



# Index

Note: Page number followed by *f* indicate figure and *t* indicate tables.

## A

Abstract floor plans, 171–172  
Access point number reduction, 262–263  
Acoustics  
    active, 335  
    positioning systems. (*see* Airborne acoustic positioning systems (AAPS))  
    signal detection and positioning  
        observables, 340–342  
    wave propagation in air  
        absorption, 337–338  
        impedance, 339  
        outdoor propagation, 339–340  
        propagation speed, 338–339  
Active Badge System, 353  
Active Bat System, 335–336  
Affinity propagation clustering, 138–139  
    application of, 146–147  
    offline phase, 147  
    RP clustering via, 145–147  
    two-step algorithm, 148  
Airborne acoustic positioning systems (AAPS)  
    broadband, 336–337  
    compensation algorithms  
        Doppler shift, 347–349  
        multipath propagation, 346–347  
        multiple access interference, 345–346  
    positioning strategies, 342–343  
        hyperbolic lateration, 344–345  
        spherical lateration, 343–344  
*Alcalá2017 Tutorial* dataset, 238  
    characteristic of, 236*t*  
    mean positioning error, 241, 242*t*  
    Radio Map Inherent Difficulty (RMID) value, 243, 243*t*  
*AmbiLoc* dataset, 238

AM radio maps, 74–75

Anchors

    antideflagration ATEX enclosure, 304  
    communication module, 303–304  
    localization module, 304  
    visualization module, 304  
Angel of Arrival (AOA), 341, 353  
    three-dimensional position, 365–368  
Apache, 235  
Apple Maps, 101  
Architectural floor plans, 171–172  
Atmospheric turbulence, 340  
Augmented reality systems, 171–172  
Auto-regressive model of order one (AR1), 315

## B

Basic Service Set Identifier (BSSID), 157–158  
Bluetooth-complaint technologies, 267  
Bluetooth low energy (BLE), 156  
    communication, 302  
    radio maps, 74  
Wi-Fi probability-based positioning and  
    beacon-based positioning  
        beacon RSSI weighted centroid, 132  
        probability-based results, 130–132  
        probability-based setup and algorithm, 129–130  
        probability density function, 127–129  
and WLAN, 268

## C

Calibration-free indoor positioning system  
    CrowdInside, 107  
    EZ clients, 106  
    iMoon, 108  
    Jigsaw, 107

## Calibration-free indoor positioning system

*(Continued)*

MapGenie, 107

SDM, 105

TIX, 105

UnLoc, 106

Walkie-Markie, 106–107

## Calibration issues, in fingerprinting

techniques

circle-based fingerprint clustering, 261–262

offline calibration, 261

RSS offsets, effects of, 260–261

test rank based method, 261–262

## Cell-ID system, 353

## Cell Space, 194–196

## CIMLoc, 77

## CityGML, 190–191

Clustering methods, 252, 253*f*

## Compression and clustering methods, 262

## Compressive sensing approaches, 257–258

Core module, of IndoorGML, 194–196, 195*f*

## Cricket system, 335–336

## Crowdsourcing, 138

indoor research

calibration-free, 105–108

equipped sensors implications, 110–111

floor plan layout dimension, 111

map-free *vs.*, 109*t*

maximum likelihood estimator, 103

privacy and security, 112

quality of, 110

simultaneous localization and mapping,  
104–105

type of architecture, 111

## outdoor map systems, 98–103

Apple Maps, 101

Google Maps, 99

HERE (Nokia Here), 101

MapQuest, 100

Microsoft's Bing Maps, 101

OpenStreetMap (OSM), 99–100

Waze, 100

radio maps building and updating,  
76–79**D**Database-size reduction, in fingerprinting  
techniques, 262–263

Dead-reckoning method, 311

Deployment cycle, passive localization system,  
289–290

Device heterogeneity, 162–163

Dijkstra's algorithm, 177–178, 179*f*

Django, 235

Doppler shift, 347–349

Drift reduction methods

height error correction, 329

heuristic drift elimination algorithms, 326

landmark-based algorithms, 328–329

multiinertial sensor fusion algorithms,  
327–328

SLAM-based algorithms, 327

**E**

Electrical calibration process, 360–361

Electrical system modeling, 357–358

Emitters, 367–368

Envelope detection technique, 340, 341*f*

EvAAL-ETRI indoor location competition, 227

EvAAL indoor localization competition

accuracy performance, 213

EvAAL framework

core criteria, 214

extended criteria, 214–215

evaluation, 212–213

long-term goal, 211

setup criteria, 211–212

**F**

Filtering, radio maps, 84–87

AP selection

offline, 85–86

online, 86–87

density and positioning performance, 84–85

samples, 87

Fingerprint calibrated weighted centroid

(FCWC) algorithm

algorithm implementations, 124–125

SPCF and, 125

validation against competing algorithms,  
125–127  
validation data, 124  
FM radio maps, 74–75

## G

Geometric calibration system, 361–365, 362*f*  
Global navigation satellite system (GNSS)  
access, 155  
Global navigation satellite system integration,  
with WLAN  
categories, 270–271  
fusing GNSS pseudoranges with WLAN  
ranges, 271  
fusing GNSS pseudoranges with WLAN RSS  
Bayesian filter, 272*f*  
cumulative distribution function, 275  
estimation stage/online phase, 273–274  
extended Kalman filter, 274–275  
Gaussian process regression, 272  
mean absolute error, 275–276, 275*t*  
performance, 274–276  
training stage/offline phase, 272–273  
Global positioning system (GPS), 97  
Google Indoor, 169  
Google Maps, 99  
GraphSLAM, 77

## H

Height error correction, 329  
Height/floor estimation, in indoor  
fingerprinting, 266  
HERE (Nokia Here), 101  
Heuristic drift elimination algorithms, 326  
Hyperbolic lateration, 344–345  
algorithm, 336–337

## I

Image acquisition, 362–363  
Image-based approaches, 254–257  
Image compression process, 255–257, 256*f*  
Image sensor (IS), 354  
Indoor cell-awareness, 190  
IndoorLoc platform  
actions, 226

*AmbiLoc* dataset, 238  
dashboard section, 229, 233  
datasets section, 228, 230*f*  
comma-separated values file format, 230  
dataset info, 229–230  
test set, 230  
training set, 230  
validation set, 230  
deterministic-based approach, 239, 240*f*  
homepage, 228, 229*f*  
implementation details, 235  
*magPIE* dataset, 238–239  
methods, 229, 231–233  
objectives, 231  
performance, 244  
probabilistic-based approach, 239–241, 240*f*  
ranking, 229, 231  
Wi-Fi-based datasets, 235–238  
Indoor maps, 187–188  
IndoorTube Map, 172  
requirements for  
cell-based context awareness, 189–190  
indoor accessibility graph, 189  
indoor space, 188–189  
indoor structure and connectivity,  
188–189  
integrating multiple data sets, 190–191  
“You are here” map, 170  
Indoor navigation, radio fingerprinting-based  
assumptions, 157–158  
challenges, 158–164  
motivation, 155–157  
Indoor positioning and indoor navigation  
(IPIN) conference, 209–211  
Indoor positioning system (IPS)  
angle of arrival, 353  
applications, 46–47  
calibration and experimental setup  
smartphone-based patient monitoring,  
47–49  
smartwatch-based patient monitoring,  
49–50  
challenges of fingerprinting  
Anyplace (Airplace), 12  
classification, 3–4

Indoor positioning system (IPS) (*Continued*)

- indoor maps, 14–15
- localization mechanisms, 4–6
- location, 3
- magnetic field fingerprint, 10–11
- modular localization system, 13
- motivation, 1–2
- navigation, 3
- position, 3
- privacy and security issues, 15
- Samsung solution, 11
- Wi-Fi fingerprinting, 6–10
- developments in, 65
- in environment, 365–367, 366*f*
- experiences and lessons learned
  - smartphone-based patient monitoring, 50–51
  - smartwatch-based patient monitoring, 51–52
- first stage, 58
- light-emitting diode, 354, 368*f*
- measurement quantities, 46
- MWMF model, 139–140
- optical sensor system
  - description of, 355–360
  - electrical system modeling, 357–358
  - optical system modeling, 358–360
  - position sensitive device sensor, 356–357
- problem/challenge with, 209
- requirements, 287
- sensor system calibration
  - electrical calibration, 360–361
  - geometric calibration, 361–365
- at very large scenarios
  - calibration and experimental setup, 52–58
  - experiences and lessons learned, 58–64
- virtual fingerprinting via, 139
- Wi-Fi fingerprinting, 52
  - heterogeneous mobile applications, 46
  - for indoor positioning, 52
  - mapping large environments, 64
  - measurements, 46
  - nonobtrusive, 47
  - offline phase, low-complexity strategy, 139–143

- online phase, low-complexity strategy, 145–149
- at university campus, 53–57
- Indoor radio propagation, RSSI-based
  - positioning algorithms
    - free space model, 116
    - indoor propagation, 117
    - RSSI measurement, 118
- IndoorTube Map, 172
- Inertial measurement units (IMU), 276
- Inertial sensors, 311
  - and magnetometers, 312–313
- Infrared emitting diode (IRED), 354, 360, 363*f*
  - mobile agents, 365–367, 366*f*
- Interacting multiple model (IMM) algorithm, 278
- Interoperability of positioning systems, 249
- Intersymbol interference (ISI), 345–346
- Inverse distance weighting (IDW)
  - interpolation, 80
- ipft R package, 235
- IPIN indoor localization competition
  - error statistics, 218
  - EvAAL framework, application of, 217–218
  - fusion strategies, 221–222
  - Kalman filter, 221–222
  - objective, 223
  - particle filter, 222
  - point error, 216
  - real-time systems
    - map matching algorithm, 221
    - pedestrian dead reckoning, 220–221
    - raw-data modules, 220–221
    - selection of, 219–220, 219*t*
    - user orientation, 221
    - Wi-Fi scanning, 221
  - smartphone-based systems, 220
  - tracks and competitors, 215*t*
- IPIN2016 Tutorial dataset, 237
  - characteristic of, 236*t*
  - mean positioning error, 241, 242*t*
  - Radio Map Inherent Difficulty (RMID) value, 243, 243*t*
  - ranking webpage of, 231, 232*f*

IPS. (*see* Indoor positioning system (IPS))  
 Iterative method, 365

## K

*Kaggle*, 227  
 Kalman filter, shoe-mounted positioning systems, 318–319

## L

Landmark-based algorithms, 328–329  
 Levenberg-Marquardt algorithm, 365  
 Light-emitting diode (LED), 354  
 Linear Frequency Modulation (LFM), 342  
 Location-based applications (LBA), 69  
 Location-based services (LBS)  
   applications, 97  
   awareness and demand, 155  
   for indoor environments, 169  
 Log-distance path-loss (LDPL) model, 83  
 Loose coupling algorithms, 327–328  
 Low-complexity strategy offline and online strategies  
   experimental setting and performance indicators, 142–143, 148–149  
   offline phase, 141, 147  
   online phase, 141–142, 147–148  
   RP clustering via affinity propagation, 145–147  
   RSS prediction via MWMF model, 139–140

## M

Magnetic field  
   fingerprint, 10–11  
   navigation, 277  
*MagPIE* dataset, 238–239  
 MapQuest, 100  
 Map systems  
   indoor  
     calibration-free, 105–108  
     equipped sensors implications, 110–111  
     floor plan layout dimension, 111  
     map-free *vs.*, 109*t*  
     maximum likelihood estimator, 103  
     privacy and security, 112  
     quality of, 110

simultaneous localization and mapping, 104–105  
   type of architecture, 111  
 outdoor, 98–103  
   Apple Maps, 101  
   Google Maps, 99  
   HERE (Nokia Here), 101  
   MapQuest, 100  
   Microsoft's Bing Maps, 101  
   OpenStreetMap (OSM), 99–100  
   Waze, 100  
 schematic, 170  
   challenges, 172  
   for mobile GIS applications, 171  
   for transport network, 171  
   web map systems, 102*t*  
 Matching pursuit (MP) algorithm, 346–347  
 Measurement gaps, in fingerprinting techniques, 263–266  
 MEMS-based inertial sensors, 312  
 MEMS-based magnetometers, 313  
 Microsoft indoor localization competition, 213–214  
 Microsoft's Bing Maps, 101  
 Multiinertial sensor fusion algorithms, 327–328  
 Multilateration. (*see* Hyperbolic lateration)  
 Multimodal positioning, 278  
 Multiple access interference (MAI), 345–346  
 Multiple Basic Service Set Identifiers selection, 263  
 Multiple position sensitive device system, 355  
 Multislope PL models, 253  
 Multiwall multifloor (MWMF) indoor propagation model  
   empirical nature, 143  
   reliability, 142–143  
   RSS prediction via, 139–140  
   virtual fingerprints, 143

## N

Navigation module, of IndoorGML, 196, 196*f*, 197*f*  
 Nonshoe-mounted positioning systems  
   step detection

Navigation module, of IndoorGML

(*Continued*)

on horizontal surfaces, 321–322

on stairs, 322–323

step&heading algorithm, 320–321, 321*f*

step length estimation, 324–325

vertical displacement estimation, 325–326

## O

Offline phase, low-complexity strategy, 141

experimental setting and performance

indicators, 142–143

online phase, 141–142

RSS prediction via MWMF model, 139–140

OGC IndoorGML, 187–188

cell geometry, 191

cell semantics, 192–193

cellular space model, 191

data models of, 188

i-locate portal and JOSM, 203*f*

implementation issues

cell determination and decomposition,  
198–199

hierarchical structure, 200, 201*f*

path geometry, 199

space closure, 199–200

thick *vs.* thin door model, 199

vertical connection, 201, 202*f*

wall texture, 201

modular structure, 194*f*

core module, 194–196, 195*f*

navigation module, 196, 196*f*, 197*f*

multilayered space model, 193

topology between cells, 192

use cases, 202–205

user navigation and asset management, 202

Online phase, low-complexity strategy,

147–148

experimental setting and performance

indicators, 148–149

offline phase, 147

RP clustering via affinity propagation,  
145–147

OpenStreetMap (OSM), 99–100

Optical sensor system

description of, 355–360

electrical system modeling, 357–358

modeling of, 355–360

optical system modeling, 358–360

position sensitive device sensor, 356–357

Order vectors, 292

Orientation estimation, 313

Kalman filter, 314

prediction stage, 314–315

update stage

absolute compass, 317

absolute gravity, 316

absolute magnetic field, 316–317

differential gravity, 316

differential magnetic field, 317

pseudo-measurement, 316

zero angular rate, 317

## P

Parallel Interference Cancellation algorithm,  
345–346

Passive localization system

data representation, 292

deployment cycle, 289–290

features, 288–289

802.11 fingerprints, 291

lecture room building

accuracy considerations, 295–297

floor plan, 293, 293*f*

occupancy services, 297–298

passive sensing characterization, 294–295

spatial sampling coverage, of monitors,  
295, 296*f*

temporal occupancy analysis, 298*f*

time window, 294

training approach, 290–292

user interface of the training application,  
291, 291*f*

Path-loss (PL) approaches, 252–253

Pedestrian dead reckoning (PDR), 77, 157

Piloting method, 311

Pinhole model, 358, 358*f*

Point-to-point telemetry, 353

Position sensitive device (PSD) sensor, 356*f*  
amplifier circuit, 357*f*

- equivalent circuit, 356*f*
  - indoor positioning system
    - AoA, three-dimensional position determination, 365–368
    - optical sensor system, 355–360
    - sensor system calibration, 360–365
  - Kalman filter, 355
  - on mobile agents, 367–368
  - 2D pincushion sensor, 356*f*
  - uniform illumination, 361*f*
  - Power/Received Signal Strength (RSS), 340
  - Probability-based positioning, Wi-Fi and BLE
    - beacon RSSI weighted centroid, 132
    - probability-based results, 130–132
    - probability-based setup and algorithm, 129–130
    - probability density function, 127–129
  - PSD sensor. (see Position sensitive device (PSD) sensor)
  - Public repository. (see IndoorLoc Platform)
- R**
- Radial basis function (RBF) interpolation, 81–82
  - Radio fingerprinting-based indoor localization
    - assumptions, 157–158
    - challenges, 158–164
    - motivation, 155–157
  - Radio-Frequency Identification (RFID), 156
  - and WLAN, 268–269
  - Radio maps
    - building and updating, 75–79
    - crowdsourcing, 76–79
    - construction, 46
    - definition, 71–72
    - for different radio technologies, 71–75
      - Bluetooth low energy radio maps, 74
      - deterministic radio maps, 73–74
      - FM and AM radio maps, 74–75
    - estimation method, 71–72
    - filtering, 84–87
      - AP selection, 85–87
      - density and positioning performance, 84–85
      - samples, 87
    - reference points, 71–72
    - standards
      - automatic discovery protocols, 89–90
      - floor maps, 90–91
      - formats and protocols, 90
      - fundamental building blocks, indoor positioning and tracking system, 88–89
      - need for, 89
      - remote positioning engines, 91–92
      - standardization initiatives, 92
    - Wi-Fi density, 79–83
      - construction using interpolation, 80–83
      - construction using propagation models, 83
  - Random walk, 313
  - Received signal strength (RSS), 137
  - prediction, 138
  - Received signal strength-based fingerprinting techniques, 250
    - challenges and solutions, 258–266, 259*t*
      - calibration issues, 260–262
      - database-size reduction, 262–263
      - height/floor estimation, 266
      - measurement gaps, 263–266
    - distance metrics, 252*t*
    - with full training databases, 250–251
    - with reduced training databases
      - clustering methods, 252, 253*f*
      - image-based approaches, 254–257
      - path-loss approaches, 252–253
  - Received signal strength-based seamless positioning
    - fingerprinting techniques, 250
      - challenges and solutions, 258–266
      - distance metrics, 252*t*
      - with full training databases, 250–251
      - with reduced training databases, 251–258
    - one-stage approaches, 250
  - Received signal strength indicator (RSSI)
    - fingerprinting, 225
    - indoor radio propagation
      - free space model, 116
      - indoor propagation, 117
      - RSSI measurement, 118

Received signal strength indicator (RSSI)

(*Continued*)

positioning algorithms

access points, 115–116

smartphone-based localization, 115–116

vector similarity measures, 121–123

readings

fingerprint point similarity, 158

logarithmic distance relation, 159

measurements, 157–158

reference point, 157–158

Reference points (RPs), 137

Refinery, tasks in, 301

Refinery worker safety, remote monitoring

system for. (*see* Remote monitoring

system, for refinery worker safety)

Remote monitoring system, for refinery

worker safety

control center, 304–305

alert manager, 305

database, 305

graphical user interface, 305

processing module, 305

remote configuration manager, 305

customized antiexplosive wristband

aim/goal, 303

functionalities, 302–303

data anonymity, 305–306

logistics, 309

person related issues

ergonomics, 308

simplicity, 308

technical and procedure robustness, 308

transparency and privacy, 307–308

wearable devices, 302–303

wireless communication infrastructure,  
303–304

RF-based indoor localization algorithms, 228

R Markdown technology, 235

Root mean square (RMS), 360–361

## S

Seamless positioning platforms, 249

Sensor system calibration

electrical calibration, 360–361

geometric calibration, 361–365

Shiny, 235

Shoe-mounted inertial positioning systems,  
318–320

Signal of opportunity (SoO), 267–268

Simulated annealing optimization technique,  
171

Simultaneous localization and mapping  
(SLAM)

ActionSLAM, 104–105

algorithms, 163–164, 327

FootSLAM, 104–105

indoor map systems' research, 104–105

traditional, 104–105

Smartphone-based patient monitoring, 50–51

Smartwatch-based patient monitoring, 51–52

Sound-based positioning systems, 277

Spherical lateration, 343–344

Stance phase detection, 319

State and Transition, 194–196

Strapdown algorithm, 318, 318<sup>f</sup>

## T

*Tampere* dataset, 237–238

characteristic of, 236<sup>t</sup>

mean positioning error, 241, 242<sup>t</sup>

Radio Map Inherent Difficulty (RMID) value,  
243, 243<sup>t</sup>

Ternary vectors, 292

Tight coupling algorithms, 328

Time difference of arrival (TDOA), 341, 353

Time-of-arrival (TOA), 341

Triangular Interpolation and eXtrapolation  
(TIX)'s localization purpose, 105

Trilateration. (*see* Spherical lateration)

Two-phase localization methods, 258

## U

UCI Machine Learning Repository, 227

UFPR CampusMap (UCM) project

classes diagram, 175<sup>f</sup>

database construction

cartographic, 176–177

database conceptual model, 174

database implementation, 174–176



- nongeometric and geometric features, 174*t*
  - indoor routing, 177–179
  - PgRouting function, 179
  - PostGIS function, 177–178
  - results
    - indoor cartographic representation, 181–182
    - indoor routes, 183, 183*f*
    - server-client architecture, 179–180
    - study area, 172–173
    - Thormap, 180–181
  - UJIIndoorLoc* dataset, 237
    - characteristic of, 236*t*
    - mean positioning error, 241, 242*t*
    - Radio Map Inherent Difficulty (RMID) value, 243, 243*t*
    - ranking webpage of, 231, 232*f*
  - Ultrasonic positioning system, 277
  - UltraWideBand (UWB), 4
    - communication, 302
    - radio, 156
  - universAAL framework, 210
- V**
- Visible light-based indoor positioning system, 354
  - Visible light communication (VLC), 354
  - Visible light positioning (VLP), 277
  - Vision navigation, 277
  - Volunteer-based data collection, 47
    - smartphone-based patient monitoring, 50–51
    - smartwatch-based patient monitoring, 51–52
- W**
- Waze, 100
  - Weighted *k*-nearest neighbors (WkNN) schemes, 138–139
  - Wi-Fi fingerprinting indoor positioning systems
    - heterogeneous mobile applications, 46
    - for indoor positioning, 52
    - mapping large environments, 64
    - measurements, 46
    - nonobtrusive, 47
    - offline phase, low-complexity strategy
      - experimental setting and performance indicators, 142–143
      - offline phase, 141
      - online phase, 141–142
    - RSS prediction via MWMF model, 139–140
    - online phase, low-complexity strategy
      - experimental setting and performance indicators, 148–149
      - offline phase, 147
      - online phase, 147–148
    - RP clustering via affinity propagation, 145–147
  - radio map, 120–121
    - sources, 156
  - at university campus, 53–57
  - Wi-Fi probability-based positioning and BLE
    - Beacon RSSI weighted centroid, 132
    - probability-based results, 130–132
    - probability-based setup and algorithm, 129–130
    - probability density function, 127–129
  - Wi-Fi radio maps density construction
    - using interpolation, 80–83
      - inverse distance weighting (IDW), 80
      - IWD, 83
      - kriging interpolation, 82
      - radial basis function (RBF), 81–82
      - RBF, 83
  - using propagation models, 83
  - Wi-Fi RSSI-based positioning
    - centroid method, 118–119
    - problem, 115
    - weighted centroid method, 119–120
  - Wi-Fi tracking, fingerprinting techniques
    - potentials and limitations of, 25–26
    - privacy-preserving
      - deterministic approach, 29–30
      - deterministic location estimation, 33–37
      - implementation and setup, 32–33
      - probabilistic approach, 30–31
      - probabilistic location estimation, 37–39
      - user movement, 39–40

Wi-Fi tracking, fingerprinting techniques  
(*Continued*)

researches on, 22–23

security mechanisms against

MAC address randomization, 27–28

protocol extensions, 27

technical background, 23–24

WLAN networks, integration of, 266–267

and BLE, 268

cloud architectures, 278–279

GNSS positioning, 270–276

inertial measurement units, 276

magnetic field navigation, 277

multimodal positioning, 278

and RFID, 268–269

signal of opportunity (SoO), 267–268

sound-based positioning systems, 277

visible light positioning, 277

vision navigation solutions, 277

**Y**

“You are here” (YAH) map, 170

**Z**

Zero velocity update (ZUPT) technique,  
220–221