Planning Statement

If W denotes the robot's workspace,

And WO_i denotes the i'th obstacle,

Then the robot's free space, W_{free}, is defined as:

$$W_{free} := W - (\bigcup WO_i)$$

And a path $c \in C^0$ is $c : [0,1] \rightarrow W_{free}$ where $c(0)$ is q_{start} and $c(1)$ is q_{goal}

Topics

- Bug Algorithms
- Curve Following
- Sensors
- Configuration Space for Round Mobile Robot
- Potential Functions
- Graph Search (A* D*)
- Pixel Maps
- Configuration Space for non-Round Robots
- Roadmaps
- Coverage
- Sample-based Methods
- Kalman Filtering (for Localization, SLAM)
- Bayesian Techniques (for Localization, SLAM)
- Dynamics and Non-holonomic Constraints, if time permits

Logistics

- ## Course schedule
  - Face-to-face lectures on Mon 13:40-15:30, Thu 12:30-14:30 A101

- ## Grade distribution (may change slightly)
  - 60% : Homeworks (5 or 6 programming assignments)
  - 15% : Paper presentations
  - 25% : Projects

- ## Prerequisites
  - Good programming skills: Matlab, Java, C++ etc.
  - Not afraid of math: Linear algebra, calculus, differential equations etc. Nothing too deep, but rigor in notation and details will be expected.

Homeworks

- ## Content
  - 5 or 6 programming assignments related to course topics
  - Must be done individually. No groups are allowed and cheating will be heavily penalized

- ## Submission
  - Write a "paper" (for each homework) with a description of the problem, your solution, graphs, animations, attached videos of your work.
  - Should be descriptive, understandable and thorough. Must be structured like a <u>good paper</u>.
  - Unless otherwise specified, you can use tools of your choice. All details must appear on the report

Paper Presentations and Project

- Content
  - Implementation of a solution to a nontrivial, preferably original motion planning problem
  - You can either use a simulated environment or a real robot if you have access to one
  - Paper to be presented must be related to your project

- Progress and Submission
  - Individual work
  - Proposal towards the middle of the semester
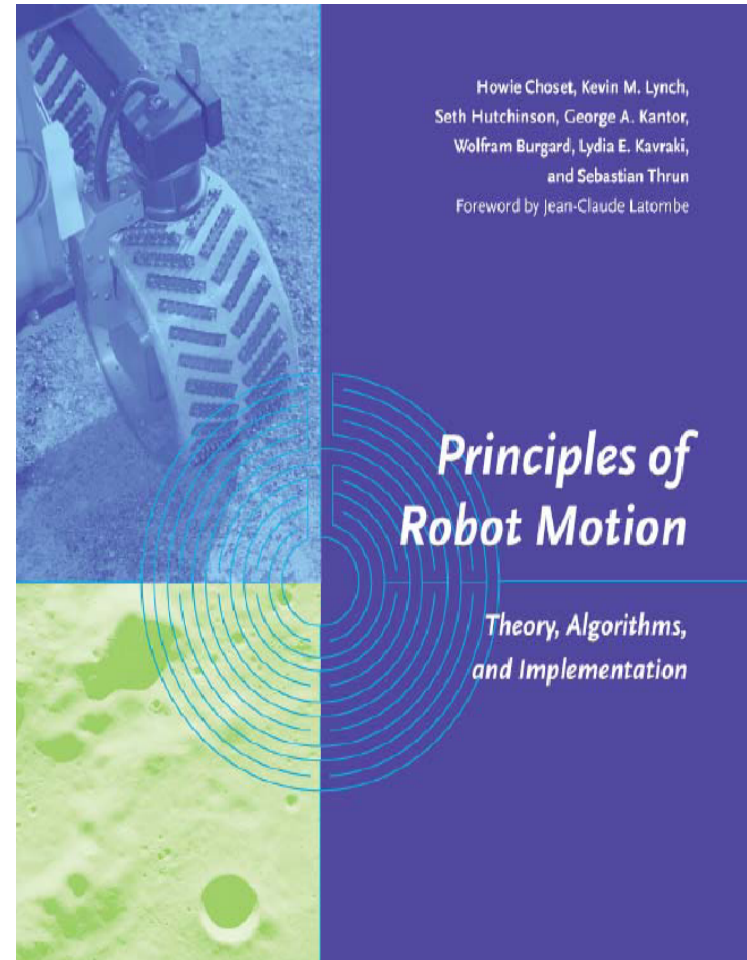 - A final report at the end, together with a demo and small presentation.

Textbook

<u>Principles of Robot Motion: Theory, Algorithms, and Implementations</u>

H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. E. Kavraki and S. Thrun,
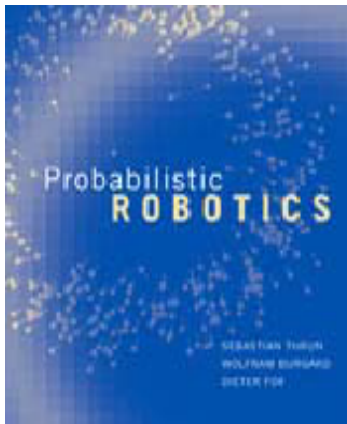
<u>MIT Press, Boston, 2005</u>.

Should be available in the bookstore. If late, let me know.

Other Books

Robot Motion Planning,
Jean-Claude Latombe, Kluwer,
1991.

Planning Algorithms
Steven Lavalle,
Cambridge University
Prress, 2006

Free download:
http://planning.cs.uiuc.edu/

Probabilistic Robotics

S. Thrun, W. Burgard, D. Fox

MIT Press, 2006