Thema:

Design and implementation of indoor-/outdoor transitions in pedestrian navigation systems

Bachelorarbeit

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Abkürzungsverzeichnis

IoT Internet of Things

ToA Time of Arrival

LBS Location-based Services

GPS Global Positioning System

GNSS Global Navigation Satellite System

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 (wise guy reports 2018) and USD 40.99 Billion (MarketsandMarkets und Rohan 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.

Ubiquitous LBS like I/O navigation 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. 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 (DoD) and the russion federation 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 later 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)) in 2009.

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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. Section 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 Section 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 Section 4d).

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 this fields' focus is on other aspects 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 transitions between outdoor and indoor navigation could be realized and implemented. Therefore, first current outdoor- and indoor positioning technologies as well as suitable methods and datamodels for positioning 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:

Section 2 gives deeper insight to the challenges coming up with hybrid navigation systems. Section 3 reviews related work in this area. The technical background including technology and method assessment is filling Section 4. Design and implementation of the navigation prototype is presented in Section 5. The evaluation of positioning and navigation results is then worked up in Section 6. Finally, Section 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) outdoors and WLAN, Bluetooth, RFID, NFC, Infrared, Ultrasound, ZigBee, ZWave and others 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 relations like spatial containment, 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 February 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 (E und Ma 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 February 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, Streamspin, (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 (E und Ma 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 February 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 for I/O positioning systems. Methods and technologies for outdoor and indoor positioning as well as applicable datamodels and I/O transition strategies are presented and evaluated afterwards. The aim of this section is to work out advantages, disadvantages and theoretical foundations of single solutions in order to have a knowledge basis for the implementation of a I/O navigation prototype.

4.0.1 Outdoor Positioning

In this section, various outdoor positioning technologies (GNSS,WiMAX, GSM) are presented and then analyzed wrt. their applicability and accuracy.

4.0.1.1 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 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. (und Andreas Teuber und Peter Zucker 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.

4.0.1.2 WiMAX

This technology is part of the IEEE 802.16 protocol family and like WLAN (IEEE 802.15) a radio technology. Unlike WLAN, WiMAX (Worldwide Interoperability for Microwave Access) can operate ät 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 accessible by receivers in an area of around 8.000 square km.

4.0.1.3 Cellular Networks/GSM

4.0.2 Indoor Positioning

This subsection presents various indoor positioning technologies and methods. Whereas outdoor positioning typically relies on trilateration, indoor environments offer lots of alternatives.

4.0.2.1 Methods: DR, Fingerprinting, MM, AoA, ToA, TDoA, RToF, Filters

- Proximity Detection
- Dead-Reckoning
- Time-based methods: ToA, TDoA, RToF
- Angle of Arrival
- Fingerprinting

- Particle and Kalman Filters

4.0.2.2 Technologies: WLAN, BT, RFID, Ultrasound, FM

- WLAN
- Bluetooth
- RFID
- Ultrasound
- Frequency Modulation

4.0.2.3 Datamodels for Indoor Localization

- Set-based
- Hierarchical
- Graph-based
- Combined

4.0.3 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

4.0.4 Assessment and Conclusion

- 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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Erklärung

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

Ort, Datum Unterschrift