

Indoor Location-Based Services

Martin Werner

Indoor Location-Based Services

Prerequisites and Foundations



Springer

Martin Werner
Ludwig-Maximilians-Universität München
Munich
Germany

ISBN 978-3-319-10698-4 ISBN 978-3-319-10699-1 (eBook)

DOI 10.1007/978-3-319-10699-1

Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014952609

© Springer International Publishing Switzerland 2014

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

To my family.

Preface

The rise of powerful smartphones equipped with many sensors has led to a huge amount of location-based services for the outside world. These applications provide orientation, navigation, and information to users in unknown locations. However, these services have long been limited to the outside of buildings, either because GPS is unavailable inside buildings or because alternative positioning based on cell towers or Wi-Fi access points is too inaccurate. The high information value of these applications, however, has triggered a lot of research towards extending the service experience from the outside into the inside of buildings. From a computer science perspective, this has led to a beautiful area of research in which many previously isolated domains converge towards new ideas and results. This book intends to bring together some of these aspects for students and researchers in a way, such that the aesthetics of indoor location-based services becomes evident. However, writing this book was quite challenging: It is sometimes hard to correctly distinguish the relevant and the irrelevant. However, I really enjoyed writing this book, and I hope that it will be helpful in making the domain of indoor location-based services accessible and attractive for others. Due to the chosen approach of covering the basics of many previously isolated domains in one book, this book cannot serve and is not intended to be a reference or state-of-the-art review. Instead, it provides readers with the needed background to enter the research area themselves.

This book would not have been possible without the help from my colleagues, my friends, and my family and without a university, which provides me with the freedom of investing a lot of time into this project. For their outstanding support and their helpful comments and discussions, I want to thank (in alphabetical order) Ulrich Bareth, Michael Beck, Florian Dorfmeister, Michael Dürr, Sebastian Feld, Moritz Kessel, Helge Klimek, Hans-Peter Kriegel, Claudia Linnhoff-Popien, Marco Maier, Philipp Marcus, Chadly Marouane, Valentin Protschky, Peter Ruppel, Lorenz Schauer, Mirco Schönfeld, and Kevin Wiesner.

Munich, Germany
May 2014

Martin Werner

Contents

1	Introduction	1
1.1	Location-Based Services (LBS)	4
1.2	What Is Special About Indoor LBS	6
1.3	Indoor LBS and Ubiquitous Computing	9
1.4	Classical Research Areas Related to Indoor LBS.....	11
1.5	Classical Applications of LBS	13
1.5.1	Information Services	13
1.5.2	Navigation Service	14
1.5.3	Safety-of-Life Applications	15
1.5.4	Retail and Commerce.....	15
1.5.5	Management	16
1.5.6	Social Networking and Joint Activities.....	16
1.5.7	Gaming.....	16
1.6	A Short History of Navigation.....	17
1.7	Structure of This Book	18
1.8	Further Reading	20
	References.....	20
2	Prerequisites	23
2.1	Mobile Computing and Mobile Communication	23
2.1.1	Mobility	24
2.1.2	Communication Systems	27
2.2	Wireless Communication	33
2.2.1	Signals	33
2.2.2	Channel Capacity, Bandwidth, and Data Rate	39
2.2.3	Antennas and Signal Propagation.....	43
2.2.4	Modulation.....	50
2.3	Sensor Technology for Positioning.....	58
2.3.1	Time Synchronization and Time Measurement	59
2.3.2	Acceleration.....	66
2.3.3	Rotation	67

- 2.3.4 Audio and Ultrasonics 68
- 2.3.5 Barometer 68
- 2.3.6 Magnetometer and Digital Compass 69
- 2.3.7 Wireless Infrastructure Components 70
- 2.4 Summary 71
- References 71
- 3 Basic Positioning Techniques 73**
 - 3.1 Methods for Location Determination 74
 - 3.1.1 Method of Least Squares 75
 - 3.1.2 Lateration 76
 - 3.1.3 Hyperbolic Lateration 80
 - 3.1.4 Angulation 81
 - 3.1.5 Proximity Detection 82
 - 3.1.6 Inertial Navigation 83
 - 3.1.7 Fingerprinting 84
 - 3.2 Properties and Evaluation of Positioning Systems 88
 - 3.3 Examples of Positioning Systems 90
 - 3.3.1 Pseudolites and High Sensitivity GNSS 91
 - 3.3.2 Light-Based Systems 93
 - 3.3.3 Camera-Based Systems 93
 - 3.3.4 Radio-Based Systems 94
 - 3.3.5 Inertial Navigation 96
 - 3.3.6 Audio-Based Systems 97
 - 3.3.7 Pressure-Based Systems 97
 - 3.4 Summary 98
 - References 98
- 4 Building Modeling 101**
 - 4.1 Coordinate Systems 102
 - 4.1.1 Geometric Coordinate Systems 102
 - 4.1.2 Symbolic Coordinate Systems 105
 - 4.2 Location Models 106
 - 4.2.1 Choice of Dimension 106
 - 4.3 Vector Maps 108
 - 4.3.1 Basic Algorithms for Vector Maps 108
 - 4.3.2 Raster Maps 113
 - 4.4 Environmental Models 116
 - 4.4.1 Set-Based Environmental Models 118
 - 4.4.2 Graph-Based Environmental Models 120
 - 4.4.3 Hybrid Approaches 124
 - 4.5 Geometric Nearest Neighbors and Range Queries 126
 - 4.6 Standardization 128
 - 4.6.1 GML and CityGML 129
 - 4.6.2 Indoor OSM 130

4.7	Summary	131
	References	131
5	Position Refinement	133
5.1	Least Squares Estimation with Correlation	133
5.2	Recursive Least Squares Estimation	135
5.3	Discrete Kalman Filtering	136
5.4	The Extended Kalman Filter	139
5.5	Particle Filtering	141
	5.5.1 Grid-Based Methods	142
	5.5.2 Sampling Importance Resampling	143
5.6	Summary	148
5.7	Further Reading	148
	References	149
6	Trajectory Computing	151
6.1	The Process of Trajectory Computing	152
6.2	Trajectories	152
6.3	Trajectory Comparison	154
	6.3.1 Hausdorff Distance	154
	6.3.2 Fréchet Distance	156
	6.3.3 Jaccard Distance	157
	6.3.4 Closet Pair Distance	159
	6.3.5 Euclidean Distance Sum	159
	6.3.6 Dynamic Time Warping	160
	6.3.7 Longest Common Subsequence (LCSS)	160
	6.3.8 Edit Distance on Real Sequences	161
	6.3.9 Edit Distance with Real Penalties	162
	6.3.10 Outlook	162
6.4	Trajectory Computing for Indoor LBS	163
	6.4.1 Trajectory Computing for Positioning	163
	6.4.2 Movement Patterns	164
	6.4.3 Spatial Movement Patterns	165
	6.4.4 Group-Based Motion Patterns	166
6.5	Summary	167
6.6	Further Reading	167
	References	168
7	Event Detection for Indoor LBS	169
7.1	Event-Driven Applications	172
7.2	Event Sources for Indoor Navigation	173
	7.2.1 Primary Events from Environmental Knowledge	175
	7.2.2 Primary Events from Infrastructure	176
	7.2.3 Primary Events from User Interface	176
	7.2.4 Primary Events from Positioning	176

- 7.2.5 Primary Events from Activity Recognition..... 177
- 7.2.6 Secondary Events Relevant
to the Navigational Task..... 177
- 7.3 Summary..... 178
- 7.4 Further Reading 178
- References..... 179
- 8 Simultaneous Localization and Mapping in Buildings 181**
 - 8.1 Data Sources for SLAM 182
 - 8.1.1 Data from Inertial Navigation Systems..... 183
 - 8.1.2 Data from Laser Scanners 183
 - 8.1.3 Data from Landmarks 184
 - 8.1.4 Data from Camera Systems 184
 - 8.2 Important Algorithms for SLAM Systems 185
 - 8.2.1 Visual Feature Point Extraction 186
 - 8.2.2 Optical Flow Estimation 187
 - 8.2.3 Iterative Closest Points 189
 - 8.2.4 Random Sample Consensus 192
 - 8.2.5 Graph-Based Optimization Algorithms 194
 - 8.3 Several Well-Known SLAM Approaches 198
 - 8.3.1 Extended-Kalman-Filter SLAM 198
 - 8.3.2 FastSLAM 199
 - 8.3.3 Grid-SLAM 199
 - 8.4 Summary..... 200
 - 8.5 Further Reading 200
 - References..... 200
- 9 Privacy and Security Considerations 203**
 - 9.1 Multiparty Computation 205
 - 9.2 k -Anonymity 207
 - 9.3 l -Diversity 210
 - 9.4 Spatial and Temporal Cloaking 213
 - 9.5 ϵ -Differential Privacy 215
 - 9.6 Private Information Retrieval 217
 - 9.6.1 Quadratic Residues 217
 - 9.6.2 Private Information Retrieval Using Quadratic
Residuosity..... 220
 - 9.7 Summary..... 221
 - 9.8 Further Reading 222
 - References..... 222
- 10 Open Problem Spaces 223**
 - 10.1 Open Problems in Prerequisites 223
 - 10.1.1 Sensor and Timing Accuracy 224
 - 10.1.2 Ambient Sensors and Building Automation..... 224

10.2	Basic Positioning Techniques	224
10.3	Building Modeling	225
10.4	Position Refinement	226
10.5	Trajectory Computing	226
10.6	Event Detection	227
10.7	Simultaneous Localization and Mapping in Buildings	227
10.8	Privacy and Security Considerations	227
10.9	Summary	228
Index	231