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# Improvement of an Indoor Positioning System with Regard to Smart City Use Cases

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by

**Nico-Alexei Hein**

and

**Andreas Rau**

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|---|---|
| **Supervisor** | Prof. Dr. Carmen Winter |
| **Nico-Alexei Hein** | |
| Student ID, Course | 7146604, TINF12A |
| Company | Hewlett Packard, Bad Homburg |
| **Andreas Rau** | |
| Student ID, Course | 4186494, TINF12A |
| Company | IBM, Böblingen |

# Author's declaration

Unless otherwise indicated in the text or references, this paper is entirely the product of our own scholarly work. This paper has not been submitted either in whole or part, for a degree at this or any other university or institution. This is to certify that the printed version is equivalent to the submitted electronic one.

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Nico-Alexei Hein | A. Rau
Nico-Alexei Hein | Andreas Rau

**Abstract**

**Background:** In order to improve the efficiency of urban areas there is currently a movement heading to the Smart City. Buildings are a part of the Smart City where the social infrastructure has gained the need for reliable positioning systems. In this paper, a short summary of literature about social acceptance of innovations is given. Then different use cases of positioning systems in Smart Cities are collected and basic approaches for positioning systems are outlined. By comparing the different approaches guidance for future implementations is given.

**Concept:** In this paper a model for a positioning system working for the user and not for a third party is given. The variety of sensors the system relies on can be spitted into two fields - motions and radio-frequency sensors. While radio-frequency sensors are using the infrastructure motion sensors are part of the navigation device.

**Conclusion:** Positioning systems are usefull for many of our daily activities but for all indoor usecases there are only a few concepts fullfilling the needs of accuracy and map matching. Our concept is an architecture combining both types of sensors with suitable algorithms and constraints. Our solution is based on an independent approach and therefore compliant with privacy by design.

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# 1 Introduction

## 1.1 Topic and Motivation

In our century, humanity will be confronted with a lot of challenges like climate changes (Nature-Climate-Change, 2014) and population growth (UN, 2012). Also the rise of new digital technologies is one of these challenges. This can be observed especially in the discussions inter alia driven by Jaron Lanier who was awarded the Peace Prize of the German Book Trade in 2014 (Jaron Lanier, 2014).

The urbanization along with the growth of population is a challenge for many cities. The United Nations is expecting that 67 percent of the world population will live in cities by the year 2015 (UN, 2012). To ensure that cities infrastructure will be capable of additional load, information technologies are used to increase efficiency. This trend, often named as Smart City, can be observed in a lot of projects taking place all over the world. There is for example, the partnership between businesses, authorities, research institutions and people of Amsterdam called "Amsterdam Smart City (ASC)" which is realizing a whole collection of projects including heat networks and flexible street lightning using smart grid systems (Amsterdam-Smart-City, 2014). Another Smart City project focussing on Mobility is the "smart card project" taking place in Riga. The so called Smart Cards are common electronic cards "that can be used as payment method for public transport, to register for different social services (e.g. catering services), for city car parking, park and ride or access to different kinds of discounts for certain social groups" (STEPUP-Smart-Cities, 2013).

Besides infrastructure all over the city, the one inside public buildings is experiencing changes too. As one major pilot project, the San Francisco International Airport (SFO) installed an Indoor Navigation System. A partnership between SFO and Indoo.rs under the lead of San Francisco Mayor Ed Lee has brought a "groundbreaking new innovation", developed in only 16 weeks, (Lowensohn, 2014). Made possible with "Apple's Voiceover technology to read out points of interest as they apear on screen" (Lowensohn, 2014). Visually-impaired passenger are now able "to navigate through SFO independently without assistance" (Yakel, 2014). The corresponding app gets it's location information from approximately 500 beacons located all over the airport to find points of interests "including gate boarding areas, restaurants, and even power outlets". (Yakel, 2014).

Competition never sleeps, in May 2014, Virgin Atlantic announced a testing of Apples's iBeacons at London's Heathrow airport. This project is administrated by indoo.rs's direct rival Estimote. "Major League Baseball installed iBeacons in 28 of its ballparks last year, and is in the process of adding them to others to give attendees point-of-interest information, and push out information about local park concessions. Britain's Odeon Cinemas is testing the same thing at some of its theaters to push out information about movies and get people to go buy popcorn" Cutler (2014).

Then the Maze Map, originaly Campus Guide, from the NTNU Gloshaugen Campus in Norway covering 350,000 sqm was released in August 2011 .NTNU was "the first university in the world where you can navigate from inside a building using a mobile phone" Jelle and Kaaro (2014). "MazeMap allows the user to see building maps on campus, locate the user's own position within the building, search for all rooms and different objects (toilets, parking lots, etc.), and get turn-by-turn directions from where the user is to where he wants to go" Biczok, Martinez, Jelle, and Krogstie (2014). Due to the object density in an indoor navigation solution as well as small distances between them, indoor maps are getting complicated. In order to present readable data to users, Maze Map uses services to scan through construction drawings which "interpret them to recognize different objects, and choose what to show or hide" Biczok et al. (2014). The technology developed in Norway was a pilot to show the potentialities (people and asset monitoring, personalized shopping, and improved emergency response) of the system. Now the solution is offered to customers globally.

Indoor positioning systems are on the rise and as a result chip manufactures like Broadcom are following the current trend by focusing on the enhancement of indoor positioning chips. Other institutes like the Boston's Children's Hospital and American Museum of Natural History have launched an app providing indoor navigation (Biczok et al., 2014).

In addition, Googles Project Tango shows in which dimensions this change is going to take place. Instead of using a given infrastructure for positioning, the navigation device (in this case a phone or tablet) is able to imagine the world around itself in 3D. The goal of Project Tango "is to give mobile devices a human-scale understanding of space and motion" Google (2014). So the Project Tango devices, equipped with special 3D motion Hardware, are able to create a map of their environment on their own. This research and development is done in collaboration with over 20 partners including Bosch and NVIDIA. (Google, 2014)

Currently dozens of technologies are in development and can be differentiated in two major groups. So called radio and non-radio positioning systems, latter rely on standard physical measurements. Due to the fact that indoor positioning is widely spread in the smartphone segment, it is appropriate to use existing hardware like the gyroscope of the phone. The so called inertial measurements benefit from the users imbalanced way of locomotion in order to count steps to calculate the walked distance. Other value, like the drift experienced in turns, also give information about the pedestrians position and movement. Another non-radio technology is magnetic positioning. This technology has an accuracy of 1-2 meters and 90% confidence level "without using any wireless infrastructure for positioning" Conti, Piffer, Barozzi, and Li (2014). "Magnetic positioning is based on the iron inside buildings that create local variations in the Earth's magnetic field. Un-optimized compass chips inside smartphones can sense and record these magnetic variations to map indoor locations" Conti et al. (2014). On the other hand, there are radio or wireless technologies. The measurements are nearly all based on intensity measurements of received signal strength (RSS). The accuracy increases with ascending amounts of access points, Chen and Kobayashi (2002). Examples are Wi-Fi based positioning systems (WPS), Bluetooth, grid point concepts, just to name a few. Sensor Data is only half the job. Once sensor data has been collected, algorithms are used to determine the most likely current location. They use mathematical principles of trilateration (distance from acces points) and triangulation (angle to access points) (Ruiz, Granja, Honorato, & Rosas, 2012). There is no one method or vendor that is suitable to all. Achieving good location coverage requires some understanding of customer devices and behaviors to make a correct choice for the customers to be served. In addition to this theory a short look at the global surveillance disclosures published by Edward Snowden is now taken.

Since this solutions are affecting the privacy of all users the social acceptance of these systems could be crucial to their success. According to a report referenced in the Wall Street Journal (Dwoskin, 2014) the erosion of trust caused by the disclosures has serious consequences for U.S. technology. This knowledge is one of the main reasons why a further discussion on computational social science and psychology is given later in this paper. The development of Indoor Positioning Systems scales up the accuracy of personal tracking and besides all the handy uses for the greenly eyed, naiv and ordinary people there is a real risk in using this technology. Edward Snowdens motivation lies in his conscience and belief in the fact that he doesn't want to live in a world where everyone is tracked by every move they make (Dwoskin, 2014). During his work at the CIA and NSA he gathered information which shocked and confronted him to choose between doing the "right" things and the ones he was asked to do. "Snowden had come to believe that a dangerous machine of mass surveillance was growing unchecked" Dwoskin (2014) after encountering closed ears on his executives he decided to share his knowledge with the world. A lot of the aspects revealed by Snowden have awaken many people forcing them to question parts of their lifes, especially technology and surveillance aspects - which includes indoor positioning.

## 1.2 Limitations

In addition to social aspects of positioning systems, there are especially legal and medial aspects of positioning systems. Legal aspects are related to data protection to prevent a complete surveillance of individuals. Since the Snowdon affairs caused debates on legal issues Dwoskin (2014) and in order not to exceed the limits of this paper they are not discussed.

Some of the Indoor Positioning Solutions (IPS) are working with wireless technologies, and there are concerns about radiation and its influence to human health. Since this is an ongiong discussion in the dicipline of applied medicine, it is also not discussed in this paper.

In this paper we do not provide new technology ore complete new approaches. We just collect existing ideas and knowledge about indoor positioning systems to combine them in an efficient way. Existing solutions are compared on a theoretical basis in combination with some experiments to find an optimized concept as basis for further discussions.

## 1.3 Goals

This paper was written in the frame of a seminar work which is a permanent feature on the bachelor of science in "Applied Computer Science" at the Baden-Württemberg Cooperative State University. The goal of this seminar work includes a research on current literature about the Smart Cities Concept and Smart City applications in our professional environment as well as the development of a new concept for an indoor positioning system as Smart City application.

Since Indoor Positioning Systems are one of the topics being discussed and requested for Smart Cities, we decided to support the development by summarizing current solutions including our ideas for improvement. It is of interest to find a solution which is as trustworthy as possible for all users and still accurate and cost efficient. Therefore, this paper includes a collection of indoor positioning systems use cases for Smart Cities which are the basis for later defined measurements for existing technologies.

The primary goal is the improvement of an Indoor Positioning System (IPS) applicable for a set of Smart City use cases. Providing a frame for the technology and use cases, aspects of other sciences are considered. Therefore, theory of computational social science and psychology is reviewed. To find a cost-efficient and accurate IPS, a large set of Smart City IPS use cases is gathered and prioritized. Further, technologies are compared with a view on the primary goal.

## 1.4 Tasks

The paper is structured in five parts. To start off, in chapter two "Smart City and Indoor Positioning Systems" basic verbalisms are set in order to clarify a basis for later on dicussions. This includes the definition of a City and later on Smart City, where approaches from different authors are taken as bedrock to build up our definition. Navigation limited to indoor use cases are lighted and later reflected on aspects like trustworthyness. Further on basic approaches on Indoor Positioning are mentioned, divided into two groups radio and non-radio. In chapter three we acquire criterias to come to a decision on the technology we want to use for our Indoor Positioning System. Then measurements are defined to compare existing solutions and work out a concept for our Indoor Positioning Solution.

# 2 Smart City and Indoor Positioning Systems

## 2.1 Definition of the Term Smart City

To derive a definition of the term Smart City at first the question "What is a city?" is answered. After that a closer look to the "Smart" City is taken. A formal definition is provided at the end of this section.

### 2.1.1 What is a city?

The first urban settlements evolved more than 5000 years ago in the two great civilizations of Mesopotamia and Egypt (Bähr, 2007). Much later in the fourteenth century with entry into the world urban system of the capitals of nation states and the centers of international trade urban settlements began to grow much faster than before (Christopher Watson, 1993). However, this leads to the first approach to define a city as as an Urban Area which is an area of continuous urban development which includes the historical core municipality, and the adjacent suburbs. Changing the perspective to the government we can also define a city as a municipality or local authority area which was done so by the International Organization for Standardization in the ISO 37120 where the city is defined as "urban community falling under a specific administrative boundary, commonly referred to as a city, municipality or local government" (ISO, 2014). As a third perspective a more mathematical approach for a definition was provided by the European Commission:

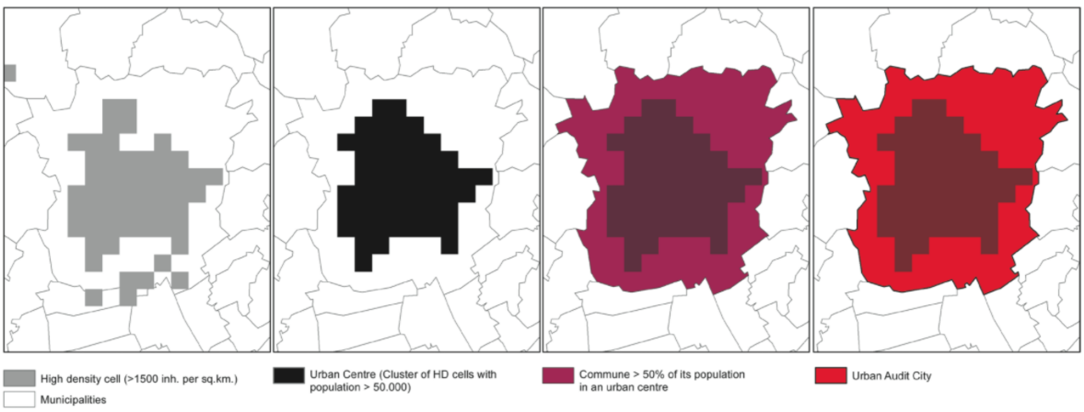


Figure 1: High density cells, urban centre and city (Graz) (Lewis Dijkstra and Hugo Poelman, 2012)

"Step 1: All grid cells with a density of more than 1 500 inhabitants per sq km are selected (1.1). Step 2: The contiguous (2) high-density cells are then clustered, gaps (3) are filled and only the clusters with a minimum population of 50 000 inhabitants (1.2) are kept as an 'urban centre'. Step 3: All the municipalities (local administrative units level 2 or LAU2) with at least half their population inside the urban centre are selected as candidates to become part of the city (1.3). Step 4: The city is defined ensuring that 1) there is a link to the political level, 2) that at least 50 % of city the population lives in an urban centre and 3) that at least 75 % of the population of the urban centre lives in a city (1.4) (4)" "(Lewis Dijkstra and Hugo Poelman, 2012).

Due to the fact that we consider Smart City projects not limited to a municipality or local authority area, or the strict constrains as given in the last described approach, a definition of a city as urban area is used for later work.

### 2.1.2 *Definition: City*

The City as Urban Area includes the "urban community falling under a specific administrative boundary, commonly referred to as a city, municipality or local government" (ISO, 2014), the adjacent suburbs as well as the exurbs being under continuous urban development driven by the central municipality or local government.

### 2.1.3 What makes a City Smart?

According to Tranos and Gertner (2012) the main smart city characteristics are the use of digital infrastructure, information and communication technologies (ICT), the emphasis of business-led urban development (which results in characteristics the Central of Regional Science at the Vienna University of Technology (2007) calls a smart economy), the social inclusion agenda via the use of e-governance and urban sustainability (Tranos & Gertner, 2012).

The motivation for Smart City projects is represented by the urbanization which requires a more efficient, effective and reliable usage of the cities infrastructure (Bähr, 2007). The goal is to improve economic and political efficiency at the same time to enable social, cultural and urban development. Which implies a community whose members have to learn adapt and innovate. To archive that the concept includes attracting creative individuals to cities in order to help stimulate urban growth (Tranos & Gertner, 2012). This aspect of smart cities being creative cities is also considered by Kourtit, Nijkamp, and Arribas (2012) stating that smart cities are "seedbeds for creativeness, innovation, entrepreneurship and spatial competitiveness".

However, there is not one general definition for a Smart City, and the number of publications with the topic Smart City was 152 only in 2012 (Cocchia, 2014). That is why we decided to recite 6 of the most cited definitions collected during a review of literature in Cocchia (2014). The other definitions given in that paper are listed in the appendix.

#### 2.1.4 *Definitions: Smart City*

> [smartcommunities.org (2001)] "A smart community is a community that has made a conscious effort to use information technology to transform life and work within its region in significant and fundamental rather than incremental ways."
>
> [Caragliu, Bo, and Nijkamp (2011)] "A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infra- structure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."
>
> [IBM (2010)] "Smart city is defined by IBM as the use of information and communication technology to sense, analyze and integrate the key information of core systems in running cities."
>
> [Hall (2000)] "A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activi- ties, and monitor security aspects while maximizing services to its citizens."

> [Setis-Eu (2012)] “Smart City is a city in which it can combine technologies as diverse as water recycling, advanced energy grids and mobile communications in order to reduce environmental impact and to offer its citizens better lives.”

> [ “Searching for smart city definition: a comprehensive proposal.” (2013)] “A smart city is a well-defined geographical area, in which high technolo- gies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development.”

All this definitions intersect each other, but are not always coincident. For our purpose we decided that the definitions of “Searching for smart city definition: a comprehensive proposal.” (2013) and IBM (2010) are underlining our view on Smart Cities precisely. To clarify our position we will outline some characteristics every smart city has. Since we do not want to define a city as smart in case of perfect monitoring and survailliance Hall (2000) is not our view on a smart city. We want to define smart city in the eyes of the user to enable the most benefit.

### 2.1.5 Smart City in Detail

Everything being part of a city is affected by the goal of a city to be Smart. Some more than others, but still there will be a noticeable change. The six main characteristics and factors of Smart Cities collected by “Smart cities: Ranking of European medium-sized cities” (2007) can help to correlate Positioning Systems with the purpose of Smart Cities. These characteristics are Smart Economy - which is the competitiveness between different cities, Smart Governance - which is measured by the possibility of participation by the citizens, Smart Environment - which is the sustainable management of natural resources, Smart People - which are the social component in Smart Cities, Smart Mobility - which is the way of Transportation and use of ICT and Smart Living - which affects the quality of life influenced by Smart Home. All this is shown in more detail in figure 2. Indoor positioning can be ranged in smart mobility as providing availability of ICT infrastructure and smart living (quality of life) in case of cultural facilities.

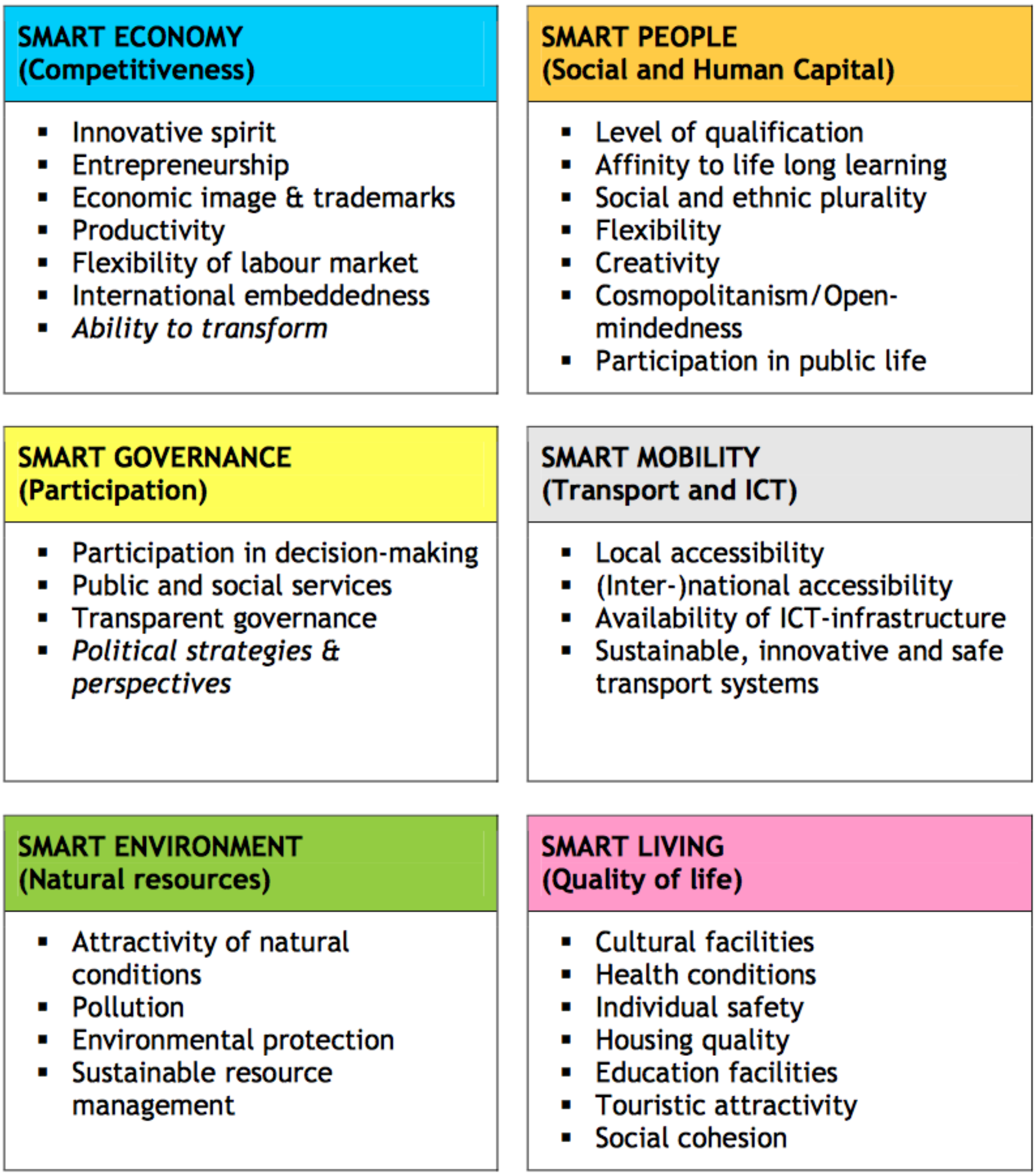


Figure 2: Characteristics and factors of Smart Cities ("Smart cities: Ranking of European medium-sized cities," 2007)

Positioning Systems in Smart Cities will hopefully increase the quality of life by providing additional ICT-infrastructure.

## 2.2 Positioning in Smart Cities

The first tools for navigation have been especially developed for sailors. Now in our century we encounter numerous navigation and positioning systems in our everyday lives. For example the automotive navigation systems in our cars, or the navigation and positioning systems in our smartphones. These applications mostly use Global Positioning System (GPS) to determine their location. Some of them are using Wi-Fi to precise the localization. These commonly used navigation systems have displaced paper street maps for many users. But taking a look at our every day behavior there are still places we have to look out for maps. All these places are potential areas for indoor navigation systems.

In the following section some use cases should make this need for indoor positioning in the context of Smart City even more comprehensible.

### 2.2.1 Indoor Positioning System Use Cases

This itimization should provide a quick overview on general indoor positioning use cases.

- **General Indoor Navigation** to navigate the user inside a building. Floors, rooms and other points of interests are supported.
  - **Customer assistance and Support** for example in malls or department stores e.g. to provide maps in different languages.
  - **Indoor Navigation for Blind People** San Francisco Airport launched a Indoor Navigation System with an interface for blind people. This is another possibility for blind people to get their direction in buildings.
  - **Navigation for Healthcare** Using personalized messages or gamification to encourage healthy behavior at work or in public buildings. (Total_Communicator_Solutions_Inc., 2014)
- **Geofence** is a virtual radius defining a real world area. A Geofence has predefined boundaries and is therefore a nice match for proximity marketing, but not limited to it. Workers can be invisibly tracked if they appear at work or not, childs can be

tracked by their parents wheather they leave a designated area and cars send their location if removed from certain area, e.g. in the case of car-napping.

- **Proximity marketing** is location based advertising. This is done by pushing notifications to smart-phone like devices whenever they are near by the advertised stores.
- **Personalized and Augmented Experiences** Based on the location users are receiving additional information on points of interests for example art installations. This could replace audio guides.
- **Location analytics** For crowd density measurements to provide dynamic people guidance on big events (Football or Baseball stadiums) or to give information about the popularity of different stores, bars or restaurants.
- **People and Object tracking** for example staff members in museums or equipment.
- **Robotics** Allowing human assisting robots or drones to navigate indoors.
- **Real Life Social Networks** Systems that send notifications if there are people or friends close to each other who share the same interest at this moment. (Anthony, 2014)

This itemization provided a limited overview of possible solutions. In the further sections we will focus on **location determination on indoor maps**. This is the basis for general indoor navigation, people and object tracking as well as robotics. All the other use cases can be implemented also by using beacons, near field communication (NFC) or image processing.

### 2.2.2 Current Solutions for Indoor Positioning

There are at first two different principles for positioning systems to distinguish: the Infrastructure and the Independent Mode not to be confused with radio and non-radio technologies.

**Infrastructure Mode / Active (infrastructure) Sensor** is where the infrastructure tracks device locations by their unique identity either over time or on-demand. Active Sensor requires no user interaction. This means that the sensor (e.g. WiFi Access Points) will gather positioning information in the background, this is hard to detect. Further more there is a risk of privacy ( e.g. passive WiFi sniffing). This location information can be used by different applications i.a. location analytics. Infrastructure mode is only possible using radio frequency solutions.

**Independent Mode / Active Client** is where the device locates itself inside a building and has access to a positioning database that allows it to pinpoint itself by some method if outdoor systems are not visible to the device. This assumes that there is software installed on the smart phone like device that can do the triangulation work. It also depends on hardware to make the services available.

To provide location determination to the citizens two different concepts can be applied: Either the client determines its location itself in Independent Mode, or the provider tracks all devices using Infrastructure Mode and forwards the location to the client.

The key difference is that in infrastructure mode the provider has all location data and forwards it to some clients requesting their own location, while in independent mode the client can locate itself still being anonym to the provider. However the client could forward its location (anonymized or not) to the system provider for inquisitions and improvement.

In the introduction we already mentioned the erosion of trust in IT solutions due to Snowden affairs. To build trust again we will focus on a solution working in independent mode. Thus the user could be empowered to decided weather he would like to share location data or not.

However positioning systems will salvage privacy risks which are suspicious to the user often due to uncertainty. This results in a negative attitude to the new technology. This led to the discussion in the next section.

## 2.3 Social Acceptance of new Technologies

At first a short look at psychological aspects of innovation processes is taken. Expressed as a short question: When do we resist change and when do we participate actively in the implementation? Regarding to Müller (2008) stated that question can not be answered in a short way. People differ in tolerating uncertainty and vagueness since they have their own "frame of reference" including their fundamental feeling of safety. "To overcome this uncertainty, most people seek out others like themselves who have already adopted the new idea." (Rogers, 2003)

The “disconfirmation message” driving innovation affects people and is interpreted either as a message of challenge or a message of shock. This depends on the persons hopes and aspirations for the future (Müller, 2008).

On the one hand change oriented persons need only little motivation to commit to change. On the other hand trying to empower "people for change whose basic needs are unfulfilled or lacking, is futile." (Müller, 2008). In addition the diffusion process from early adopters to a wide spread user community typically takes months or years (Rogers, 2003). Therefore sociological psychological educational and political concepts applied to communication are key driving innovation to success.

General corresponding concepts are not part of this paper - the academic review of literature on this topic needs to be discussed in an additional paper. However, currently for all indoor positioning systems on the marked custom Apps need to be installed. Due to this fact the biggest concern of the customer is data privacy (later referenced as trustworthiness). One communication concept to handle this concern is provided in Technology_Review_Custom_MIT (2015). In the following itemization this concept is cited literally.

- Adopt the “privacy by design” approach. Consider privacy issues and build the appropriate protections into applications and services right from the start.
- Seek consumers’ permission before collecting potentially sensitive or confidential data about them.

- If you're obtaining information from children 13 or younger, ensure that your efforts comply fully with the FTC's Children's Online Privacy Protection Act (COPPA) rules.
- Develop a clear, comprehensive mobile-privacy policy. Be sure it's prominently displayed, easy to understand, and readily accessible. Update it regularly.
- In that policy, inform customers about exactly what personal data you're collecting and why. (Then collect only that data.)
- Consider reassuring customers by also spelling out what data you won't collect.
- Describe how you store personal information. State how long it will be kept, how you protect it, and how you'll dispose of it.
- Explain whether and how you share personal information.
- Tell customers how they can decide which information they will allow you to collect and share and how they can opt out entirely.

(Technology_Review_Custom_MIT, 2015)

Item three can be generalized by stating: "Ensure that your efforts comply fully with the applying law." All in all the user is well informaed and should be able to choose how much private information he wants to share.

Having a well developed communication concept in mind we now consider the different existing technologies.

## 2.4 Basic Approaches for Indoor Positioning

Now we try to collect all currently used or developed positioning systems. Due to limits in time we cannot guarantee a complete list of indoor navigation strategies. The two general types of indoor positioning - radio and non-radio positioning - have already been named. This differentiation is used to bring a bit order into the collection. At first the radio systems, then the non radio systems are listed.

### 2.4.1 Radio positioning strategies

Radio positioning systems for active clients are based on intensity measurements of received signals (received signal strength RSS). (For active sensors e.g. CUPID (HP) calculations on energy of directed graph are the alternative to RSS.) The accuracy increases with ascending amounts of access points, (Chen & Kobayashi, 2002). The signals are processed and interpreted using mathematical principles of Trilateration (distance from access points) and Triangulation (angle to access points) (Ruiz et al., 2012) or fingerprinting which is explained later on.

**Active RFID Systems** use self powered RFID (Radio Frequency Identification) tags in order to broadcast their signal to the clients.

**WiFi** There are different methods when it comes to WiFi localization. One is Wi-Fi-based positioning system (WPS) or WiPS/WFPS, using a global WiFi hotspot database like *Combain Positioning Service* or *Mozilla Location Service* to locate the smart device. SSID, MAC address and the signal strength of the access point give information about the current position using multilateration and triangulation. Accuracy is limited by the number of AP positions that have been entered into the database and the accuracy of the distance measurements. Two approaches to gain accurate measurements used by CUPIT (an HP indoor positioning solution) are the Energy of the direct path and the Time of Flight of direct path (Mariakakis, Sen, Lee, & Kim, 2015). Both methods are based on message exchanges between access points and the mobile device.

Another method is fingerprinting where a map containing the Received signal strength (RSS) of different APs at all locations is created. Afterwards the client just needs to match its measurements to the map - no message exchange between AP and client is neccessary.

**Bluetooth Beacons (iBeacons)** are broadcasting their own (Universally Unique Identifier) UUID. Bluetooth Low Energy (BLE) is not really “location based services” but a “proximity detection” method. Proximity categories are *unknown*, *immediate* (50cm), *near* (2m) or *far* (30m). Via Trilateration the position can be determined roughly. Fingerprinting is here the better approach.

**Zigbee** (radio network system) A network mesh consisting of several devices communicating directly or through neighbor devices in the network (Hernandez, Jain, Chakravarty, & Bhargava, 2009). Position determiniation is enabled by dynamic distance vectors.

**A-GPS (Assisted GPS)** Regular GPS was not designed for jumpy location changing which acure when passing tunnels or navigating between high rising buildings. Assisted GPS is aided by different other technologies like radio cell positioning and pseudolites can therefore be used in more GPS unfriendly environments. **Pseudolites** - *pseudo-satelites* are terrestrial wireless stations which emulate GPS staelite signals in order to reenable positioning where GPS signals are either blocked or jammed.

**NFC Tags** Several NFC tags are positioned inside a building and deposited in a database. The user can *touch* the smart device to such a NFC tag in order to determine its current position. Location determination is just possible in the range of an NFC tag (1 - 30mm), but very precise (NFC_tag_shop, 2015).

### 2.4.2 Non-Radio Positioning Systems

**3D sensors** Using 3D sensors instead of using a given infrastructure for positioning, the smart device is able to imagine the world around itself in 3D. Maps are not neccessary in order to perform a relative positioning (Google, 2014).

**LED Patterns** a camera detects unique light pattern emitted by LED lights mounted at the ceiling (ByteLight, 2015).

**Magnetometer** can recognize magnetic field. This works because of building specific anomalies in the magnetic field caused by metal structures. The Magnetometer works best during motion. In addition to magnetic flux the data can be used to determine the direction. The magnetometer is usually assisted by gyroscope and accelerometer which are used to recognize movement within 3D space (Macintyre, 2000).

**Compass** is technically not a standalone sensor but more an instrument used for navigation based on the Magnetometer. Compasses found in mobile phones are so called Solid State Compasses build out of two to three magnetic field sensors. The correct heading is calculated by the use of trigonometric algorithms (Macintyre, 2000).

**Gyroscope** consists of a spinning wheel so mounted that its axis can turn freely in all direction. Thus is is possible to measure a change of the orientation in any direction (Poisson, 1813).

**Accelerometer** measures proper acceleration ("g-force"). Thus in free fall the accelerometer would measure $0m/s^2$ but while lying on the ground it would measure an acceleration of $9.81m/s^2$ (Adam J. Aviv & Smith, n.d.).

**Barometer** The barometer relies on surrounding air pressure in order to determine altitude (D. Burch & T. Burch, 2009).

There is no one method or technology that is common to all. Achieving good location coverage requires a flexible system architecture for motion sensing. Techniques with a possibility of location determination using **active clients** are active RFID systems, WiFi localization, Bluetooth beacons, Zigbee, Magnetic Flux, Magnetometer, Gyroscope, Compass, Accelerometer and Barometer. Raw sensor data on itself can't guaranty success in indoor navigation scenarios. One step further are architectures which include constraints like floor plans, accesspoint locations, landmarks and magnetic flux maps. The implementation of such constraints will be covered in the next section.

## 2.5 Constraints

The following section will cover some convenient constraints:

**Floor Plan** constraints the allowable motion of a user - people cannot walk through walls and can only enter a room through a door Xiao, Wen, Markham, and Trigoni (2014). The approximate position range given by the sensors is adjusted with the map using map matching explained in the section 2.7 (Error Correction and Filtering). In addition floor plans are usually stored in various image formats (Xiao et al., 2014) (Google, 2015) later on these images are processed into graphes representing real world including physical constraints. A sample floor map is shown in figure 3.

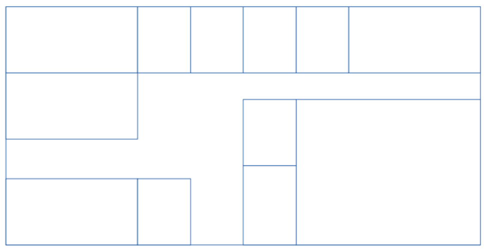

Figure 3: Sample floor maps (Xiao et al., 2014)

**Beacon locations** are used to determine the position by measuring the distance to the beacons with the help of signal strength and multilateration. This method is unprecise. More accurate positioning is achieved in combination with fingerprinting. A map showing beacon positions is given in figure 4.

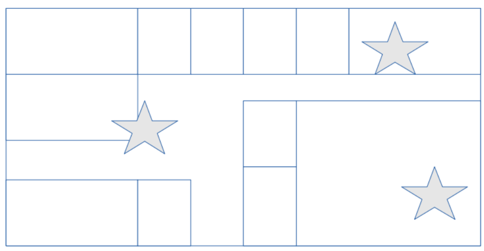

Figure 4: Sample iBeacon locations (Xiao et al., 2014)

**Landmarks** function as extensions to floor maps due to the fact that a persons position can't intersect with landmarks (Xiao et al., 2014). This leads to more precise location determination. Furthermore landmarks are easy to spot and can be navigation destinations. A map including landmarks is shown in figure 5.

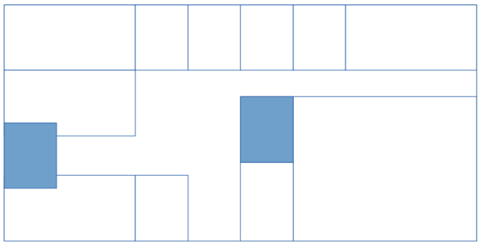

Figure 5: Sample landmarks (Xiao et al., 2014)

**Magnetic Flux Maps** are maps based on the fluctuation of magnetic fields influenced by obstructed metals. Flux maps store magnetic density fingerprints in $\mu T$ (Tesla) ranging from 25 to 65 $\mu T$ shown in figure 6 (Vandermeulen, Vercauteren, & Weyn, 2013).

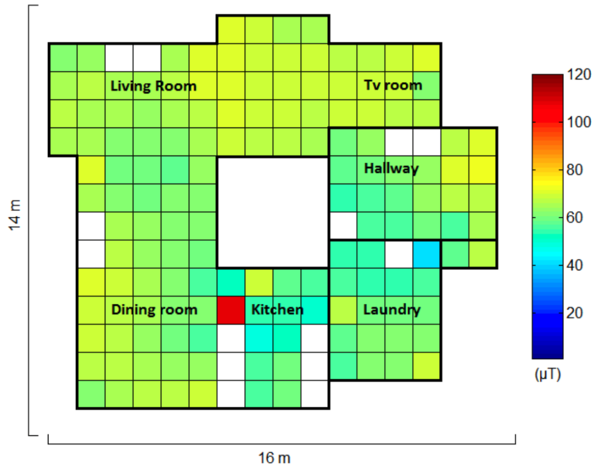


Figure 6: Sample flux map (Vandermeulen et al., 2013)

**WiFi, Blotooth or Zigbee Fingerprinting** based on measuring the intensity of the received signal analoge to magentic flux density maps with additional information about the device ID. These maps are referencing RSS-based localization where RSS means "Received signal strength". A sample map is shown in figure 7.

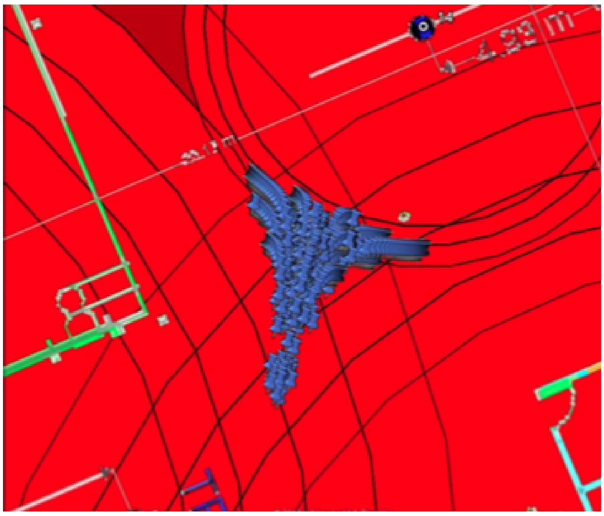

Figure 7: Intersection of accessspoint ranges including possible locations of the user (blue)

**LED pattern map** is used to enable LED Pattern based positioning. The map stores the positions of all mounted LEDs in three dimension. Using the internal magnetometer and accelerometer as well as the angle of view the position can be calculated by patternmatching (ByteLight, 2015).

**Pedestrian Movement Model** In addition to all these maps pedestrian movement model could be used as constraint. Since this is one big area of research itself we are not discussing it in detail in this paper. However in general models of swarm computing could be applied for infrastructure mode systems - since humans are often behaving like a swarm of birds or ants. For independent mode a statistical model could be applied taking constraints like Landmarks and Floor-plans into account.

As could be observed these different constraints are expecting different sensors as input. However redundant systems are known to guarantee a higher reliability. This brings up the topic of the next section: Sensor Fusion.

## 2.6 Sensor Fusion

A comprehensive solution for indoor navigation should be able to combine different types of sensors. Sensor fusion was already mentioned 2008 by Uwe-Carsten Fiebig (2008) as a essential part for future pedestian navigation systems. Sensor fusion could be done using different methods and algorithms. One prominent algorithm for example is the Kalman Filter that is used by the German Aerospace Center. Other algorithms that could be used are the Central Limit Theorem, Bayesian Networks or the Dempster-Shafer theory. These four methods are now explained shortly.

**Bayesian Network** A Bayesian Network is a directed acyclic graph with nodes representing random variables and edges representing conditional dependencies. In case of sensor fusion one node would represent the result and other nodes the observed sensors influencing the result. Since the sensors are generating continuous instead of discrete random variables an approximating continuous model needs to be used. In case of localization this does mean that it is assumed that the sensor measurements are conditionally independent of each other given the state (where the states represent user locations). This fact is visualized in figure 8. Then the problem of sensor fusion can be seen as: find $p(S_t|Z_t = z_t[0], z_t[1], ..., z_t[n])$ where $z$ are the positions given by different sensors, $S$ is the state and $t$ is the time (Xiao et al., 2014).

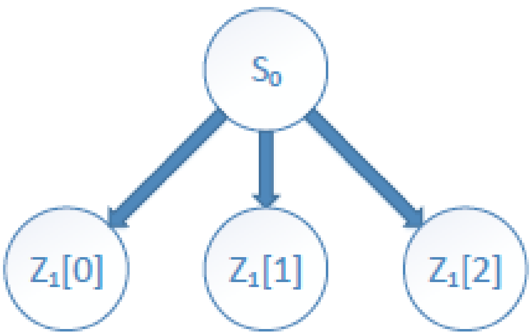


Figure 8: Sample Bayes model showing the independence of the measurements given the state.

Extending this model to a sequence of states linked through transition probabilities leads to recursive Bayesian models, such as Hidden Markov Models "where state variables are discrete, and the transition model $p(S_t|S_{t-1})$ is a matrix" (Xiao et al., 2014).

**Kalman Filter** The location of the user is considered as a continuous variable and the filter relies on the Bayesian model. The Kalman Filter estimates the new position of a moving node by taking into account the old position - *prior knowledge* of the state - and some internal sensor data - *measurements*. The *prior knowledge* of the state and reliable RSS Maps (Fingerprinting) are used to generate a *prediction* of the next state - this prediction is defined by a Gaussian function. The (noisy) measurements itself are forming another Gaussian distribution. The fact that the product of two Gaussian functions is another Gaussian function is applied to generate the best estimate. Thus the Kalman Filter is differentiating explicitly between a State-model (including the constraints) and filtering. During filtering the measurements are all assumed to be mutually independent. This causes a problem of separating between measurement noise of the sensors and unmodelled dependencies. One Kalman Filter especially extended for localization is called Extended Kalman Filter. The real time sensor fusion system developed by the DLR is using a Kalman filter for the stride estimation, and fuses other sensors and maps at a higher-level with an own optimized algorithm (Uwe-Carsten Fiebig, 2008). (This "own" algorithm was not explained in the source.) *Note: The Kalman Filter is not to complex to work on a real time system in Independent Mode (Active Sensor System) (Uwe-Carsten Fiebig, 2008) and works well with low cost sensors often used in wearable devices.*

**Central Limit Theorem** The Central Limit Theorem generally states that a sequence of similar processes is Gaussian distributed. This statistical method thus can be applied for sensor fusion with unknown underlying distribution. The only conditions are that $n$ is large (rule of thumb is $n > 30$) where n is the number of independent experiments (stages), in each stage the same experiment is executed and expectation and variance of all stages are equal (Klöss, 2014). Since for multiple sensors as sources not exactly the same experiment with the same expectation and variance can be assumed. However if the sensors are considered as independent, applying the condition of the Bayesian Network (that the sensor measurements are conditionally independent of each other given the previous state) - and no sensor is dominating the expectation - it can be assumed that $E(Z) = \mu = \mu_1 + \mu_2 + ... + \mu_n$ and the variance as $Var(Z) = \sigma^2 = \sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2$ for the different sensors (1 to $n$). Thus with preprocessed error corrected sensor data and if the user can tolerate some delay (time needed to perform $n > 30$ measurements using $k$ sensors and $k << n$) the theorem is a satisfying model.

Not only sensor fusion, but software able to analyse and filter the raw sensor data is necessary to get useful data. This is discussed in the next Section.

## 2.7 Error correction and Filtering

It is no secret that there could be various measurement errors by each of the possible sensors. To reduce the amount of errors before the sensor data is used by the positioning system various filters could be applied. In this paper three of these possible filters are explained in detail, after classical mathematic error analysis is explained shortly.

### 2.7.1 Error Analysis

Error analysis can be applied to a series of measurements, thus to a random variable is used to calculate:

- a mean value
- the variance for individual measurements
- the variance, confidence interval and the uncertainty of measurement.

After these values have been calculated error propagation is of interest for all indirect measured value. Therefore law of error propagation (If $Z = f(X;Y)$ then $s_z = \sqrt{(f_x(\bar{x};\bar{y})s_x)^2 + (f_y(\bar{x};\bar{y})s_y)^2}$ and $\bar{z} = f(\bar{x};\bar{y})$ where $s$ is the corresponding standard deviation) can be applied, and in some cases the determination of a regression curve can help improving the measurement results (Papula, 2011). Especially for magnetometer, gyroscope, accelerometer and barometer error analysis including error propagation and regression is of interest.

Error analysis can only be applied to random errors and not to systematic errors. Systematic errors exist if the measurement method is not completely reliable or the environment does not allow reliable measurements. The two filters described are an example on how to reduce systematic errors.

### 2.7.2 Invalid Position Filter

A correction filter that is implemented directly in the GPS Receiver is Invalid Position Filtering (Xiao et al., 2014). Every GPS position object is numerically flaged to be filtered out whenever certain circumstances apply. There are different vendors and different flags used to do so, common ones are for example the amount of satellites available for this position computation. If there are less than three satellites available the position obect is flaged as invalid. Other approaches verify whether the current position is too far away from the previous to be valid (Xiao et al., 2014). Objects which are flaged invalid are nullified and thus cannot be used from the host application. After beeing processed by the Invalid Position Filter the position objects are passed down the filterpipeline to the next available filter (Xiao et al., 2014). There have to be made considerations if this filter is to be implemented for different sensors since not every sensor is qualified to set usefull flags. Never the less Invalid Position Filters make sense for sensors calculating specific positions.

### 2.7.3 Mask Filter

Deferred threshold levels for specific measurements are referred as masks (Xiao et al., 2014). Their purpuse is to eliminate GPS positions that do not meet certain quality standards defined through the masks. Examples are Position Dilution of Precision (PDOP), Signal to Noise ratio (SNR) and dimensions of the position (2D or 3D). Low values for PDOP or SNR combined with high treshold levels lead to rejection of the position, but do not neccessarily mean that the position is inaccurate, more that the chances for the position being accurate are low (Xiao et al., 2014). In other words nullification of positions that do not meet masks is undesirable. Considering the case that more and more sensor data gets low PDOPs or SNRs for whatever reason, this would lead to more rejection of positions. Unlike other error correction Filters, the threshold levels can be adjusted. Dynamic filtering of GPS positions are implemented in the Mask Filter. Meaning that the ratio of accepted versus rejected amounts of positions by the mask filter have an influence on the mask threshold levels (Xiao et al., 2014). Dynamic adjustments up to the point of disabling masks are made in order to remain at least few positions. "The motto here is that a bad position is better than no position"(Xiao et al., 2014). Hence Mask Filter are very simmilar to Invalid Position Filter.

The mask filter is eliminating systematic errors and is thus considerable for WiFi and Bluetooth signals.

### 2.7.4 Map Matching

The idea behind the map matching filter is to correct any position that does not match the rules of a map. Whenever an object to track with the help of GPS can be bound to a grid like system, map matching is used to determine the exact possible position in relation to the original gps data, cancelling out errors during GPS data gathering. This works with automobile navigation because the assumption that a car always has to travel on a particular road. Therefor the amount of possible positions for the car are shrunk down dramastically thus increasing the accuracy of tracking. On the other hand this rules for traffic cannot be easily transfered to pedestrian navigation system. The fact that people usually walk in wide spread areas without defined allignment or direction makes it nearly impossible to define routes of travel (Xiao et al., 2014). New strategys have to be developed. Due to the fact that pedestrians only can walk on pavement like underground the algorithm has to make assumptions about where the user can not be. Therefor excluding walls, lakes and other obstacles. Crosspassing walls is only possible by using doors, changing levels only by using elevators or stairs. All this areas are handled with lik "off-limits" where usually no pedestrian will be traveling. If any GPS position points on obstacles of either kind, it can be safely reasoned that the position must be inaccurate.

**Particle Filter** There have to be taken multiple measurements when estimating position with the help of Particle Filters. The true position is estimated by combining these measurements. The concept behind the Particle Filter is to generate randomly distributed particles that represent positions in space. First the distance to an object has to be derived from measurements (e.g. sonar). From all the distributed particles the algorithm selects only those particles that best match the measured distance to the object. Particles that match the measured distance live on while the others die away. The particles that match the measurements the closest are propaganding their position into the next iteration by spawning new particels around them. The more accurate the particles are to the real measurements the more are spawned around them in the next iteration. The second measurement is the true direction to an object. As in the distance measurement particles which match the true dirction closely live on the others die. Now both, distance and direction data is used to localize an agent in the system. the result is a cloud of particles which respresent the approximated true position. This cloud can be mapped to a single position by calculating the average of all particles. By using a system of marked obstacles in maps and map matching, Particle Filters seem to be a usefull extension to the that. Real world measurements like distance and direction can be taken into account and further on be used in Map Matching.

**Hidden Markov Model(HMM)** The Hidden Markov Model is a statistical model based on a dynamic baysian network. The idea behind the HMM is a state based system where every state transition is random. Furthermore every transition has a probability depending on the current state. No history is involved. Additionaly these transition probabilitys are constant considering time. The state model is not known (hidden) whereas every state has its own emissions, outputs that occure with a certain probability. A sequence of emissions is used to jump to conclusions about the hidden state model. Yingjun Zhang et al used the Hidden Markov Model for pedestrian Navigation System in conjunction with MEMS Inertial Sensors, based on accelerometer and a special form of gyroscope with six degrees of freedom (Zhang, Liu, Yang, & Xing, 2015).

**Dempster-Shafer Theory** is a framework for reasoning with uncertainty used to apply a mathematical theory of evidence. The theory is based on believes and plausibility. A Believe is a probability assigned to sets of possibilities. For example an agent being in an area (area would be a set op possible locations). The plausibility would be the sum of events which do not contradict the assumptions of believe - i.e. single measurements (Reichardt, 2014).

In case of map matching degrees of belief could be assigned to different locations based on sensor information and combined with the conditions provided by the map.

# 3 Concept of discrete and reliable Indoor Positioning System

In the following sections we want to develop a trustworthy accurate and cost efficient indoor positioning system working in independent mode. To be able to do so the idea is to compare existing technologies on our three preconditions and learn from them. Therefore in the next section the measurements are defined followed by the comparison of the solutions worth considering. Then our concept is presented and discussed.

## 3.1 Measurements

The three measurements we have chosen are directly concluded by the goals for our indoor positioning system. Trustworthiness is the only measurement which is not measurable directly but it is possible to derive measurements by more accurate defining trustworthiness.

### 3.1.1 Trustworthiness

Trustworthy means that data privacy is guaranteed. To ensure this in general systems which collect, use and handle personal data underlay restrictions by law. However, many companies as well as cities are interested in Data Mining. (Data Mining is of high importance for many decision making processes and getting even more important in times of Big Data.) Since we are talking about personal data like who was when where it is of high importance that this information cannot be tracked back to one specific person. Therefor only anonymized data is stored and analyzed. In the german Bundesdatenschutzgesetz § 3 Abs. 6 Data anonymization is defined as: "Anonymisieren ist das Verändern personenbezogener Daten derart, dass die Einzelangaben über persönliche oder sachliche Verhältnisse nicht mehr oder nur mit einem unverhältnismäßig großen Aufwand an Zeit, Kosten und Arbeitskraft einer bestimmten oder bestimmbaren natürlichen Person zugeordnet werden können." (Deutscher-Bundestag, 2014)

(translated from German)

"Anonymizing is manipulating personal Data in such a way that it is not, or only with a excessive effort in time, cost and manpower possible to match the single information - containing personal or factual coherences - to one determined or determinable individual." (Deutscher-Bundestag, 2014)

For the later measurement on trustworthyness we won't focus on the amount of data collected, but on the way it is, or could be collected. Thus a solution that collects only sparse data, but is able to determine the individuals is ranked less than one which collects a huge amount of data but is unable to determine the individual. For later comparison trustworthiness is roughly estimated in percent.

### 3.1.2 Accuracy

Accuracy can be measured by exact values in three or two dimensional space. Given a variable $S$ containing the real positions and a variable $Z$ containing the assumed positions accuracy is defined as $\Delta = |S - Z|$.

### 3.1.3 Expected Cost

We define expected costs as cost for 10.000 square meters for one year including the implementation and additional fixed cost for services like a server providing constraint information. Cost per square meter is only possible to determine for solutions requiring a special infrastructure like WiFi or iBeacons. Solutions relying on infrastructure independent sensors (i.e. gyroscope and accelerator) are currently all assisted by constraint services.

Cost efficiency can be calculated by setting the measurements in relation to each other. Therefore we define that efficiency is an index without any bounds. Since trustworthiness is an estimated value in percent it could be used to influence the result directly by multiplication. For the accuracy smaller values are better. Thus the expected cost need to be divided by the accuracy. This leads to the function
$efficiency = (cost/accuracy) * trustworthiness.$

## 3.2 Compared Existing Systems

Under consideration of the Smart City context and the fact that we are focusing on systems working in independent mode (i.a. because the infrastructure mode collects data without knowledge of the user) the following use cases of the previous collection are still covered.

1. General Indoor Navigation (with all its sub use cases)
2. Personalized and Augmented Experiences
3. People and Object tracking by active clients only
4. Robotics
5. Real Life Social Networks
6. Geofences

Not covered are:

1. Proximity marketing, because our system is not about determining proximity, it is about determining a location.
2. Location analytics, because every of the compared solutions could be extended by an analytic tool if the user agrees to forward his positions by various solutions - thus our later described solution.
3. People and Object tracking by active sensors which we expect to be the more favored by customers.

To cover these use cases solutions currently on the marked and able to work in Smart Cities are compared. The list of solutions is provided in the next section.

### 3.2.1 Systems Worth Considering

As systems worth considering different solutions covering subsets of the covered use cases are taken into account. Since not every solution on the market can be considered, we tried to cover all use cases and all presented technologies on hardware site. Which algorithms are used in the background is often not published thus we wouldn't have been able to find enough solutions to compare the algorithms with at least a little bit of objectivity. The compared solutions are given in the next table:

| **Solution** | **Technologies** | **Use Cases** |
|---|---|---|
| Indoo.rs | Bluetooth 4.0 | Routing, Analytics and Proximity marketing |
| Estimote | iBeacons | SDK for Distance, Proximity and Notification |
| MazeMap | Flexible, but WiFi divided by Cisco is default | Interactive Indoor Map supporting indoor paths and positioning |
| infsoft | WiFi, Bluetooth 4.0 and internal sensors | Locating, Routing, Augmented Reality and Analytics |
| Sailstech | WiFi, Bluetooth 4.0 and internal sensors | Locating, Routing |
| Navizon | WiFi Fingerprinting (& Active Beacons) | Locating, Routing |
| Locata | Locata-GPS like | Locating, Routing |
| ByteLight | LED light patters, Bluetooth, internal sensors | Routing, Proximity Marketing |
| IndoorAtlas | Magnetic Flux | Locating, Routing |

### 3.2.2 The Comparison

The following information was collected and estimated for the named solutions:

**Indoo.rs** installed a Indoor navigation system at San Francisco International Airport (SFO) mentioned in the introduction (Yakel, 2014). The complete solution is built on Bluetooth 4.0 beacons. They do both proximity measurements and fingerprinting. If the corresponding app is installed in the navigation device it can work offline. If enabled real-time data collection is also provided. According to the Beacon calculator provided by indoo.rs for 10.000$m^2$ around 150 Beacons would be needed (indoo.rs, 2015). (The following prices have been found on 7th May 2015: StickNFind: $24 per beacon, shop.beaconinside.com: $18 per iBeacon, shop.kontakt.io: $20 per Beacon, bluesensenet-works.com: around $20 per beacon. For our rough calculations 20$ per beacon is assumed. And the small but full featured package is given with $95 per month. For one year minimal cost would be $150 * \$20 + 12 * \$95 = \$4140$. An additional amount of development or adaption cost for an app and install the beacons at the customer site is not included.nOn their website the accuracy is given with up to 2 meters (indoo.rs, 2015).

The trustworthiness is hard to estimate since the solution is able to work offline but if enabled can provide real-time data collection and analytics. The last feature is optional and analyzing could be done with anonymized data. For the comparisson we assigned 90% to tis value.

**Estimote** installed a solution using iBeacons at London's Heathrow airport and Britain's Odeon Cinemas also mentioned in the introduction. Estimote itself is focusing on SDK development for routing, analytics & proximity marketing. Since the SDK provides Distance measurements with trilateration localization can be implemented. Pricing is given with $198 for 6 iBeacons on the website and an unknown volume discount is offered for larger quantity (Estimote, 2015). Assuming that the discount is around $5 and still 150 beacons are needed the price would be $150 * \$25 = \$3750$ for the hardware plus additional individual cost on application development and installation. The accuracy is assumed with 2 meters the same as is for indoo.rs.

Since the application programming would be done customized the trustworthiness can be taken as 100%.

**MazeMap** originaly a Campus Guide, from the NTNU Gloshaugen Campus in Norway and now available for enterprises (Jelle & Kaaro, 2014), (MazeMap, 2015). MazeMap now is focusing on IndoorMaps that "are searchable, linkable, user-friendly and always up-to-date" (MazeMap, 2015). For positioning they are writing "MazeMap can integrate with your Wi-Fi network or with other indoor location sources" (MazeMap, 2015). Since they are partnering with Cisco for Wifi positioning. Cisco itself uses a location aware WLAN Design with angle and distance based measurements and WiFi Fingerprinting for location determination (Cisco, 2008). To implement this service not necessarily new hardware is needed. For the pricing they are writing: "The basic bundle has an establishement cost of \$0.15/$m^2$. For feature add-ons, such as integration API and floorplan updates, pricing is giving upon request." (MazeMap, 2015). While the basic bundle does not include indoor positioning and indoor path. However assuming a doubled price for 10000$m^2$ \$3000 and again plus additional individual cost on application development and installation.

Since the positioning itself is not part of this solution and the map is able to work with both independent and infrastructure mode a statement on trustworthiness is not possible.

This solution is still in the list because MazeMap delivers a key element of every positioning systems and the map could be used for precise Map Matching. However it is not listed below because it could be linked to every solution, has no fixed accuracy, cost or trustworthiness. (Deep Map SDK and Visioglobe (European leader) are alternatives to MazeMap. Even Open Streetmap now offers Indoor Mapping.)

**infsoft** offers a solution in infrastructure mode and one in independent mode. The one in independent mode uses WiFi and internal sensors (gyroscope etc.) which can optionally be enhanced by Bluetooth Beacons. The accuracy is advertised wit 1m only, and there is no word on pricing on their website. In independent mode trustworthiness is guarantied accorting to their statement "The application periodically transmits the current position to the server, so that all smartphones using the application can be tracked. No personal data is captured, so that infsoft Indoor Location Analytics can be used in compliance with data protection regulations." infsoft (2015). In infrastructure mode the devices can be tracked without any knowledge of the customer. In both cases the tracked person does not have any choice or does not even know that he is tracked. This fact reduces the trustworthiness for us to 70%.

**Sailstech** is a public project. The provider of a solution using Sailstech is completely free in the effort it invests. The softwaretools to use however are fixed: JOSM, SAILS MRE, BuildNGO and the SAILS SDK. The development costs, accuracy and trustworthiness for a project with Sailstech will highly depend on the goals of the project. Thats why we decided to not include the solution in the table below.

**Navizon** can be seen as direct competitor of infsoft. They are also providing positioning in infrastructure as well as independent mode. In independent mode accuracy is given with below 1m for iOS and Android and about 3m for other OS (Navizon, 2014). The solution uses WiFi fingerprinting as main technology for positioning (Navizon, 2014). The decision if the determined location is transmitted to an analyzing server or not can be made during application development. Therefore trustworthiness is high and the costs are again depending on the use case specifications. In Infrastructure Mode Active Navizon Beacons can determine the location of every WiFi enabled device - but this is not of importance for the comparison.

**Locata** invented its own GPS like technology "that creates terrestrial networks that function as a 'local ground-based replica' of GPS-style positionin" (Locata, 2014). Locata is suitable for wide area positioning system, but still does work inside due to a received signal strength of $-84dBm$ at $10km$ and $-64dBm$ at $1km$ from the LocataLite compared to the strongest GPS satellite signal of $-125dBm$ (Locata, 2014). This technology thus would be suitable to be installed at a whole urban area, but special receivers are needed. The potential of this technology are high if the major smartphone and GPS manufacturers consider to implement Locata receivers. The trustworthiness of this solutions is as high as it is for GPS - which is 100% - because only receivers are able to locate themselves.

Locata is a big opportunity for cities and even states to improve existing positioning systems and making indoor positioning in all buildings available at once. However such a project does not add any value to a cities infrastructure until receivers are not implemented into the commonly used devices.

**ByteLight** is combining light patterns with bluetooth 4.0 and internal sensors. The light patterns increase the accuracy reached by bluetooth only solutions to less than one meter. In addition to all the other solutions the front camera needs to be enabled during positioning (ByteLight, 2015). Trustworthiness is again could be a problem. The ByteLight platform is designed for personalized proximity marketing in the focus. Therefore the sharing of personalized data is one goal and trustworthiness would depend on how the data is stored. We decided to assign only 50% of trustworthiness to this solution.

**IndoorAtlas** is focusing on magnetic flux and providing a cloud based solution. The SDK they provide enables the development of an indoor navigation app with three steps: At first the maps are uploaded to the IndoorAtlas Cloud, the IndoorAtlas app is used to record a magnetic flux map and afterwards the own app can be developed (IndoorAtlas, 2015). Since the use case is not given or limited by the SDK the trustworthiness won't be causing any problems and pricing starts at $99 per month for use of the cloud of IndoorAtlas.

Finally a comment to the **In-Location Alliance**, a cooperation between more than 20 members with the goal to accelerate indoor position solutions. This alliance announced three winners of a best use case contest 2014. The winners are indoo.rs with the San Francisco International Airport project, infsoft and vodafone for a solution at vodafones campus in Düsseldorf and iMap as well as Sailstech with a solution at the largest station in Taiwan - Taipei Railway Station (Celusak, 2015).

| **Solution** | **Accuracy** | **Costs** $10000m^2$ | **Trustw.** | **Efficiency** |
|---|---|---|---|---|
| Indoo.rs | 2m | $4140 + $x | 90% | $e = ((4140+x)/2) * 0.9$ |
| Estimote | 2m | $3750 + x $ | 100% | $e = ((3750+x)/2) * 0.9$ |
| infsoft | 1m | $x | 70% | $e = x * 0.7$ |
| Navizon | 1m | $x | 100% | $e = x * 1$ |
| Locata | 0.1m | $y | 100% | $e = 10 * y$ |
| ByteLight | <1m | $x | 70% | $e > x/2$ |
| IndoorAtlas | 2m | $1200 + z | 100% | $e = z/2$ |

### 3.2.3 The Winner

Assuming $x$ to be high the range of costs for a solution is not as much influenced by the technologies as it is by the use case. We expect the overall costs for a Locata solution ($y$) much more expensive than for every other solution. However the average cost per square meter can be much less than for a single building or campus solution. So far this is only speculation and we will focus on solutions suitable for implementation not to far in the future. Assuming that the implementing team would always be the same ($x$) - the highest efficiency is reached by Navizon. Only IndoorAtlas is expected to be cheaper since the setup using the SDK is done by using only three simple steps without any special hardware needed and the software is provided for free.

Summarizing it is remarkable that most of the solutions are hybrids and use different sensors to calculate the position. WiFi and Bluetooth based positioning is used by the most solutions. The fact that fingerprinting can be achieved using manual fingerprinting, additional infrastructure or crowdsourcing - relying on users willing to share sensitive sensor and location information - is one big disadvantage of all these solutions (Mariakakis et al., 2015). (A new technology in development using round trip signal propagation (Time-of-Flight) could possibly be a solution to this problem for WiFi (Mariakakis et al., 2015).) The alternative to use light patters is only applicable in special use cases where the navigation device can be assumed to have a camera with a clear view to the ceiling.

But before we start designing our own system we decided to run some experiments to test some hypothesis regarding single positioning technologies.

## 3.3 Preliminary Consideration of Experiments

The two big competitors indoo.rs and estimote are both using iBeacons. While indoo.rs is using both fingerprinting and proximity measurements estimote is focusing on proximity measurements. Due to this we decided to make some experiments to decide which method to use.

Then there is IndoorAtlas mainly relying on Magnetic Flux measurements. The question which popped up in our minds was: Is it possible to locate a device inside a environment with a little amount of metal?

In the following section three experiments to answer the design questions are described.

### 3.3.1 Proximity measurements with iBeacons

**Hypothesis:** It is better to focus on Bluetooth proximity measurements then fingerprinting.

**Experiment design:** In our test environment we set up two Bluetooth beacons as shown in figure 9. The proximity will be measured based on signal strength in all the 20 marked points. The shown walls and landmarks are barriers for the signals.

If the results will show that the measured distances are highly influenced by these barriers we could assume that proximity measurements are not the way of choice. (Proof by contradiction.)

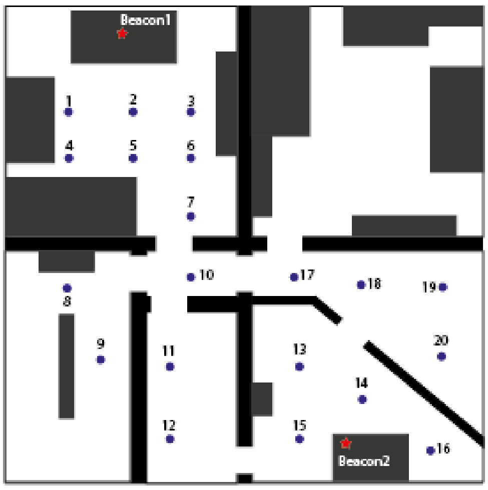


Figure 9: 20 positions for measurements in our test environment ($9.5m \times 9.5m$).

**Evaluation:** In figure 10 the measured values of *Beacon 1* are shown for the 20 points. In figure 11 the measured values of *Beacon 2* are shown for the 20 points.

As we can observe the measured values are up to $30m$ in an $9.5mx9.5m$ environment. This already shows that direct distance measurements are not very accurate. In more

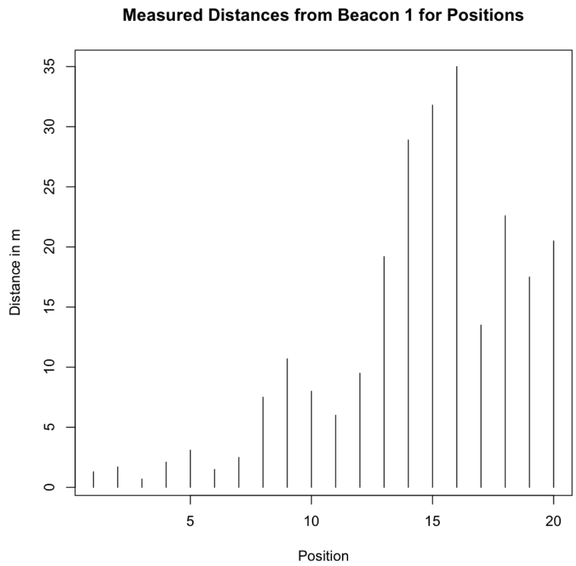


Figure 10: Measured distances from Beacon 1 for the 20 locations

detail we can observe for *Beacon 1* that the measured distance at position 9 is higher than on position 12 while the bee-line is shorter for position 9.

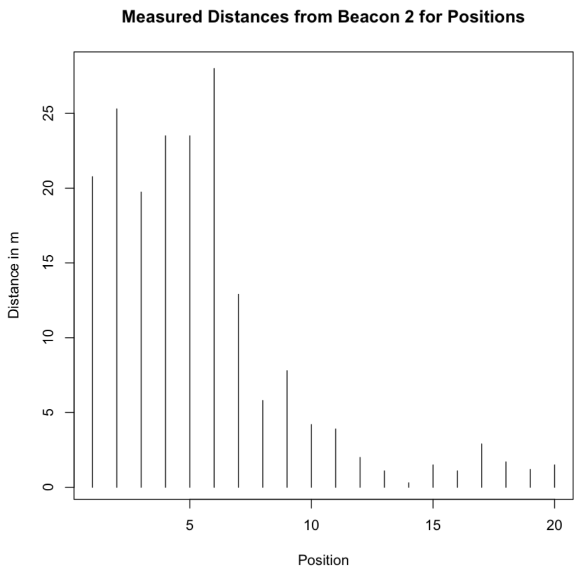


Figure 11: Measured distances from Beacon 2 for the 20 locations

However we are able to observe that the values are highly depending on the barriers and that there are individual combinations of the values from the two beacons. Due to this fact a fingerprinting map is possible with only two beacons. This leads to the next experiment where we try to proof that the fingerprinting map is the method of choice.

**Hypothesis:** It is better to focus on Bluetooth fingerprinting then on proximity measurements.

**Experiment design:** For a proof by contradiction - to show that fingerprinting is not better than direct proximity measurements we use the weak point of the fingerprinting map. The fingerprinting map assumes a static environment. Only if in every point in time at a specified location the measurements will have nearly the same values as stored in the map they could be matched.

Thus we need to show that a simple dynamic change will adulterating the results to much for a fingerprinting map. The simplest dynamic change we can assume is the body of the person navigating through the environment.

For this experiment we used only one Beacon placed in a way that a direct path for measurement is possible and made measurements on distances $1m$, $5m$ and $8m$. For every distance we collect 10 measurements for the direct path and 10 with a body between Beacon and the receiving device.

In figure 13 the three points of measurement are marked.

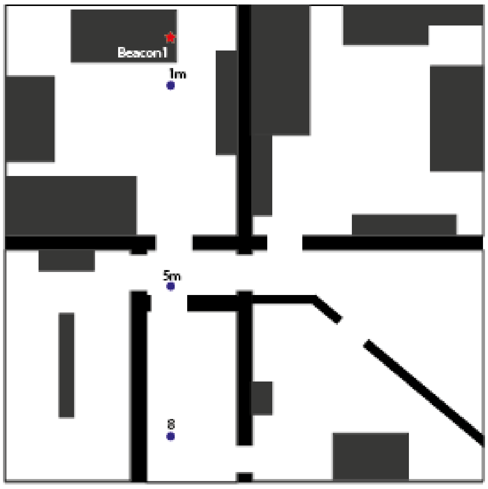


Figure 12: 3 Distance measurements with a direct path.

**Evaluation:** In figure 13 the boxplots for the measurements at the different positions are shown. Always at first the measurement without a barrier and the second one with a body as barrier.

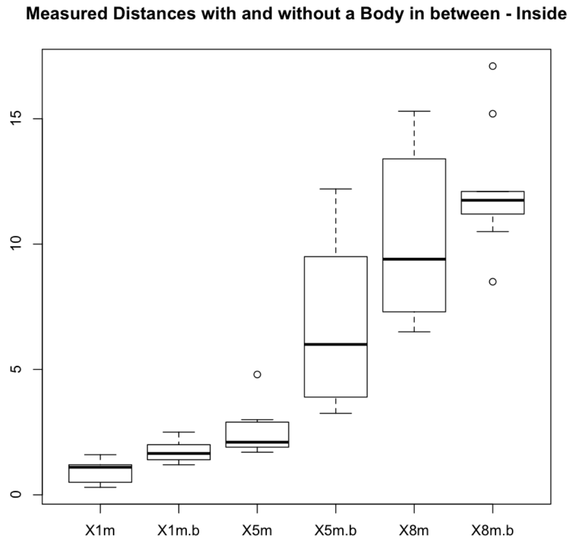


Figure 13: Boxplots of proximity measurements with and without a body in between (Inside).

If we combine the measurements with and without barrier we have a maximum difference above 10m (for mean values still 4m). This already shows that even fingerprinting maps could not be used to determine a accurate position.

Surprisingly the diffusion rate of the measurements grows with the distance except for the last measurement (at 8m distance with barrier). Our assumption was that the reflection of the signal results in multi-path measurements for the higher distances, which would explain the higher diffusion rate. For position 3 the body maybe screening-off a lot of possible path which results in a lower diffusion rate (with outliers) again. However we decided to explain the effect by a third experiment.

**Experiment design:** To avoid refections and therefor multi path measurements we decided to repeat our measurements outside on wide grassland. Again we measured at a distance of $1m$, $5m$ and $8m$ one time with and the second time without a body as barrier.

**Evaluation:** The results in figure 14 show that the variance does not grow as much as in the experiment before. Even more the variance grows with the barrier more than with the distance. The theory that the multipath effect caused the big variance fits to these results. This leads to the assumption that the most of the measurements are direct path signals which have been evaluated. Then the measured distance for 5m with barrier is higher than for 8m without body, and the measurement for 8m with barrier is far above 20m while it was below 15m indoors. Which fits to our theory again.

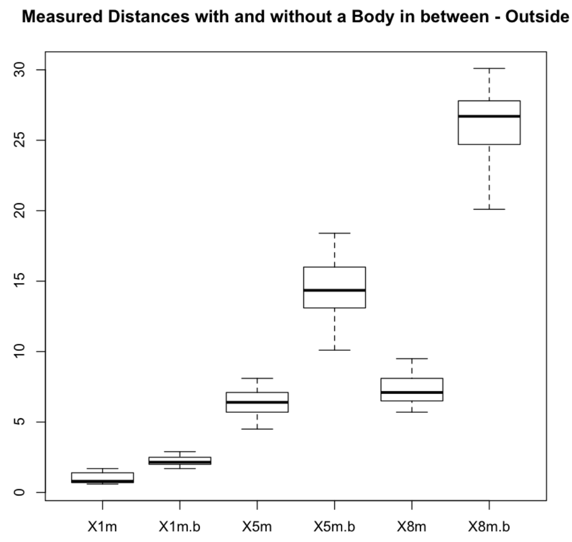


Figure 14: Boxplots of proximity measurements with and without a body in between (Outside).

**Conclusion of Beacon Experiments:** Neither proximity measurements nor fingerprinting map are providing results beyond doubt. The reflection rate and possible multipath measurement can highly influence measurements if no direct path is given. Even the position of the person navigating through an environment can adulterate the measure signals.

These results show that a positioning system cannot trust absolute values. Only the deltas between signal strengths should be taken into account. To assure measurement deltas resulting of dynamic changes like a person passing the signal path wont affect the positioning evaluation of internal sensors will help out.

However a combination of proximity and fingerprinting will be the best choice for our system.

### 3.3.2 Magnetic flux in a house without steel

At the beginning of this chapter we already denoted the Question: "Is it possible to locate a device inside a environment with a little amount of metal using magnetic flux?". We assume that the system IndoorAtlas sells is working in the most of the offices and public buildings having a lot of metal in it. However in a smart city there may be places with less steel.

**Hypothesis:** It is possible to locate a device inside a environment with a little amount of metal using magnetic flux.

**Experiment design:** For this experiment we use the same test environment (inside of a wooden building). Since IndoorAtlas is providing a free iOS app for Development we just used this app. After downloading the app we needed to upload our indoor map into the IndoorAtlas Cloud. Then for calibration we needed to place a path on the map and then walk along this path in an constant speed. After doing so for half an hour we assumed to have a reliable map. We tested the map using again predefined test path. For out own tests we then tried to locate ourself while walking through the mapped area.

**Evaluation:** In figure 15 the real position versus the measured position is shown for four situations.

The test results partly contradict our hypothesis. In this small area the possible paths should have been a small set. However the positioning failed. Therefore we cannot assume that magnetic flux is a feasible solution in all environments.

**Conclusion:** This experiment shows that the positioning does not work very well in our test environment. We conclude that the magnetic flux measurement should only influence the result in an metal full environment. The later described filter combining different sensor data should take this into account. Even more the magnetic flux map shows that there are no individual magnetic flux values allowing us to find a concrete position on a map. It is more a magnetic flux path - the measurements taken during

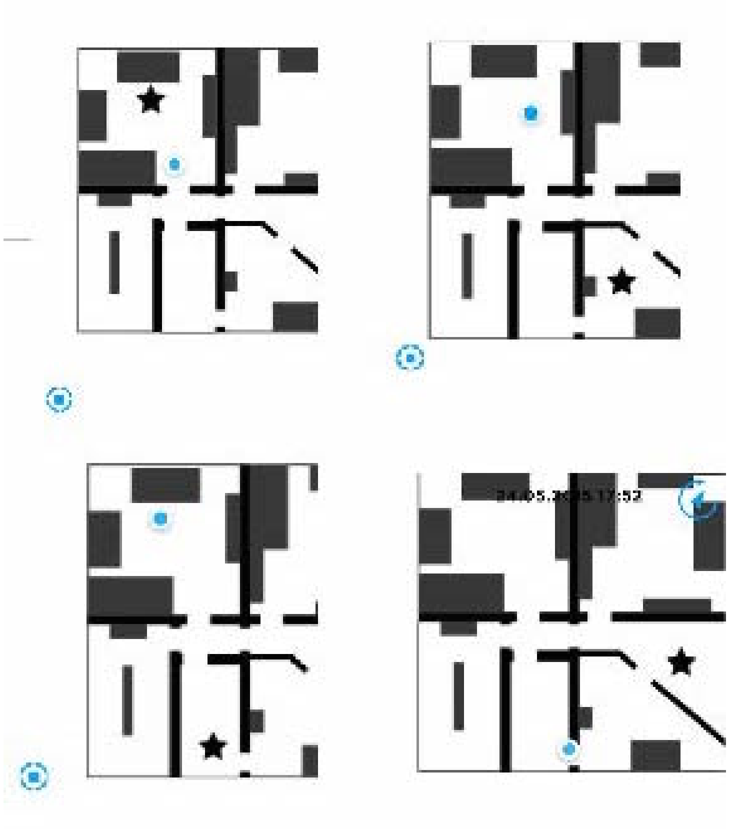

Figure 15: The real position (star) versus the measured position (dot).

some steps give magnetic flux changes characteristic for an specific area. In case of large buildings there will be steel graders influencing the magnetic flux much more. However it could happen that these steel graders are placed all in fixed distances resulting in self-repeating magnetic flux patterns. Altogether we can say that we are able to use Bluetooth to determine a rough absolute position and magnetic flux measurements to find the most likely path of movement (and thus position) inside this area. Since the results of the Bluetooth experiments show that the absolute position will be a very rough one.

Now we take a short look at Wifi fingerprinting and internal sensor data in praxis.

#### 3.3.3 WiFi Fingerprint

Only a short look at for different WiFi signals in the test environment in figure 16 shows that determining absolute positions using WiFi won't be a big problem if there are enough access points in the area.

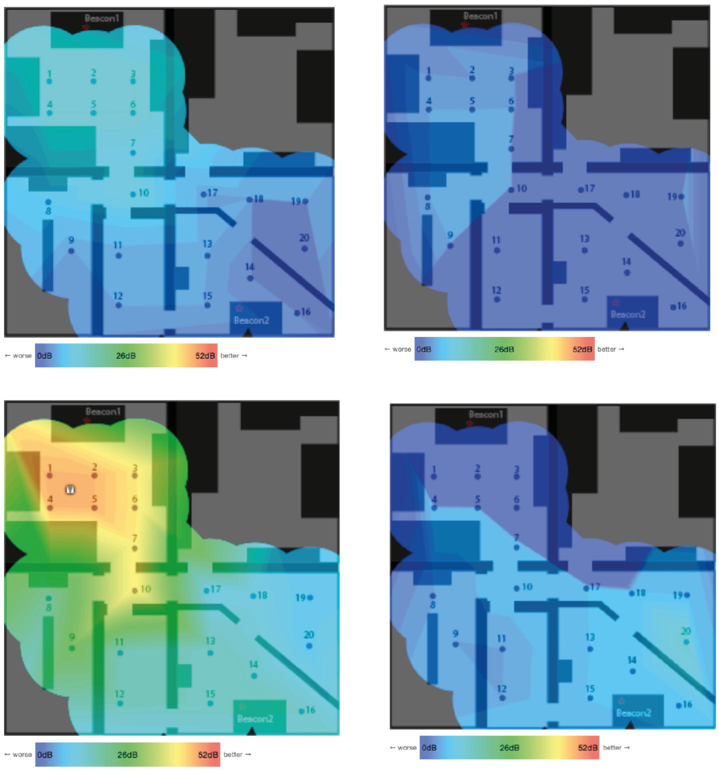


Figure 16: Four fingerprint maps of WiFi signals in the test environment.

Since not all WiFi signals have the same source the combination of at least three Access Points will enable a rough absolute positioning comparable to Bluetooth.

### 3.3.4 Internal Sensors

None of the above methods could enable a accurate and stable service of positioning. However a rough absolute positioning is possible using beacons and WiFi. In these rough determined areas which can be assumed being reliable magnetic flux measurements can be used to state more precisely which area is the most likely one.

However to enable accurate positioning the evaluation of internal sensors is the best chance. To just show that a accurate positioning is possible we present the sensor data for different movements.

At first a simple rotation. The rotation can be observed very accurate using the magnetometer, since it can be used to determine the absolute alignment to the magnetic field of the earth. In figure 17 a horizontal rotation is shown. The rotation is represented in sinus curves.

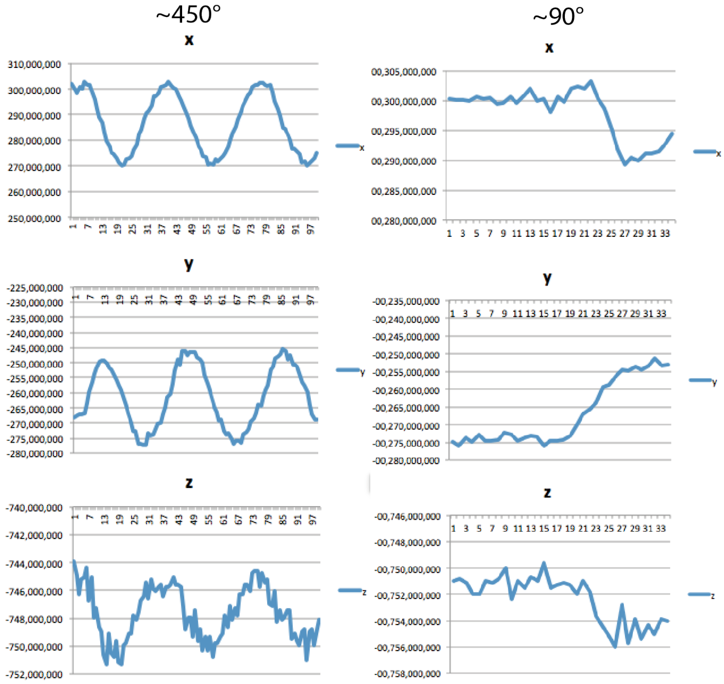


Figure 17: Measurements of the magnetometer for two different rotations.

Simple steps are shown in figure 18. They can easily count by finding all local maximum and minimum values.

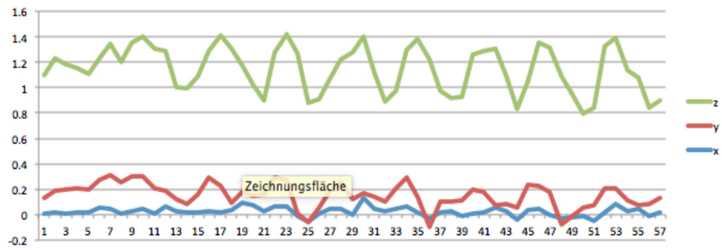


Figure 18: Measurements of the accelerometer for steps on a straight line.

In figure 19 both movements are combined by going around an edge. We can observe the steps in the measurements of the accelerometer and are able to see the rotation in the measurements of the gyroscope and the accelerometer.

Even if these measurements can be interpreted easily there are situations where they can by misleading. For example measurements of the accelerometer, gyroscope and magnetometer measurements for going around an edge are very similar to rotating the phone while walking (visible in figure 21).

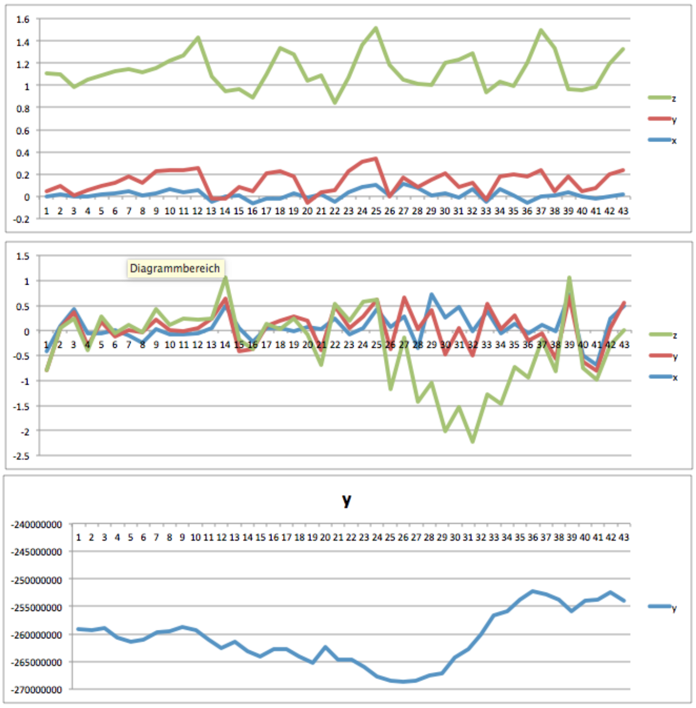


Figure 19: Measurements of the accelerometer (1), gyroscope (2) and magnetometer in y-axis (3) are shown for going around an edge.

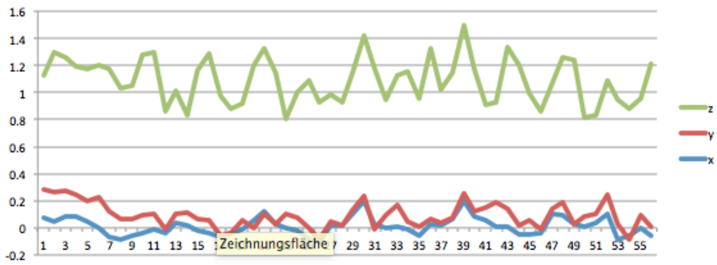


Figure 20: Measurements of the accelerometer going stairs up.

Another example are stairs (see figure 20) which are very similar to regular steps. Therefore the barometer will hopefully clarify the situation. Unfortunately we have not been able to make an experiment with an barometer.

However this background knowledge is now applied to our own system design.

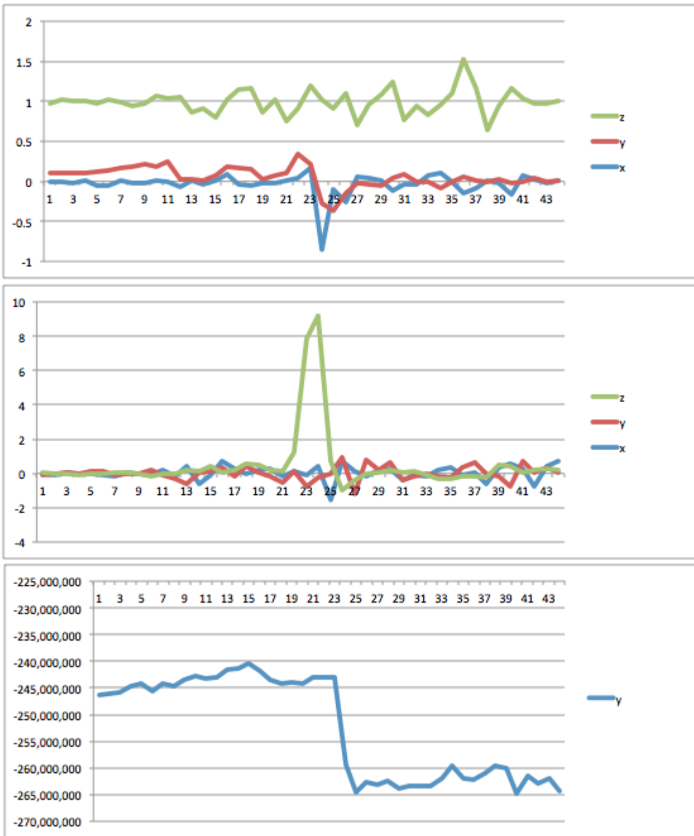


Figure 21: Measurements of the accelerometer (1), gyroscope (2) and magnetometer in y-axis (3) are shown for rotating the phone while walking a strait line.

## 3.4 The Concept

The concept of the system architecture we are designing had the goal for a high overall efficiency. We decided to use a modular approach for the solution to make sure that different Smart City needs can be fulfilled. To guaranty trustworthiness and reach social acceptance we suggest to stick to the concept of the MIT and give the user ability to choose which and how much information he want to share.

In the next steps we explain our decision for different technologies presenting the model and discuss the advantages and disadvantages of this model.

The model contains three main elements: Sensors, Constraints and Filters. Clients could just load the constraints from one application server or they are already included into the app before they are applied through filters to the sensor data.

In figure 22 the model is shown. The infrastructure contains WiFi Access Points and Bluetooth. In the most buildings Wifi is already provided and no additional infrastructure

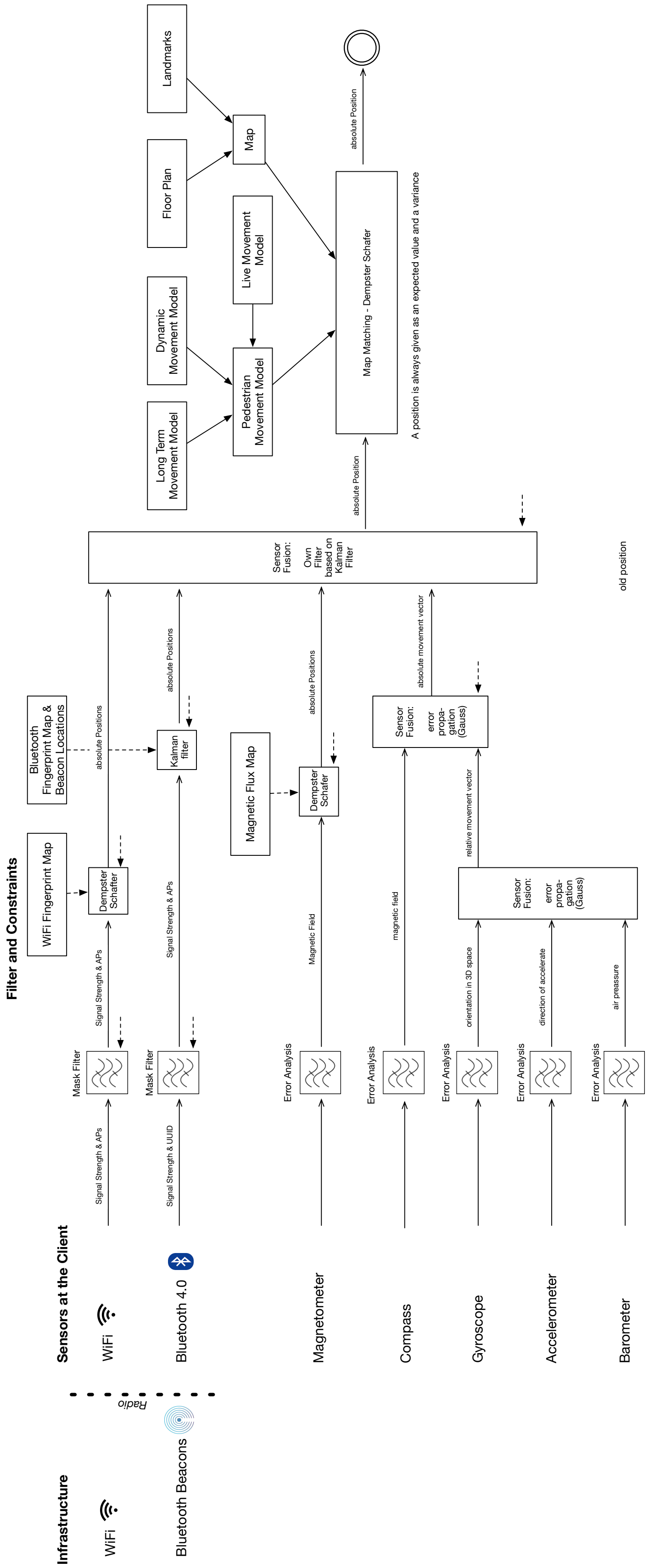


Figure 22: Concept of a new Indoor Positioning System

has to be deployed. By just monitoring signal strength and access points no direct communication between AP and Client needs to be established. Signal strength and access points in reachable range enable us to use fingerprinting. It is not possible to use energy of the direct path and the Time of Flight of direct path calculations without communication between client and AP. The measured signals strengths from different access points are filtered by a modified mask filter - like the one for GPS explained in section 2.7 - and flagged if they can be identified as unreliable.

After enough measurements to ($> 30$) for each AP have been collected a Dempster Schafer is applied to combine the measurements with the WiFi Fingerprint map and the previous position - as output an absolute position in form of an expected value $\mu$ and the associated variance $\sigma^2$ for every dimension is given.

Unlike for WiFi, Bluetooth beacons need to be installed in the infrastructure. However Bluetooth beacons are working with Buetooth Low Energy and are able to work with batteries for longer time. There are two major advantages of using both Bluetooth and Wifi. First the technologies complement each other and improve overall positioning, second they backup each other. Thus devices with disabled Bluetooth or WiFi are still able to calculate acceptable positioning information. Additional devices not supporting Bluetooth 4.0 are able to locate themselves. The received Bluetooth signals are marked by a mask filter and afterwards interpreted using a Kalman filter and a corresponding Bluetooth fingerprint map. (Kalman filter is used here to take advantages of Kalman and Demster Shafer if both Bluetooth and WiFi is available) Again the output would be an absolute position.

We decided to not use GPS, ZigBee or Locata in first place since GPS is to unreliable indoors and the average moblie device does not support ZigBee or Locata. Even if the LED solution could enhance the systems performance especially to differentiate between different floors in the same design we decided us against it because of an big overhead on development of non reusable components for the initial solution.

The magnetometer could improve the performance and would not increase development effort too much. The principle applied is the same as it is for WiFi and Bluetooth.

Therefore all fingerprint maps can be generated at once. For the first filtering to smooth the sensor data we want do use error analysis and throw out outliers. The matching of the measured information to the magnetic flux map again is done using a Kalman filter.

All of the described above strategies are ranging between 1 and 2m accuracy. The output of each sensor interpretation is already a position on a map. The internal sensors Gyroscope, Accelerometer Barometer and Compass need to be interpreted to derive a movement vector which then can be applied to the previous position to calculate an absolute position.

As a first step to get an relative movement vector the signals of Accelerometer, Gyroscope and Barometer are taken. The Gyroscope gives the orientation in 3D space. Combined with the information of the accelerometer - which gives the direction of accelerate it is possible to calculate the direction of accelerate relative to a horizontal plane. Using the air pressure change the direction of the vector can be refined by means of angel to the plane. The relative movement vector (relative to the phones alignment orthographic projected onto the plane) can then be transformed into an absolute vector using the compass. This sensor fusion should be done using the principle of error propagation.

At this point there are four absolute positions derived using the different technologies which need to be combined. For this combination we decided to develop an own algorithm. The thoughts behind this decision are that all four positions will have different reliabilities which will be visible after testing. An implementation of the Kalman filter is not able to learn - or react to some at this moment unknown coherences but a modified version using a Kalman filter combine with a Bayesian network or even OneR-Algorithem known from Data Mining could fit our purpose. However the decision how to fuse these four given positions the best way could only be made after some field experiments and will be part of future work.

For Map Matching we decided to include different constraints. At first there are the Floor-plan and maybe highlighted and maybe dynamic landmarks. These two maps are combined just by putting one on top of the other. Then there are the movement models. All three movement models can be seen as heat-maps with hot areas with a lot of human traffic and cold areas where humans are less often. The long term movement model is generated using all tracked movement data of a long run (like a bulb exposure in photography). The dynamic movement model can be subject of different rules; Thus if there are patterns detected referencing different times of days in a week (e.g. every saturday at 10.00 till 18.00 o Clock high density of people) this patterns can be modeled in heat-maps again loaded at the expected time. The Live movement Model includes the accumulated data of a short time period. All three movement models are combined building the sum for each position with weights ($p_{ij} = x * long_{ij} + y * dyn_{ij} + z * live_{ij}$ where $i$ and $j$ are the coordinates defining a position and $x$, $y$ and $z$ are the weights). The weights cannot be define at this stage of the work. They will be subject of futur work again.

After the Pedestian Movement model and the Map are generated they both are combined in one step using Dempster-Schafer. To do so, for all positions considerable the plausibility is calculated using the Map and the Movement Model to find doubt for specific position.

To underline the decisions made in the concept we shortly summarize advantages and disadvantages of the design.

### 3.4.1 Advantages and Disadvantages

At this point we will discuss the concept again and measure ourself on the earlier defined measurements.

Trustworthiness at this point is easy to answer. Our solution will enable every device to locate itself after initially loading the available constraints from a central service. After this has been done no further communication - including forwarding location information - to the system provider is necessary. Thus the whole system is able to run without any feedback data from the user except the pedestrian movement model. This movement model however could be generated with highly accumulated and anonymized data colleced from users willing to share information. In summary we won't expect any trustworthiness issues since "privacy by design" is part of the concept.

Accuracy is at this point unknown but we expect to be able to allow positioning with accuracy below $1.5m$. This looking at the accuracy of the compareable solutions of infsoft and Navizon of $1m$ this is our pessimistic guesstimate. An optimistic value is $< 1m$ and our goal for further developments. One advantage of the described concept regarding accuracy is that in all stages measurement errors are propagated and thus no measurement will be lost. All this information is then included into the Map matching process and our unique concept of movement models. Another advantage is that all filters are replaceable and field tests of different realization of the same structure are possible. The corresponding disadvantage is that the development of an optimal solution will need a huge amount of tests and development effort. However the modular structure allows a step by step development with continuous improvements.

Cost efficiency is tried to realize by this stated step by step development and a small working sub-solution. Due to this, the localization will later on work even if WiFi or Bluetooth is turned of. Additional Hardware will only be needed for the Bluetooth beacons and no infrastructure changes are necessary. In fast moving environments however the effort of generating Fingerprints could be enormous if there are not enough users willing to share their measurements.

At a last step we check which of the chosen use cases are covered.

### 3.4.2 Use Cases covered

With this solution positioning is guarantied and therefor all the focused use cases can be realized. General Indoor Navigation with all its sub use cases, Personalized and Augmented Experience, People and Object tracking by active clients only real life social networks, robotics and more are possible. For proximity marketing the effort would not be in proportion with the return. Location analytics would be possible partly being aware that all very private users are missing in the statistic.

# 4 Conclusion

This paper covers an approach for indoor navigation systems for Smart Cities by first defining the buzzwords. Indoor navigation systems are based on technologies separated into two divisions Non-radio technologies rely on sensors like magnetometer, compass, gyroscope, accelerometer and barometer and Radio technologies using access points in form of iBeacons, WiFi hotspots, NFC tags, GPS based sensors and some more. Considerations concerning trustworthiness and security issues are done to actually develop a solution which will most likely be adopted by the mass. The so called social acceptance is crucial to gain traction in the current floods of new technologies.

Further, algorithms like Central-Limit-Theorem, Dempster- Schafer and Bayesian Networks are taken into account to purify the information taken out of the sensors. To combine the gathered information sensor fusion is done by choosing the best fitting solution - a form of map matching - to actually get a real world location. Later criterias for measurements are defined which then are taken into account to work out a concept for an indoor positioning solution. This solution is based on independent technologies without bidirectional communication to its infrastructure. Further on no extra infrastructure has to be installed in case of WiFi, nor do mobile phone developers have to implement new technologies to later be shipped with their smart phones, this solution is based on exisiting technologies currently implemented into all common mobile devices. Approaches for data protection are hard to realize because every solution can push its location to servers which can be used to exploit personal information. To enable a secure environment focus lies on the security of steps taken until the user gets an absoulte position.

## 4.1 Reflection

Developing an Indoor Navigation System for the purposes of Smart City's emerged more complex as expected. The most people like us may have heard of the iBeacon solution for indoor navigation as a big innovative step in this area. The hype around iBeacons was enormous regarding proximity marketing and navigation. However looking deeper into the needs of a Smart City, supporting different kinds of locations and client devices as well as trustworthiness, it was foreseeable that iBeacons alone won't fit for everything.

That was the point where we started to research for alternative solutions covering different use cases and found the huge difference between solutions working in infrastructure and independent mode. Deriving from the smart city definitions that a city's first goal won't be surveillance (this may be different for the police) we decided to focus on services for the citizens - thus independent mode solutions.

Once we have found a suitable solution to convince citizens to adopt the new technology - by applying the step by step guide of the MIT including trustworthy explanations, honesty and patience - we were able to understand the properties a suitable indoor positioning system would have.

So we gathered informations about all suitable technologies allowing independent mode and compared them step by step. The differentiation between the technologies itself and the corresponding constraints mirrors our goal to reach transparency regarding data transfers. One of the most time consuming parts was understanding the found strategies and derive their conditions, advantages and disadvantages. Surprisingly different methods covered in Math and Knowledge based systems lectures came up as Sensor Fusion, Error correction or Filtering technique; This includes the Central-Limit-Theorem, Dempster-Schafer and Bayesian Networks.

At this point the original goal to implement a solution was dropped and we decided to compare the most common with some alternative indoor positioning vendors to be able to design a suitable solutions for smart cities and not just repeat mistakes people have done before us.

During this comparison we realized that there are only two types of possible solutions for the future. Either a system like the one Locata is developing: a wide area GPS like solution working indoors due to stronger signals. Or a hybrid solution combining all possible measurement and prediction methods to provide strongly reliable positioning. The one huge problem with Locata is that no common smartphone is able to receive the signals yet. We considered us unable to influence the big smartphone vendors in that matter, thus we decided to focus on an hybrid solution.

The development of the concept was strait forward regarding the rough structure. One goal of design - beside data privacy and accuracy - was to not lose any information on the way to the final assumed position. Another one was to be modular, using fixed data objects like absolute or relative positions to enable quick exchange of algorithms for dynamic and fast testing and later improvements. Decisions about the used filters have been more complicated. In some cases we are confident that only field tests can help finding the optimal filters.

Map Matching is the one thing being in early stages of development for pedestrians and on movement models we couldn't find suitable existing approaches. Thats why we transfered the swarm behavior of ants - using pheromones to help other finding optimal paths - to indoor positioning systems. This resulted in different types of movement heat-maps. Especially this improves current indoor positioning systems.

To sum up trustworthiness of our indoor positioning solution in a nutshell: "The Chosen One, the boy [solution] may be. Nevertheless, grave danger, I fear in his [its] training." (Yoda 1985).

All in all we found critical information recommendable to read before just installing any indoor positioning system, and are hoping that some approaches will prove their correctness in a working solution.

## 4.2 The Result

The key cognitions of this paper are:

1. In smart cities a high demand of indoor navigation systems is given.

2. Satisfying data privacy is possible using independent mode for localization and therefore applying sociological psychological educational and political concepts to communication will enable a success of this technology

3. All non-radio solutions must be assisted by radio solutions except the magnetometer and the 3Dsensor

    - the magnetometer needs the magnetic flux map to work properly and
    - the 3D sensor generates relative positions within its own imaged world.

4. Indoor positioning and location analytics are the most common and basic applications followed by proximity marketing and people and object tracking

5. Our experiments shows that there is no one method better than others, regarding Bluetooth fingerprinting and proximity measurements. Further more a combination of sensors, provided by the method of sensor fusion is the way to go.

6. Solutions using sensor fusion are the most accurate once. Using adequate Sensor Fusion and Filtering techniques is the key for a good accuracy. Furthermore technologies working with WiFi and Bluetooth are the majority just because all smartphone or wearable like devices can support them.

7. Map Matching as an extension to sensor fusion and filtering can improve the accuracy again and guaranties that users are not irritated by the position shown on the map.

8. The range of costs for a solution is not as much influenced by the technologies as expected. It depends more on the specific use case.

9. Locata would be a real city or state project and would enable indoor positioning in all buildings. This solution should be observed during the next years.

Based on these cognitions our own system architecture was built and is the main achievement. The modular structure enables continues development and improvement. Using statistical methods and error propagation the final result is based on all measurements combined in a strategic way.

## 4.3 Future Work

The next fundamental step would be to start an implementation and make a proof of concept. To do so at first data model and then input and output interfaces should be defined for the test environment. After that all the algorithms need to be implemented and tested. Then open questions on how to fuse the four given absolute positions before map matching and defining weights for the movement models need to be answered by field experiments.

Open questions besides accurate positioning are for example regarding the energy consumption. Especially in case of WiFi as positioning System. We do not expect Bluetooth 4.0 low energy and internal sensors to have a huge impact on battery live.

Besides the implementation a concrete business model and the realizations of the communication strategy are missing. We suggest a Canvas Business Model would fit our purposes.

Projects like FlySfo have to be observed for complications and user feedback to make further improvements. To actually measure social acceptance, long term studies have to be done.

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# Appendix

## A Further Smart City definitions

> [OECD (2011)] "A Smart City is a city well performing built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens."

> [Su, Li, and Fu (2011)] "Smart City is the product of Digital City combined with the Internet of Things."

To understand this quote one definition for Digital City follows:

> [Schuler (2002)] "A Digital City has at least two plausible meanings: (1) a city that is being transformed or re-oriented through digital technology and (2) a digital representation or reflection of some aspects of an actual or imagined city."

> [Northstream (2010)] "Concept of a Smart City where citizens, objects, utilities, etc., connect in a seamless manner using ubiquitous technologies, so as to significantly enhance the living experience in 21st century urban environments."

## B Experiment Data

### B.1 iBeacon Setup

We used two Raspberrypi's as iBeacons. To configure them we used these commands:

sudo apt-get update

sudo apt-get install libusb-dev

sudo apt-get install libdbus-1-dev

sudo apt-get install libglib2.0-dev –fix-missing

sudo apt-get install libudev-dev

sudo apt-get install libical-dev

sudo apt-get install libreadline-dev

sudo mkdir bluez

cd bluez

sudo wget www.kernel.org/pub/linux/bluetooth/bluez-5.18.tar.gz

sudo gunzip bluez-5.18.tar.gz

sudo tar xvf bluez-5.18.tar

cd bluez-5.18

sudo ./configure –disable-systemd

sudo make

sudo make install

sudo shutdown -r now

//on development machine to generate a unique UUID:

python -c 'import sys,uuid;sys.stdout.write(uuid.uuid4().hex)'|pbcopy && pbpaste && echo

//then back on the Raspberrypi

cd bluez/bluez-5.18

sudo tools/hciconfig hci0 up

sudo tools/hciconfig hci0 leadv 3

sudo tools/hciconfig hci0 noscan

sudo tools/hcitool -i hci0 cmd 0x08 0x0008 3d51edcce3774b429de181aa1f8ff52d 00 00 00 00 C8

The UUID of cause is different for both beacons.

## B.2 Raw measurements

In the next table the raw measurement data of to first experiment is shown:

| **Beacon1** | **Beacon2** |
|---|---|
| 1.3 | 20.77 |
| 1.7 | 25.3 |
| 0.7 | 19.74 |
| 2.1 | 23.5 |
| 3.1 | 23.5 |
| 1.5 | 28.0 |
| 2.5 | 12.9 |
| 7.5 | 5.8 |
| 10.7 | 7.8 |
| 8.0 | 4.2 |
| 6.0 | 3.9 |
| 9.5 | 2.0 |
| 19.2 | 1.1 |
| 28.9 | 0.3 |
| 31.8 | 1.5 |
| 35.0 | 1.1 |
| 13.5 | 2.9 |
| 22.6 | 1.7 |
| 17.5 | 1.2 |
| 20.5 | 1.5 |

The raw measurements of the indoor proximity experiment with and without a body as barrier.

| 1m | 1m with body | 5m | 5m with body | 8m | 8m with body |
|---|---|---|---|---|---|
| 1.3 | 2.0 | 4.8 | 3.25 | 15.3 | 8.5 |
| 1.6 | 1.6 | 3.0 | 3.9 | 8.3 | 10.5 |
| 0.5 | 1.4 | 2.7 | 4.0 | 7.5 | 11.2 |
| 0.45 | 1.2 | 2.1 | 7.5 | 10.5 | 11.5 |
| 0.3 | 1.4 | 1.7 | 10.3 | 11.4 | 17.1 |
| 1.2 | 1.7 | 1.9 | 9.5 | 7.3 | 12.1 |
| 1.2 | 1.6 | 2.1 | 6.1 | 7.0 | 11.7 |
| 1.0 | 1.7 | 2.9 | 5.9 | 6.5 | 11.8 |
| 1.2 | 2.0 | 1.9 | 12.2 | 15.3 | 12.0 |
| 0.6 | 2.5 | 1.7 | 3.9 | 13.4 | 15.2 |

The raw measurements of the outdoor proximity experiment with and without a body as barrier.

| 1m | 1m with body | 5m | 5m with body | 8m | 8m with body |
|---|---|---|---|---|---|
| 0.6 | 1.7 | 4.5 | 11.1 | 6.5 | 20.1 |
| 0.7 | 2.5 | 4.7 | 18.4 | 7.1 | 24.4 |
| 0.8 | 2.1 | 5.7 | 13.1 | 8.1 | 24.7 |
| 0.6 | 1.9 | 6.0 | 14.2 | 7.0 | 26.3 |
| 1.5 | 2.9 | 6.5 | 13.1 | 6.3 | 27.1 |
| 1.3 | 2.1 | 7.0 | 14.5 | 9.5 | 26.5 |
| 1.4 | 2.2 | 7.1 | 18.4 | 5.7 | 26.9 |
| 0.8 | 2.0 | 6.3 | 16.0 | 7.9 | 27.8 |
| 0.7 | 2.3 | 8.1 | 14.5 | 8.7 | 28.5 |
| 1.7 | 2.5 | 7.3 | 10.1 | 7.1 | 30.1 |

### B.3 Locate

As tool to measure the iBeacon data we used Locate developed by Radius Networks. In figure 23 is it shown that locate is collecting iBeacon locations to setup a global location location proximity service.

### B.4 Magnetic Flux Sceenshots

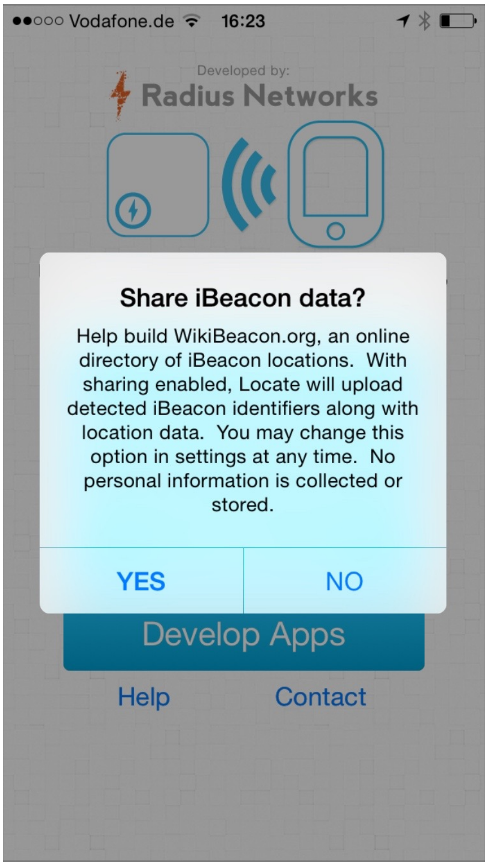


Figure 23: Radius Networks is collecting Bluetooth beacon location data.