Robot Motion Control and Planning

http://www.ceng.metu.edu.tr/~saranli/courses/ceng786

Lecture 1 – Introduction and Logistics

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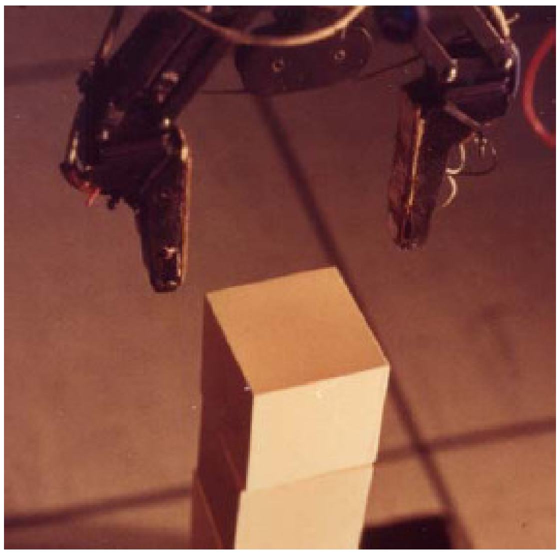
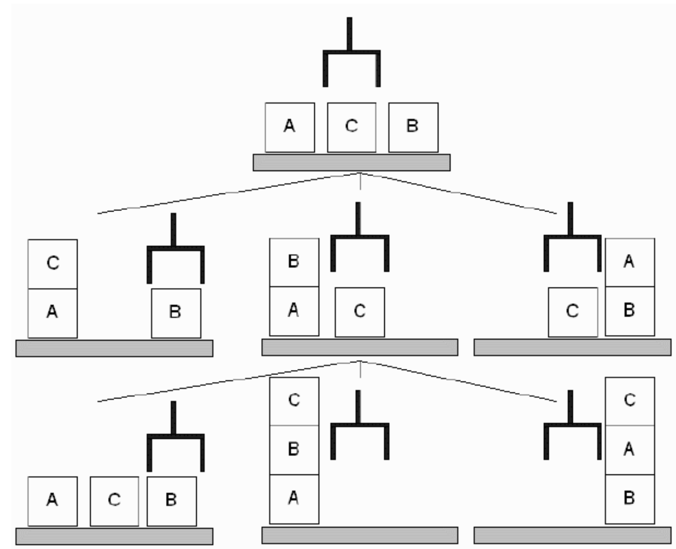
Introduction

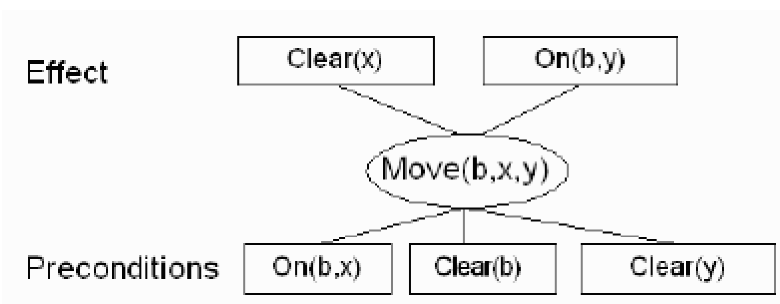
- What is a robot?
  - First defined by Czech writer Karel Čapek in his play R.U.R. (Rossum's Universal Robots) in 1920.
- Many alternative definitions but common features:
  - Should be able to "move" (i.e. do physical work)
  - Should be programmable
  - "Intelligence" and autonomy are optional but desirable
- Our motivation:
  - Programming motion is a tricky problem to define and usually very difficult to solve!

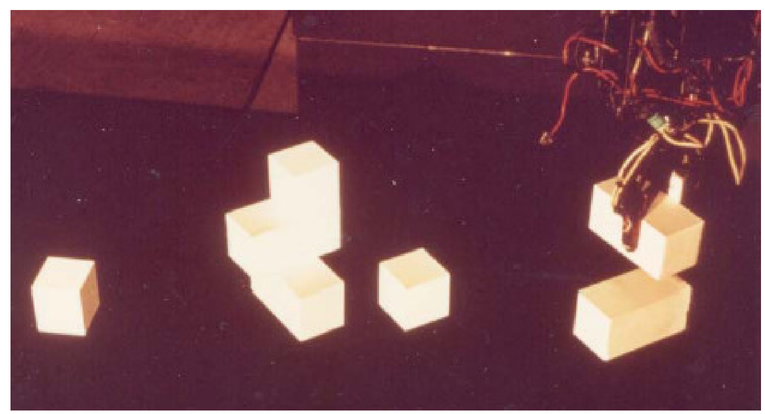
A Little History: Search Based AI

- Blocks World and STRIPS action planning (1960s)



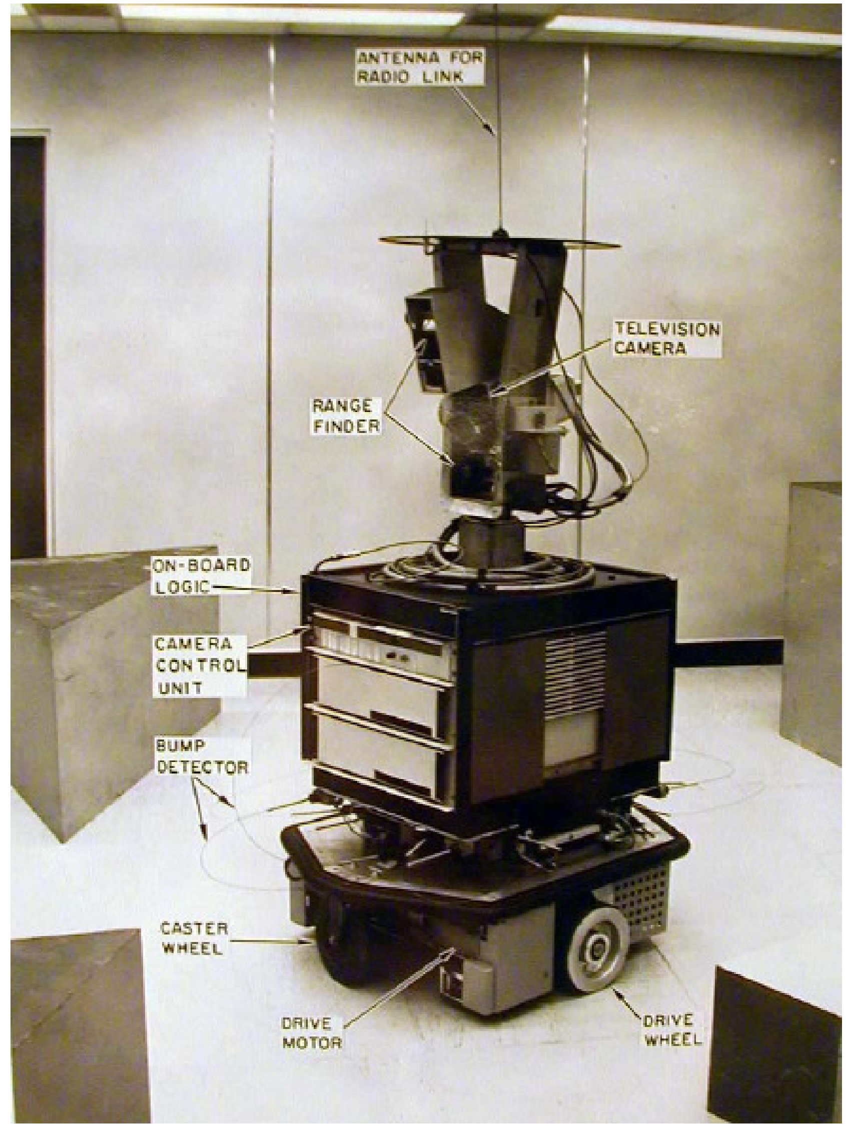






A Little History: Search Based AI

- 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

Classical Robotics (mid-70's)
- exact models
- no sensing necessary

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

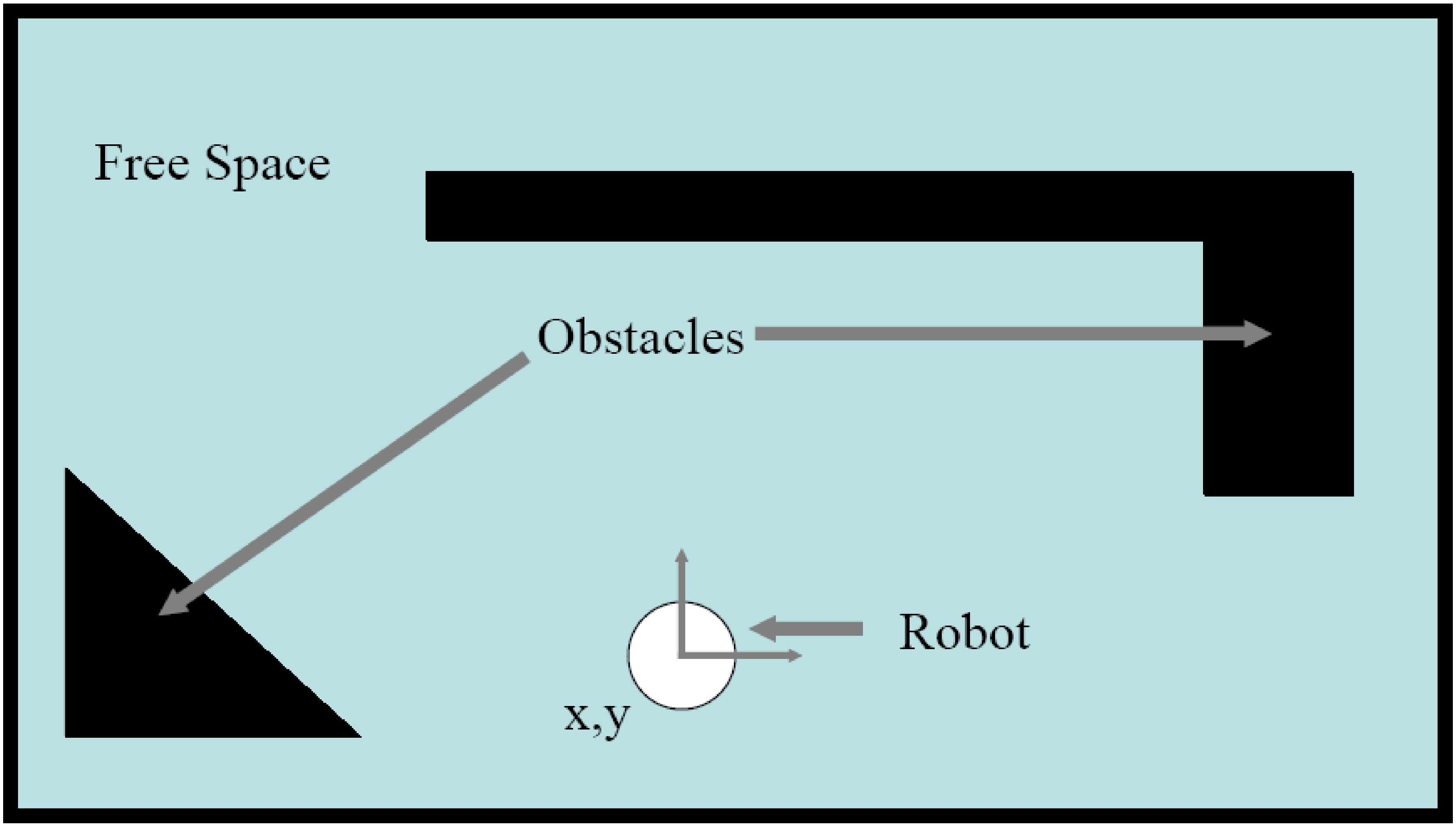
Hybrids (since 90's)
- model based at higher levels
- reactive at lower levels

Probabilistic Robotics (since mid-90's)
- 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
$\bigcup$	union
$\bigcap$	intersection
$\setminus$	set difference
$\Rightarrow$	implies. $p \rightarrow q$ is p implies q
$\Leftarrow$	implies. $q \rightarrow p$ 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
$\mathcal{Q}_{\text{free}}$	free space
$x(k)$	state at time k
$\|\|x\|\|$	norm of x
$\subseteq$	subset of
$\subset$	strict subset of
$\text{cl}(A)$	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
$\text{atan2}(y, x)$	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)

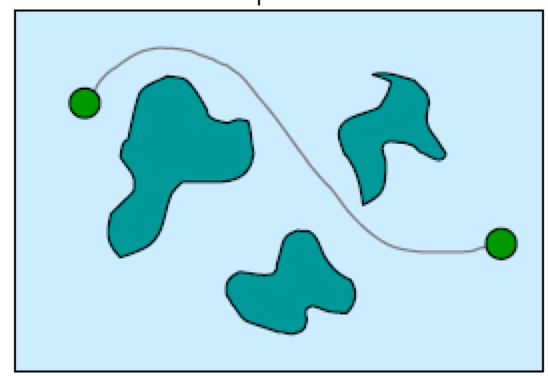


Example: Basic Path Planning

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

- Grade distribution
  - 5% : Quizzes, attendance and participation
  - 40% : Homeworks (5 or 6 programming assignments)
  - 10% : Paper presentations
  - 25% : Projects
  - 20% : Final
- 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
  - Make a web page (for each homework) with a description of your solution, graphs, animations, videos of your work.
  - Should be descriptive, understandable and thorough. Must be structured like a good report.
  - Unless otherwise specified, you can use tools of your choice. All details must appear on the web page

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 or groups of two, but group projects must be substantial
  - Proposal towards the middle of the semester
  - A final report at the end, together with a demo and small presentation.

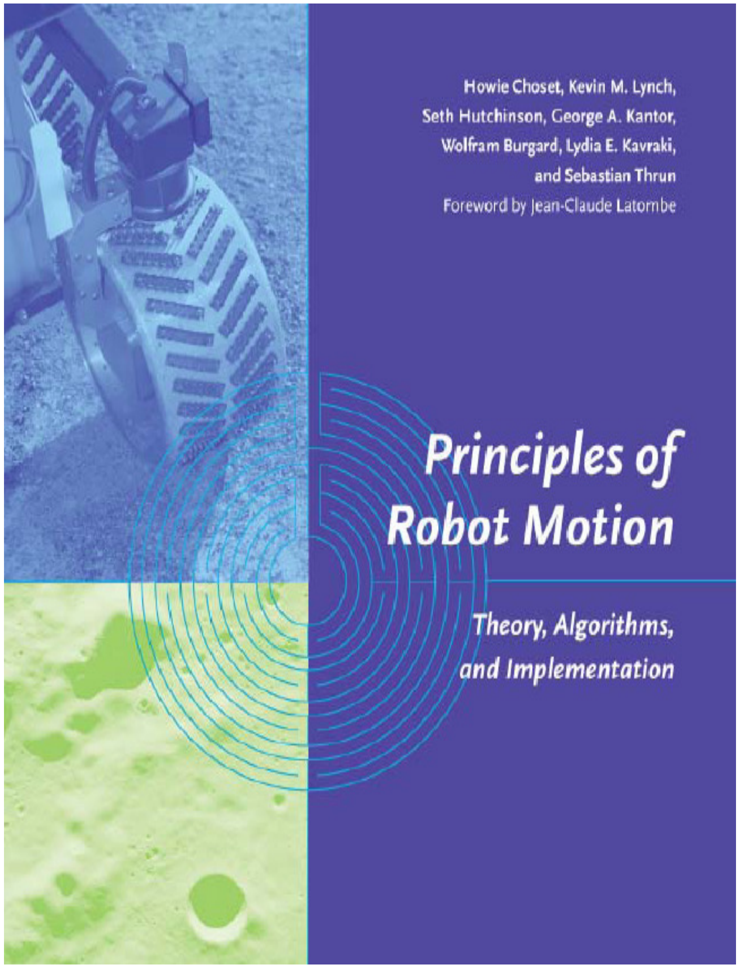
Textbook

Principles of Robot Motion: Theory, Algorithms, and Implementations

H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. E. Kavraki and S. Thrun,

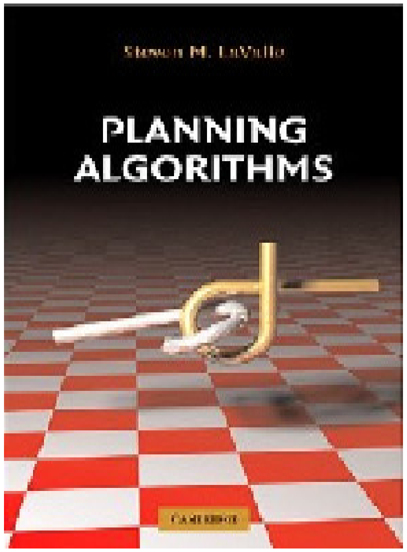
MIT Press, Boston, 2005.

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



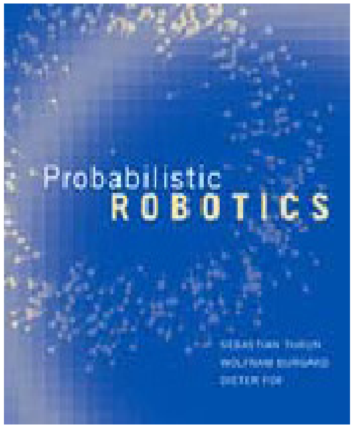
Other Books

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