Thema:

Design and implementation of a seamless indoor-/outdoor pedestrian navigation system

Bachelorarbeit

im Studiengang Software Systems Scienceder Fakultät Wirtschaftsinformatik
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Abkürzungsverzeichnis

IoT	Internet of Things
AP	Access Point
ToA	Time of Arrival
TDoA	Time Difference of Arrival
OTDoA	Observed Time Difference of Arrival
RToF	Round Trip Time of Flight
AoA	Angle of Arrival
RSSI	Received Signal Strength Identification
DR	Dead Reckoning
WPAN	Wireless Personal Area Network
GSM	Global System for Mobile Communications
LBS	Location-based Services
WLAN	Wireless Local Area Network
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
IR	Infrared
RFID	Radio Frequency Identification
BT	Bluetooth
SNR	Signal-Noise Ratio

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This paper is about indoor outdoor transitions.

1 Introduction

Seamless indoor-/outdoor (I/O) positioning forms a backbone for numerous upcoming applications: not only for ubiquitous Location-based Services (LBS) like navigation, but also with regard to (wrt.) several Internet of Things (IoT) areas such as in sports, *Smart Healthcare* and *Industry 4.0*.

The fact that people spend between 70% and 90% of their lives indoors (Kalliola 2008) and the emergence of new applications in the area of navigation, decision making and connection of devices might explain the high valuation of the indoor localization market in the coming years. While determined to be at 7.11 Billion in 2017, the forecasts vary between USD 29.4 Billion (reports 2018) and USD 40.99 Billion (Markets and Markets 2017) in 2022, and even USD 58 Billion in 2023 (KBV-Research 2017).

There are various applications conceivable: they range from apps providing location-based traffic and whether information up to emergency systems informing hospitals in case of detected accidents and navigating attending physicians to injured persons, or navigation systems guiding people through complex, large buildings like airports, leisure parks or university campuses.

I/O navigation services require smooth interaction between indoor and outdoor positioning technologies, including a handover strategy for switching between them. That is because outdoor localization technologies are mostly not able to provide satisfying accuracy indoors and vice versa.

Although there are several choices for outdoor localization technologies, most system designers select the (almost) ubiquitous Global Navigation Satellite System (GNSS) technology for outdoor positioning due to its ubiquity, reliability and precision.

GNSSs can also be applied in some special indoor cases:

for example, if persons reside close to windows or in areas where the sky is partially visible (Eissfeller et al. 2005). But in most cases it is not available indoors and people can typically expect signal loss on entrance.

Historically, GNSS-assisted localization has been developed independent but in paralell by the US Department of Defense (GPS NAVSTAR) and the russion federation (Glonass) in the mid 1970's and was first operational in the early 1990's ((Mai 2017); (Cosmos-Indirekt 2017)). In 1996, researchers published the paper "Global Positioning System: Theory and Applications, Volume I", informing about GPS fundamentals like physical and technical concepts and applicable algorithms, and being basis for further research and economical interest in this area. In May 2000, the U.S. government switched off the Selective Availability (SA) interfering signal, which basically made GPS not publicly applicable due to a approximate error of 100m.

Building on those achievements, and the development and dissemination of the WLAN technology, fundamental research in the field of indoor localization has been carried out by Bahl and Padmanadhabhan in 2000 ("RADAR: An In-Building RF-based User Location and Tracking System"), Chen and Kobayashi in 2002 (SSignal Strength Based Indoor Geolocation"), and in 2009 by Tan et al. ("Positioning techniques for fewer than four GPS satellites"), Li and Rizos ("Positinoning where standard GPS fails") and Gallagher et al. ("Wi-Fi + GPS for urban canyon positioning"(Gallagher et al. 2009)).

According to various authors, best practice for seamless positioning is hybridization of GPS and at least one other indoor positioning technology, such as WLAN ((Gallagher et al. 2009), (Hansen et al. 2009), (Atia et al. April 2012)). The used datamodel has to meet challenges origining from the combination of multiple technologies, e.g. supporting different levels of granularity and the ability to handle both symbolic indoor coordinates as well geometric GPS coordinates. Chapter 2 focuses on those and other challenges.

Indoor positioning systems typically make use of WLAN, because the required infrastructure is either already provided in most buildings or can easily be installed. Also Bluetooth, Ultrasound and RFID represent applicable technologies, but they have several drawbacks like the need for additional hardware. The evaluation in Chapter 4d) provides a more detailled overview to the individual pros and cons of positioning technologies.

Localization methods such as triangulation and fingerprinting form the algorithmical backbone for positioning and use provided information to calculate or estimate a person's most likeliest position. Their difference in complexity, applicability and calculation effort and cost will also be evaluated in Chapter 4.3.

This work arised from the idea of the *Living Lab Bamberg*, which is an open research and development environment for sensor-based applications in the domain *Smart Cities*, established at the University of Bamberg and other local stakeholders. The prototype designed in this work constitutes a demonstrator for how seamless, predestrian, I/O navigation with different technologies could be realized in a simple but extendable manner, and thus represents an environment-friendly solution to our cities' last-mile problem. Besides that, an user-supported alternative to high precision solutions is proposed.

Obviously, methods and technologies presented in this work could also applied to localize objects or robots, or measurement accuracy could be improved using artificial intelligence or mathematical models like Kalman filters, but those fields' focus is on other aspects like always improving accuracy and will therefore not be part of this work.

The aim of this work is to give an overview to the field of I/O positioning with a special focus on how seamless navigation indoors and outdoors could be realized and implemented. Therefore, first current outdoor- and indoor positioning technologies as well as suitable methods, data models and I/O transition solutions are presented and evaluated. Subsequently, an indoor/outdoor pedestrian navigation system prototype is implemented based on that evaluation's findings. Finally, the prototype's navigation results are presented and evaluated. The findings are then summarized and flown in future work proposals.

Key questions this work provides answers to are:

- Which techniques, methods and datamodels are available to provide seamless indoor/outdoor transisions in pedestrian navigation systems?
- Which hybrid localization approaches are promising?

- What is the best time and strategy for switching of positioning technologies?
- How could a flexible and expandable datamodel be designed?
- Which possibilities exist to overcome low indoor accuracy in navigation apps?

The rest of this paper is structured as following:

Chapter 2 gives deeper insight to the challenges coming up with hybrid navigation systems. In Chapter 3 related work in this area is reviewed. The technical background including technology and method assessment is filling Chapter 4. Design and implementation of the navigation prototype is presented in Chapter 5. The evaluation of positioning and navigation results is then worked up in Chapter 6. Finally, Chapter 7 gives an outlook to possible future works in the field and concludes this work.

2 Challenges wrt. Hybridization

Facing the need for hybridization in seamless I/O navigation systems, system designers have to conceive and construct solutions for multiple challenges. This section gives an overview to the main challenges and possibly occuring problems in this field.

1. Technology selection:

   First of all, the selection of suitable technologies: There is a spread of technologies available for indoor and outdoor positioning, such as WiMAX, GPS and CellID (GSM) for outdoors and WLAN, Bluetooth, RFID, NFC, Infrared, Ultrasound, ZigBee, Z-Wave etc. for indoors. Outdoor positioning technologies typically require clear sky view for optimal positioning, as walls and steal in buildings attenue the signals by the 100-1000 fold. It is thus necessary to evaluate the technologies' advantages and disadvantages wrt. their suitability to the respective requirements.

   Mostly, a single technology is insufficient for seamless I/O positioning: on the one hand, outdoor technologies are either not available indoors or do not provide satisfactory accuracy. On the other hand, indoor positioning technologies require configuration and/or installation of hardware and are thus only available (and reliable) in presence of sensors. Regarding this fact, various other challenges arise, such as the

2. Determinition of handover strategies:

   Positioning systems need a strategy to decide which technology to trust more in case both indoor and outdoor positioning signals are available. Multiple variants are conceivable, e.g., one could either consequently only use one of the available technologies, or use mathematical functions like the mean of all received positioning results origining from both indoor and outdoor technology. Also solutions assigning weights to the measurements in different, predefined situations are imaginable, but this would require elaborate pre-configuration for every building (and the area around it). (Hansen et al. 2009) reveals that a strategy where GPS is prefered over WLAN uppon continuous readings (in intervals of five seconds) performs more accurate than use one of both until signal loss. The main drawback of the 'use GPS or WLAN until signal loss' strategy, for example, is that WLAN signals are typically available outdoors for a long distance but with a remarkable worse accuracy and reliability than GPS would provide.

3. A common datamodel:

   In order to combine GPS with an indoor localization technologies like WLAN, Bluetooth and RFID, a common datamodel has to be implemented which has to include different levels of granularity. It has to support various types of symbolic indoor spaces (coordinates), i.e., the differing between building parts like entrances, floors, corridors, rooms, stairs, elevators and possibly more entities, which all shall be annotatable with semantic information like naming and spatial relations and distances to other entities and other specific attributes. Additionally, the model has to include geometric GPS coordinates, i.e. measurement values indicating latitude, longitude, and altitude of buildings for outdoor positioning.

4. Method selection:

   Like for technologies, there is a need for evaluation of localization methods, as they different properties also aim at different areas of application. According to (Farid et al. 2013), fundamental aspects in method selection are accuracy, coverage, the requirement for line of sight, the affection by multipath and cost. It can be obeserved that there is a tradeoff between cost and accuracy: the article reveals that methods like Time of Arrival (ToA) and fingerprinting, for example, provide high accuracy at medium to high costs, whereas dead-reckoning and proximity detection require low costs, but also typically provide low accuracy.

5. Navigation requirements:

   For outdoor navigation issues one could easily use the road network detected by GPS, but for indoor approaches spatial relations like containment, adjacent entities and distances between entities have to be explicitly modeled. Also the different movement patterns, i.e. walking, taking stairs or the elevator, with their specificly required time shall be considered. For further refinement one could provide semantic information like accessibility, barrier liberty or the room type.

6. Positioning strategy evaluation:
   The determinition of which positioning strategy to use highly depends on a system's requirements: in case security and privacy is essential, all positioning calculations have to be done on client-side. In contrast, if a real-time monitoring of all entities in a certain area is required, a server-based approach is a better option. Another alternative represent cooperative strategies where positioning is based on other entities' signals (i.e. not only from satellites and APs). The respective advantages and drawbacks are discussed in Section 4.

3 Related Work

This section presents and assess related works covering indoor/outdoor navigation and datamodels. Their respective drawbacks are determined and their approaches delimited in relation to this work.

The research area of indoor and outdoor positioning technologies and methods also forms part of this work, but this area is already explored sufficiently in recent years by various other researchers ((Maghdid und Lami 2016); (Gu et al. 2009); (Farid et al. 2013)), such that no prototyping and testing is required anymore and one can use their well-confirmed evaluation results.

Among others surveying different technologies and methods for indoor positioning systems, (Gu et al. 2009) covers an evaluation of systems wrt. the criteria security and privacy, cost, performance, robustness, complexity, user preferences, commercial availability, and limitations. However, the authors' focus is on indoor localization only, aspects like I/O transitions or hybridization are ignored. Also, they have only regard to existent systems and used technologies and methods are not included in any evaluation tables, such that there is no satisfying overview to the systems' most relevant components (on one page).

In contrast to the survey discussed before, the authors of (Farid et al. 2013) examine single technologies like GPS, Infrared, WLAN, Ultrasound, RFID, BT, ZigBee and FM regarding the criteria accuracy, applicable positioning methods, coverage, power consumption and cost. Methods are evaluated wrt. measurement type, indoor accuracy, coverage, the requirement for line of sight, multipath affection and cost. Nevertheless, topics like hybridization of methods or combination with GPS technology and seamless IO transitions are not discussed.

Some authors treating I/O transition only focus on single technologies and methods like (Xia et al. 2017) (fingerprinting) and (Török et al. 2014) (dead-reckoning), or basically only present their system design like in (Zhu et al. 2019) (machine learning approach), such that their foundings can not (or only partially) be used for a sensible overview and assessment of technologies and methods.

I/O transitions are also topic in (Kray et al. 2013), but they focus on finding and presenting examples for transitional spaces and their properties only, and a answer to the question how to integrate this knowledge into a positioning system is not provided.

A comparison of existent systems can be found in (Jinlong et al. 2013), but there only four existing systems are presented, which does not even yield a sensible overview - other authors assess more than ten solutions (Maghdid und Lami 2016). Also, existing technologies, methods and transition strategies are poorly described - and a series of them even completely omitted.

Fortunately, various authors also provide sensible overviews to indoor/outdoor transitions, such as (Hansen et al. 2009), who worked out and evaluated four different strategies for transition in I/O positioning with WLAN fingerprinting and GPS: 1) always prefer GPS, 2) always prefer WLAN, 3) prefer GPS until lost signal, then prefer WLAN until lost signal and 4) prefer GPS upon continuous readings (until signal loss of five seconds). The authors conclude that strategy 4) is the most precise and reliable solution, which is also confirmed by (Jinlong et al. 2013). However, they do not assess other technologies and methods, specially hybride low-cost approaches like with RFID or BT technology and approaches focusing on minimal configuration are left out. Furthermore, their system design is ineffizient, cause as soon as users pass a building (and do not enter it) its indoor radio map is downloaded, which could possibly lead to massive overhead. This work's Section 4.2.1 gives deeper insight to drawbacks of the WLAN fingerprinting solution.

(Maghdid und Lami 2016) discusses available indoor positioning systems, outdoor positioning systems and also hybride approaches being able to seamlessly locate smartphones inside and outside buildings. Different technologies, methods and their combinations are also part of discussion. The authors claim aspects like poor performance or accuracy, the absence of a plattform for integrating multiple positioning solutions, and demand infrastructureless, cooperative solutions and hybridization of methods and technologies in combination with sensor fusion and Kalman filters.

However, they do not implement their own positioning system and focus on evaluating other solutions. Their aim is to identify weaknesses and opportunities and upcoming challenges wrt. seamless and precise IO positioning.

Another related work is (Kim et al. 2012), where the handover from GPS to an indoor localization technology is faced. The authors experimentally found that GPS signal loss might be an insufficient indicator to mark outdoor/indoor handover points. The Signal-Noise Ratio (SNR) is rather a better choice, as SSNRs of the specific satellites rapidly decrease around building entrances". This refers to the fact that satellites at elevation of 30-90 degrees show significantly higher SNR drop when entering a building than those at 0-30 degrees (sometimes even no significant changes are apparent). SNR does not provide any significance in case of indoor/outdoor handovers, as the values it supplies outdoors are almost equal to values measurable indoors near windows. In this case, GPS accuracy attribute turned out to be decisive. More details on their foundings and other GPS fundamentals are rehashed Secton 4. Unfortunately, they do not evaluate the aid of indoor localization technologies and methods and other possibilities to determine the best handover time and only focus on GPS technology. In addition, their current system design is worthy of improvement: it requires a user to visit a respective building at least once before being fully operable. Cooperative strategies would represent a promising alternative to that issue.

Papers published in the past two years mostly use advanced methods like fuzzy logic, artificial intelligence (Iwata et al. 2018), sensor fusion (Wang et al. 2019) and extended Kalman or particle filters to overcome noisy measurements and improve accuracy. One of the drawbacks of such techniques is their complexity and high calculation effort, such that the required computing power can either not be provided on smartphones or is only feasible under massive energy consumption.

As shown in this section, some articles in this area only consider single technologies and methods but not hybridization (of methods or IO technologies) and IO transitions. Most papers also do not show an interest in presenting the invented datamodel for localization systems.

This work catches up with this issue and examines indoor-/outdoor transition and positioning strategies as well as relevant datamodels with the aim to provide proposals for various system requirements.

4 Technical Background/Technology Assessment

This section focuses on the technical background and theoretical foundations for I/O positioning systems. Advantages and disadvantages of single solutions are worked out to build a knowledge basis for the implementation of an I/O navigation prototype. This prototype shall be able to navigate users at an an address arbitrary location outdoors to a predefined location indoors, in this case a room at the university campus.

To fulfill this task the system needs several components, such as at least one indoor and one outdoor positioning technology, localization methods, an underlying data model and a transition strategy for positioning technologies. Representatives of those components are presented in the following and then evaluated at the end of this chapter wrt. their applicability. As this work focuses on the transition between outdoor and indoor navigation, for the prototype only one indoor and one outdoor technology is used. A combination of several technologies and methods would improve quality of positioning services (Patterson et al. 2003). Further system design considerations and decisions are part of the next chapter.

4.1 Positioning Methods

Localization methods can be used in combination with both indoor and outdoor technologies and form the algorithmical basis of every positioning system. Although GNSSs which uniquely make use of the ToA method, are the most promising solutions for outdoor positioning, the application of other methods outdoors is also conceivable and partially already in operation.

There exist several methods for position determination, such as *Proximity Detection*, *Dead-Reckoning*, the time-based methods *ToA* and *Round Trip Time of Flight (RToF)*, also refered to as *Trialateration*, *Fingerprinting*, *Map Matching* and *Particle Filters*. Their applicability depends on environmental properties and the required positioning accuracy.

Hint: The content of the following section 4.1 Positioning Methods *is extracted in reduced form from the author's last paper 'Indoor Localization - A Comparison of Different Methods and Approaches'*

Like depicted in Figure 4.1, there are three classes of methods: proximity detection, triangulation and scene analysis.

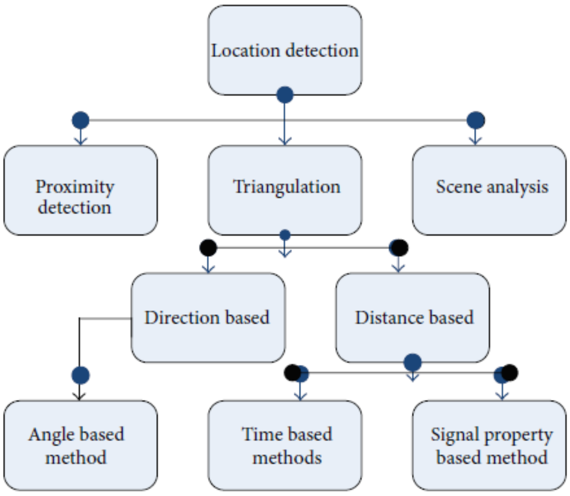

Abb. 4.1: An overview to indoor localization methods (Farid et al. 2013)

The later includes image- and video-based positioning, but also fingerprinting techniques that "first collect features (fingerprints) of a scene and then estimate the location of an object by matching online measurements with the closest a priori location fingerprints."(Liu et al. 2007b) Related to scene analysis techniques are map matching and particle filters. Triangulation can either be performed with the angulation or lateration methods. Proximity detection methods estimate a target's current position based on proximity to base stations or on movement patterns like Dead Reckoning (DR).

Proximity Detection

The proximity detection method is a very simple localization method where multiple detection sensors (like routers, Infrared (IR) or Radio Frequency Identification (RFID)) are used to mark proximity areas.

On detection, an object can be estimated to positioned in the detector's area. Whenever more than one sensor detects the same object, it is expected to be in the area of that sensor receiving the strongest signal. This process is also called 'forwarding'. An illustration of this method can be seen in Figure 4.2.

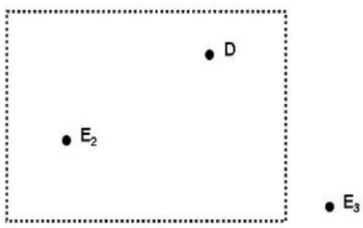

Abb. 4.2: The proximity detection method (Khudhair et al. 2016)

In case further or even global range is required, the cellular mobile Global System for Mobile Communications (GSM) network can be used to identify the radio station the device is allocated to (e.g. its cell-id). The observable is then expected to be in proximity to the radio station, hence in its cell. (Liu et al. 2007b, p.5) For this reason, this method is also called cell of origin or cell identification.

For both, indoor and outdoor localization, the method's accuracy highly depends on the "density of beacon point deployment and signal range"(Khudhair et al. 2016, p. 3). For improvement of accuracy, which is very limited in general, parameters like signal travel time can be included (see methods RSS, ToA and TDoA).

Triangulation

This family of methods is based on calculations on the properties of triangles. For location determination, the known position and distance of three or more base stations is used to locate an object. There are basically two derivations of triangulation, namely lateration, which subsumes time- and distance-based methods, and angulation.

There are several varieties of triangulation methods, e.g. angle-based, time-based and signal property-based methods (Farid et al. 2013).

4.1.0.1 Angulation - Angle-Based

In the angle, or Angle of Arrival (AoA)-based localization method, intersections of at least two lines of bearing are computed. Although angulation with two base stations could work in some cases, it is mostly implemented with three base stations to improve accuracy - then also called triangulation. (Farid et al. 2013) reveals that for "finding direction, it requires highly directional antennas or antenna arrays", which forms, despite the fact that they are very costly, a big issue for indoor localization. Interferences origining from entities (people, walls, other signals) in indoor environments distort measurement values and result in erroneous position calculation. In (one of the rare) cases the signals remain uninterferenced, this technique would bring excellent accuracy. Figure 4.3 shows basic operations with that method.

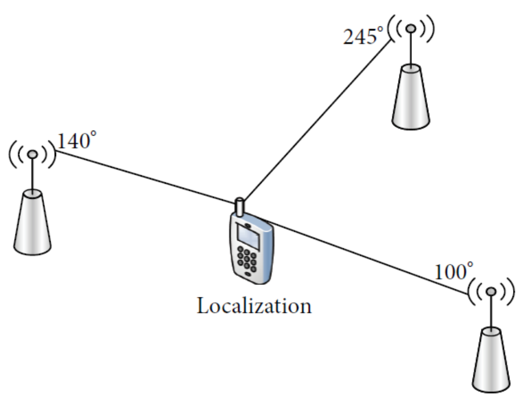

Abb. 4.3: The angle-based method(Farid et al. 2013)

4.1.0.2 Lateration - Time-Based

Lateration methods calculate ä position determined from distance measurements"(Farid et al. 2013), either relying on abolute or relative travel time. Unlike to angulation, lateration with two base stations does not bring any significance: like depiced in Figure 4.5, two hyperbolic shapes (here simplified as cycles) always have two intersection points such that an exact position can not be determined. Thus, lateration methods are implemented with three or more base stations, then refered to as trilateration or multilateration.
All methods share the assumption that electromagnetic waves propagate with the same speed as light (∼300.000 km/second).
There are four approaches:

- ToA:
  This method requires all nodes in the network (object under observation and receiving stations) to be highly synchronized at any time. The localization process starts at client side, where a timestamped signal is emitted and received by multiple base stations. The single distances d_i are computed using absolute travel time t and the assumed propagation speed c:
  Assume
  $$t_i = t_{\text{receive}_i} - t_{\text{send}}$$
  with t_{send} as sending and t_{receive_i} as time of arrival at receiver station i, then
  $$d_i = t_i * c\ .$$
  Observing the equation, it can be seen why precise synchronization is an absolute requirement for this method: due to constant c being that high, even small discrepancies in time can result in a completely different distance.
  Due to time-based signals are not directed in any way, an object must be located anywhere on a circle around the receiver station, with a radius of the computed distance. The intersection of those circles is then the most likeliest position. The TOA method using three base stations is shown in Figure 4.4.

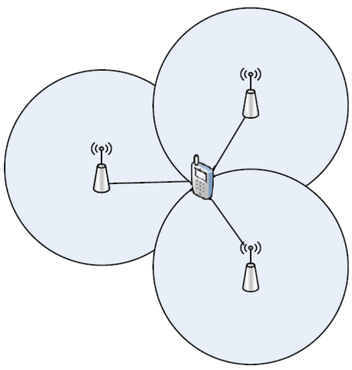

Abb. 4.4: The RToF/TOA method (Farid et al. 2013)

- Observed Time Difference of Arrival (OTDoA):

This time-based method, also called multilateration, infers positions by using relative arrival times captured by at three time-synchronized base stations with known location. A signal's OTDOA at the base stations can also be converted to a distance:

$$D = OTDOA * c$$

For example, regarding two base stations BS1 and BS2, an OTDOA of +3.3 μs would indicate, that BS1 is 1000m closer than BS2. There are infinitely many points where the transmitter is exactly D entities closer to the one base station than to another. Combining those points results in a hyperbolic shape. The intersection of multiple hyperbolic curves then represents the most likeliest position of the transmitter. The OTDOA method is illustrated in Figure 4.5, on which the bespoke hyperbolic curves are depicted in green.

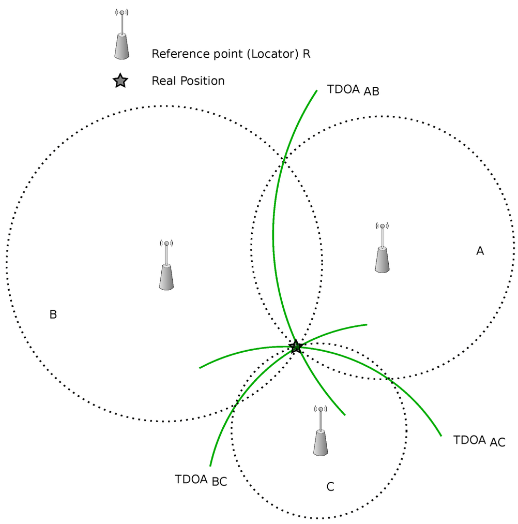

Abb. 4.5: The observed time difference of arrival method(et. al. 2016)

- Time Difference of Arrival (TDoA):
  TDoA makes use of at least two different technologies, or rather their different propagation times, and relative arrival times. In many systems, electromagnetic and ultrasound waves are used, such as in (Yang et al. 2012). A mobile client simultanously emmits signals using both technologies. At receiver side, the (relative) difference of arrival times and the actual phase difference are used to compute the distance. (Priyantha et al. o. J.)

- RToF:
  Similary to ToA, the RToF method uses absolute time to localize objects. The only difference is that the RtoF method uses rount trip time, i.e. the time required to send a message from mobile transmitter to receiver station and back to transmitter, instead of only the time required to send and receive once. In case interferences occur only in one of the two transmissions, averaging can be applied, such that this method can supply a more accurate positioning result than ToA. Obviously, the above kinds of lateration could also be combined with RtoF method in order to improve positioning accuracy. Also,

positioning calculations could then be done on client-side. The method is depicted in Figure 4.4.

4.1.0.3 Signal Property-Based - Received Signal Strength Identification (RSSI)

Besides regarding time as mayor indicator for distance, the received signal strength indicator (RSSI) approach focuses on a technology's propagation model. The distance to a sending point can then be estimated based on inverse-square law:

$$intensity \sim \frac{1}{distance^2}$$

Assuming an isotropic source (like APs or routers), the intensity of the emitted signal is inversely proportional to the square of the distance. Figure 4.6 illustrates this relation: in nearby areas, the intensity (illustrated with red arrows and red dots in the single areas), is significantly bigger than in marginal areas.

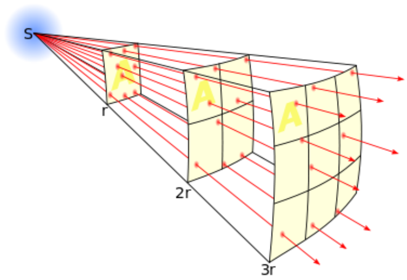

Abb. 4.6: The inverse square law used in signal property-based methods(*Image source:* o. J.a)

As in other trilateration techniques, the single distances from a mobile client to the base stations form circles around them, whose intersection finally represents the positioning result. The signal property-based method with just a single base station is depicted in Figure 4.7.

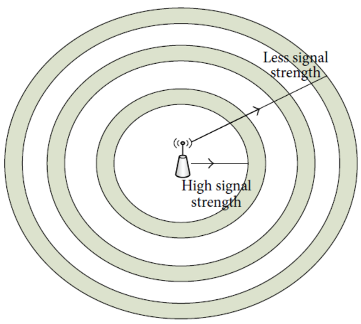

Abb. 4.7: Signal property-based lateration (Farid et al. 2013)

Dead Reckoning (DR)

Another very simple but widely used method is *Dead Reckoning*, where localization is "based on last determined position and incrementing that position based on known or estimated speeds over elapsed time"(Farid et al. 2013). The result can thus only result in an estimation of the current position. Furthermore, ïnaccuracy of the process is cumulative, so the deviation in the position fix grows with time"(Farid et al. 2013). DR is also implemented in inertial navigation systems and is employed when GPS signal is lost, e.g. in tunnels.

For indoor purposes, according to (Pratama et al. o. J.), accelerometer sensors in smartphones or attached sensors modules can be utilized to obtain the travelled distance, where distance estimation is then based on steps detected and the direction obtained by the magnetic sensor. Besides this orientation projection, the overall localization process includes "filtering, step detection and step length estimation"(Pratama et al. o. J.). As gravity and noise interferences accelerometer measurements, the values are filtered using physical constants and formulas, which will not be explained further here but can be looked up at (Pratama et al. o. J., p.3). Step detection can either be performed with zero-crossing or peak detection, whereas the later uses local maxima of the curve emerging from accelerometer measurement values. Unfiltered, all maximas were considered as steps, such that thresholds for further filtering are applied: all values under a certain threshold and also those not fitting in a typical time intervals of steps while walking (120ms – 400ms, according to (Pratama et al. o. J.)) are rejected.

An exemplary measurement result with three valid steps detected (depicted in blue) and the threshold (in red) is illustrated in Figure 4.8.

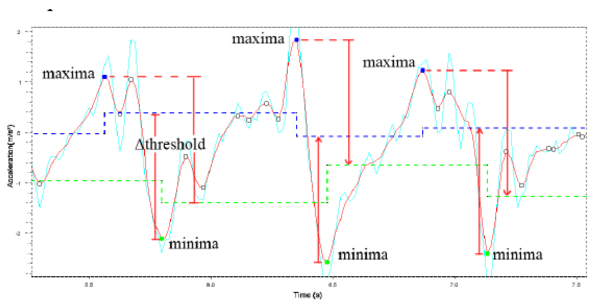

Abb. 4.8: An exemplary DR measurement result with three steps detected (Pratama et al. o. J.)

Zero-cross detection announces a step whenever the x-axis is crossed within a typical time interval (see peak detection). Obviously, this process is very errorprone, especially when step-size or -interval change.

Last step in the process is step length estimation. Besides some dynamic methods, which can be looked up in (Pratama et al. o. J.), the static approach uses a person's height and a gender-specific constant:

$$stepSize = height * k$$

with "k equal to 0.415 for men and 0.413 for women."(Pratama et al. o. J.)

Map Matching

The Map Matching method makes use of a building's roadmap and (mostly noisy) localization samples, such that "building information provide a logical threshold to bound the solution into a certain region"(Attia et al. 2014). Thus, a system is able to return valid positions somewhere on the floor plan, even if the real measurement values diverge.

As nowadays most big buildings are equiped with many rounters or Access Point (AP)s, map matching positioning samples mostly origin from WLAN signal strength values. The required electronic map can either be designed in a floor plan builder or generated automatically using crowd-sourced data samples.

There is a variety of applicable algorithms and data models such as graph- and link-based or room- and floor 3D-models. In the link-based approach, an ID and respective coordinates are assigned to each room. Map matching algorithms typically origin from the following types: 1) geometrical, where the shortest distance from a measurement point to a trajectory is calculated, 2) topological, where links, i.e. the floors own attributes like "floor number, proximity of a height change access, stairs, and all possible links diverged from its start and destination nodes"(Attia et al. 2014), 3) probabilistic, where a target's direction and speed is considered (i.e. DR) and 4) sophisticated methods using fuzzy logic, belief theory and Bayesian networks. Figure 4.9 shows a typical map matching navigation result with floorplan in black, measurement values in blue and map matched path in red.

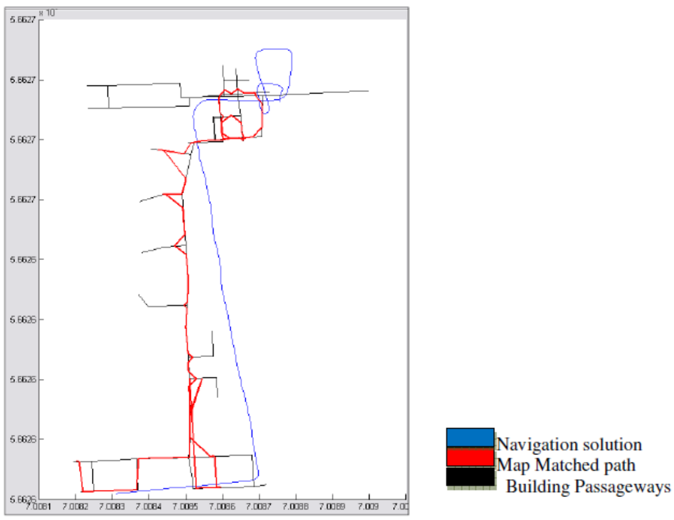

Abb. 4.9: A typical map matching navigation result (Attia et al. 2014)

Fingerprinting

Fingerprinting can be seen as an extended version of the RSSI method, where a database and further positioning algorithms are added to improve accuracy. The overall process is splitted into two parts, namely training (calibration, offline) and tracking (localization, online) phase. The basic idea in the training phase is to "collect features of the scene (fingerprint) from the surrounding signatures at every location in the areas of interest and then build a fingerprint database"(Farid et al. 2013). In the tracking phase, a mobile client requests all base stations in its region to reply to its positioning query. The strengths of signals received by the client can then be compared with those in the database, resulting in the closest known position.

A mobile device could for example collect WLAN signal strengths from different APs at every point of interest in a building and safe them together with actual location in a database. During online phase, current RSSI measurements can be mapped to known locations.
The overall process is illustrated in Figure 4.10.

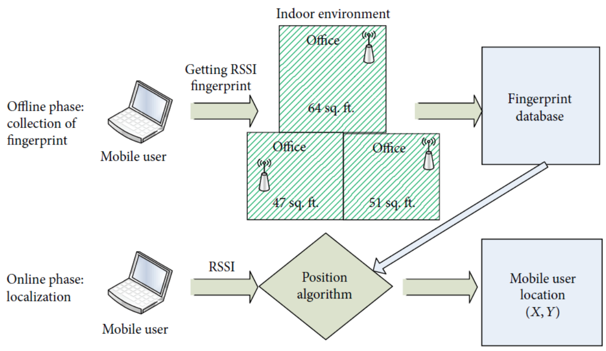

Abb. 4.10: The location fingerprinting process (Farid et al. 2013)

Particel Filters

Particel filter method represents a class of hybrid methods combining the advantages of DR and Map Matching with sequential Monte Carlo approximations.(Davidson et al. o. J.)
The idea is to use randomly distributed samples - so-called *particles* to represent all possible positions of an object. Based on any available information, e.g., pre-configured floorplans, motion profiles and laws of physics (e.g., targets move away with a well-known speed throgh buildings and can not go through walls, etc.), a *weight* or probability is assigned to each particle. The next step is *resampling*: Whereas unlikely particles are removed, those with enough weight are re-distributed according to their density and weight. The resampled particle set is then relocated based on the motion model. In order to eliminate noise in the resulting set, the particles are again distributed among the now likeliest places (see step *Diffuse* in Figure 4.11) and finally weighted based on available DR (and possibly additional) positioning information. That location showing the highest probability density is then the particle filtering positioning result.

The overall particle filtering process including subprocesses is depicted in Figure 4.11.

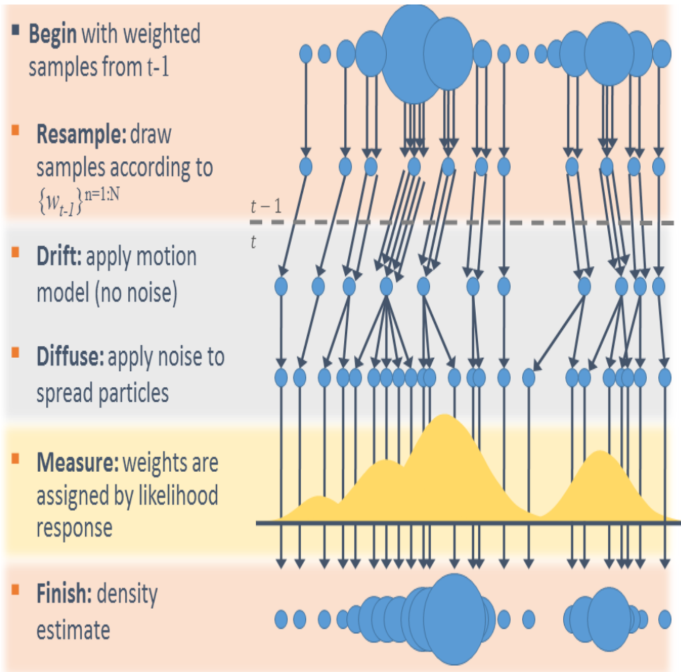

Abb. 4.11: The processes involved in particle filtering (*Image source:* o. J.b)

4.2 Outdoor Positioning

This section is about the outdoor positioning technologies GNSS, WiMAX and cellular networks. GNSSs are on the rise and only global solution, but other technologies are also capable to provide localization services in limited outdoor areas. Although their main drawback, limited coverage, makes them hardly applicable in a global context. Besides that a globally networked installation fails due to its inapplicability in many places at earth (oceans, high mountains or deep valleys), also the required density and amount of base stations to reach comparable coverage and accuracy to GNSSs is technically and monetarily inconceivable.

GNSS

Global Navigation Satellite Systems provide positioning functionalities with global range for navigation, emergency rescue and other applications of public and military use to land, air and water.

As already briefly outlined in Section 1, the only fully operational and most popular GNSS is NAVSTAR (Navigational Satellite Timing and Ranging) Global Positioning System (GPS). It was developed by the U.S. DoD since 1973 until being fully operational in 1995. Besides GPS, there are various other GNSS approaches, such as China's Beidou (Kompass), India's IRNSS (Indian Regional Navigation Satellite System) Russia's Glonass and E.U.'s Galileo. (Link 2018)

GPS is applied in social, economic and scientific areas. Typical applications range "from spacecraft navigation and geodesy, to land surveying and mapping, to precise agriculture and vehicle fleet management, to emergency services and professional navigation, to mass market applications such as in mobile devices (cars and smartphones) and location based services (LBS)."(Li et al. 2010)

The common concept of all GNSSs are interconnected, clock-synchronized satellites (mostly more than 20) and ground stations such that trilateration (ToA) with a radio signals (GPS L1 signals: 1575,42 MHz) and calculations respecting the doppler effect are applicable. By that, an accuracy of 2-500m can be achieved.

General information about exact satellite orbits, statuses, clock deviations and atmospheric data is summarized under the GPS Almanach. Clients with corresponding GPS receiver can download this Almanach and start positioning. The Almanach is mostly receiced over the GSM network, as downloads directly from the satellite might take several minutes and is thus not applicable.

Whereby other trilateration methods calculate positions using distances to three base stations, GPS uses the Time-of-Arrival method which requires clock synchronization in all entities and thus four satellites: As the clocks on receivers like smartphones might differ form those on satellites, a fourth satellite is required to deal with that synchronization task. (Maghdid 2015, p. 58)

The geomatric position of used satellites is also an important factor: if satellites rely closed to each other, the intersection line is larger and positioning more imprecise (see ToA method section). Thus, in order to inform about such positioning deteriorations, every GPS signal carries the so-called dilutions of precision (DOP) which is calculated wrt. geometric, horizontal and vertical orientation. Values ranging from 1 to 6 indicate good precision, signals with DOP higher than 10 are basically not evaluable.

Every satellite emitts a radio signal including timestamp and individual code, which can then be received by e.g. smartphones or car navigation systems. All positioning calculations are thus performed on client-side. In order to be synchronized and precise, satellites are mostly equipped with multiple, frequently updated atomic clocks, such as Galileo satellites with two passive hydrogen maser clocks (deviation of 1s/3 mio years) and, alternatively, two rubidium atomic clocks (1s/760.000 years).

Accuracy and functioning of GNSSs has also its limits and is susceptible to faults. Occuring issues are clock deviations, cheap (inaccurate) GNSS receivers on smartphones or navigation systems, ionospheric disturbances leading to angle change of signals, change of satellite constellation (less/other satellites available), signal reflection and multipath issues.

A Satellite-based augmentation systems (SBAS), such as the European Geostationary Nevigation Overlay Service (EGNOS) can be used to improve accuracy: reference stations deployed across the area of interest report all measured GNSS errors to base stations, where errors are collected, processed and send to geostationary satellites. The satellites then broadcast the augmentation information as overlay to the origninal GNSS message. (*What is EGNOS?* 2018) Inside and around buildings GNSS signals are not or rarely available. (Eissfeller et al. 2005) state that in houses there is an attenuation of 5-15dB (4-20 fold), in offices around 30dB (1000 fold) and in underground parking over 30dB. They conclude that signal acquisition through concrete walls with 25dB attenuation and more is not possible without further assistence.

WiMAX

This technology is part of the IEEE 802.16 protocol family and like WLAN (IEEE 802.11) a radio technology. Unlike WLAN, WiMAX (Worldwide Interoperability for Microwave Access) can operate at "higher speeds, over greater distances and for a greater number of users"(Brain und Grabianowski 2004).

In particular, this technology works with partially interconnected base stations which are connected to the internet via high bandwidth, wired connection and are wireless accessible by receivers within a cell radius of three to ten kilometers (WiMAX Forum 2019).

The overall functioning is illustrated in Figure 4.12.

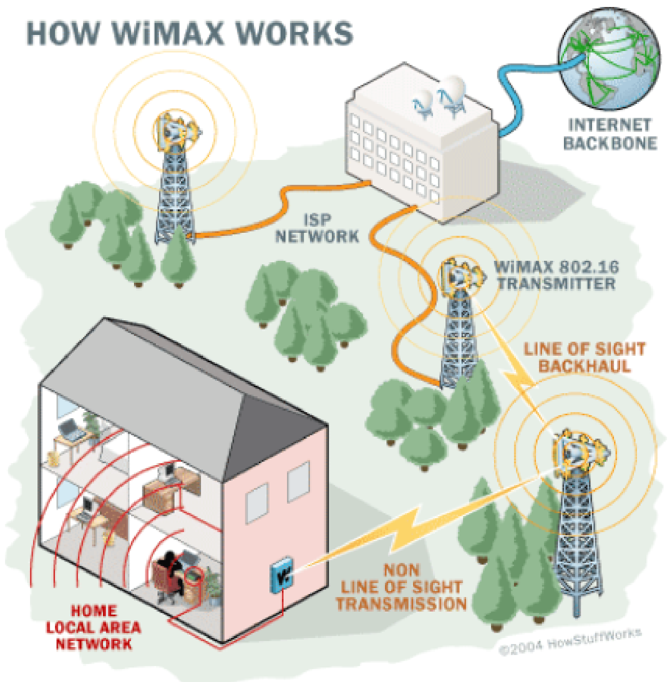

Abb. 4.12: How WiMAX works (Brain und Grabianowski 2004)

There are two modes of operation: Line-of-sight and non-line-of-sight, whereas the former sends at higher frequencies (licenced 2-11 GHz and unlicenced 10-66 GHz) and is thus more stable and offers lots more bandwidth (Brain und Grabianowski 2004). By that, wireless internet access in rural areas and small cities can be provided, and can even deep indoors be accessed, e.g. with receiver stations on buildings acting like as repeaters.

Cellular Networks/GSM

Cellular networks such as mobile GSM networks for telecommunication are organized in cells of different size. In general, positioning in those cells is done with distance-based methods and is thus, due to the base stations' high distance, not very percise (25-100m whenever there is good coverage). Cellular-based positioning is also possible in combination with triangulation and high-directional antennas.

Nevertheless, researchers found that accuracy with GSM could also be improved to up to 2.5m indoors using wide signal-strength fingerprints of up to "29 additional GSM channels, most of which are strong enough to be detected but too weak to be used for efficient communication."(Liu et al. 2007a)

4.3 Indoor Positioning

This subsection presents various indoor positioning technologies and methods. Whereas outdoor positioning typically relies GNSSs, indoors other technologies, such as WLAN, Bluetooth, RFID and Ultrasound can provide much higher accuracy.

WLAN

Wireless Local Area Network (WLAN) (IEEE 802.11) was standardized in 1997 and is the most popular midrange local wireless networking technology. Its infrastructure, i.e. routers and APs, is usually provided in most buildings. WLAN devices operate at 11, 54, or 108 Mbps and have a typical range of 50-100m.

The most applied method with WLAN are signal-strength-based methods, such as RSSI and fingerprinting. Time- and distance-based methods are "less common in WLAN due to the complexity of time delay and angular measurements"(**?**). The accuracy of positioning systems using RSS can vary from "3 to 30m, with an update rate of a few seconds"(Liu et al. 2007a). However, most systems can provide accuracy of less than 5m (Maghdid und Lami 2016), such as RADAR which was invented by a Microsoft research group in 2000 and provides 2-3m accuracy using "signal strength and signal-to-noise ratio with the triangulation location technique"(Gu et al. 2009).

Bluetooth

Bluetooth (IEEE 802.15) is a wireless Wireless Personal Area Network (WPAN) standard operating at the 2.4 GHz ISM band. It offers "high security, low cost, low power and small size"(Farid et al. 2013) but has, compared to WLAN, also a smaller range of 10m to 15m and lower bit rates of 1 Mbps (Liu et al. 2007a). Localization with Bluetooth works with small transceivers, called tags, which have unique IDs that can be used for localization.

The main drawback of Bluetooth-based positioning is the lengthy positioning process which requires Bluetooth (BT) device discovery to be processed. As this step takes several seconds (10-30), it is unsuitable for real-time approaches (Farid et al. 2013). Also pre-installation of tags in various points of interest is required. Nevertheless, indoor navigation with Bluetooth tags is a lightwight alternative to WLAN or Ultrasound.

RFID

The RFID technology works with wearable tags, radio waves and a network of scanning devices covering a small area. RFID readers can read emitted data from tags which are available in two variants, active or passive. The former are battery-driven transceivers and are mostly applied in combination with proximity detection, as most of the tags are limited in range. But there are also tags which can transmit signals over tens of meters (Liu et al. 2007a), such there is basically any positioning method applicable. The RFID technology offers three different frequencies: low (125-134 kHz), high (13.56 MHz) and ultra-high frequency (860-960 MHz) and can thus successfully operate at non-line-of-sight environments (Khudhair et al. 2016).

Passive tags act as replacement for traditional barcode technology. They have no battery and thus only "reflect the RF signal transmitted to them from a reader and add information by modulating the reflected signal"(Liu et al. 2007a).

The main drawback of the RFID technology is its limited range of low and high frequency, the need for a tag to be carried along and the required installation of receivers.

Ultrasound

Another positioning technology is Ultrasound

4.4 Datamodels for Indoor Localization

Set-based

Hierarchical

Graph-based

Combined

4.5 Indoor-/Outdoor Transition Solutions

Use GPS or WLAN until signal loss

prefer WLAN over GPS

prefer GPS until signal loss (of 5s)

vision/ user interaction-based approaches

use SNR and GPS accuracy, dependent on going indoors or outdoors

4.6 Assessment and Conclusion

Methods

(Khudhair et al. 2016) methods comparison

RFID is, compared to BT more applicable for real-time apps. (Farid et al. 2013): evaluation tables:

Method	Measurement type	Indoor accuracy	Coverage	Line of sight (LOS)/nonline-of sight (NLOS)	Affected by multipath	Cost	Notes
Proximity	Signal type	Low to high	Good	Both	No	Low	(1) Accuracy can be improved by using additional antenna. However, it will increase the cost. (2) Accuracy is on the order of the size of the cells.
Direction (AoA)	Angle of arrival	Medium	Good (Multipath issues)	LOS	Yes	High	(1) Accuracy depends on the antenna's angular properties. (2) Location of antenna must be specified.
Time (ToA, TDoA)	Time difference of arrival	High	Good (Multipath issues)	LOS	Yes	High	(1) Time synchronization needs. (2) Location of antenna must be specified.
Fingerprinting	Received signal strength	High	Good	Both	No	Medium	(1) Need heavy calibration. (2) Location of antenna is not necessary.
Dead reckoning	Acceleration, velocity	Low to medium	Good	NLOS	Yes	Low	Inaccuracy of the process is cumulative, so the deviation in the position fix grows with time.
Map matching	An algorithm based on algorithms based on projection and pattern recognition	Medium	Medium (indoor) Good (outdoor)	NLOS	Yes	Medium	(1) Map matching purely focus on algorithms and not fully on position methods, coordinate transformation, and geocoding. (2) Using pattern recognition, high computing complex and poor real time issue occur.

Abb. 4.13: Evaluation of positioning methods wrt. accuracy, coverage, multipath affection and cost (Farid et al. 2013)

System	Accuracy	Principles used for localization	Coverage	Power consumption	Cost	Remarks
GPS	6 m–10 m	ToA	Good outdoor Poor indoor	Very high	High	(1) Satellite based Positioning. (2) Processing time and computation is slow.
Infrared	1 m-2 m	Proximity, ToA	Good Indoor	Low	Medium	(1) Short range detection. (2) No invasion of multipath.
WiFi	1 m–5 m	Proximity, ToA, TDoA, RSSI Fingerprinting, and RSSI theoretical propagation model	Building level (outdoor/indoor)	High	Low	(1) Infrastructure available everywhere. (2) Initial deployment is expensive. (3) Multipath susceptible slightly.
Ultrasound	3 cm–1 m	ToA, AoA	Indoor	Low	Medium	(1) Sensitive to environmental. (2) No invasion of multipath.
RFID	1-2 m	Proximity, TOA, RSSI theoretical propagation model	Indoor	Low	Low	(1) Real time location system. (2) Response time is high. (3) Manual programming.
Bluetooth	2 m–5 m	RSSI fingerprinting and RSSI theoretical propagation model	Indoor	Low	High	(1) Data transfer speed is high. (2) Limitation in mobility.

Abb. 4.14: Evaluation of positioning technologies wrt. accuracy, coverage, power consumption and cost (Farid et al. 2013)

An advantage of this method is its low cost: it does "not require specialized hardware in either the mobile device or the receiving end nor is no time synchronization necessary between the stations."(Farid et al. 2013) On the other hand, the method has its drawbacks in the heavy calibration process: Ïn order to eliminate the deviation of attenuation in the signal, the RSS values are to be averaged over a certain time interval up to several minutes at each fingerprint location."(Farid et al. 2013) Infrastructural changes, for instance (re-) moving of objects and APs entail modifications in the RSSI database, such that the calibration process must be repeated periodically to keep the system up-to-date.

Obviously, combinations of those algorithms improve positioning accuracy, such that they often occur at least pairwise. (Attia et al. 2014), for example, uses a combination of geometrical, topological and probabilistic algorithms to ensure an optimal result. The authors also refined the geometrical algorithm such that the shift between positioning estimate and projection is applied to the next measurement, which leads to a more accurate localization.

Outdoor positioning

A network of satellites is the only way to cover global range, as for example networked base stations would require partially unfeasible installation of transceivers anywhere on Earth (e.g. in oceans, mountains, dells and gorges etc.) to provide equal coverage.

Indoor positioning

Datamodel

Transition solution

combination of interaction and measurement

5 System Design und Implementation

5.0.1 Objective and Requirements

5.0.2 System Design Decisions

5.0.2.1 Technologies and Methods

5.0.2.2 Datamodel

indoor gml als vorlage..

5.0.2.3 IO and OI Transition

5.0.2.4 Software

5.0.3 Implementation

5.0.3.1 Programm Logic

5.0.3.2 Appearance

6 Evaluation

6.0.1 Positioning and Navigation Results

6.0.2 Maybe: Users Experience

7 Conclusion and Future Work

Anhang

Weitere Informationen werden im Anhang abgedruckt (z. B. Listings). Für die Überschriften wird der Gliederungs- und Nummerierungslose section*-Befehl verwendet. Die Nummerierung erfolgt dann mittels Großbuchstaben.

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Image source: (o. J.b). `https://taylor.raack.info/tag/particle-filters`.

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Erklärung

Ich erkläre hiermit gemäß § ### Abs. ### APO, dass ich die vorstehende ###arbeit selbst-ständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Ort, Datum Unterschrift