Indoor Localization - Todays and Future Applications

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ABSTRACT
In this paper we discuss todays and future applications of indoor localization. To outline the large scale of indoor localization applications, we give an overview of several possible use cases and their specific requirements. We discuss the fundamentals of localization going into numerous different source technologies and mathematical approaches for general localization of target objects. Furthermore we go into the major problems of indoor localization and how these problems can be tackled using again mathematical and stochastical models. Finally, four applications of indoor localization are presented each aiming for a different use case scenario and using different technologies. After all, we discuss the future prospect in the research field of indoor localization applications.

Keywords
Indoor, Localization, Positioning, Lateration, Angulation, Fingerprinting, Accuracy, Tracking

1. INTRODUCTION
The disire to determine an objects location is a widely spread purpose. In biology, bats have developed a complex method using an echo system so they can move and hunt in totally darkness. In navigation, ships and airplanes need to know their position so that the maritime and air traffic can be handled safe and efficient. Nowadays more and more people carry small mobile devices like smartphones and tablets and the number of applications using the physical position of the device is increasing as well. Prominent examples are maps or route traveling services and even advertisements use location information by now. Due to this progress the require of an accurate localization system is also getting more important.
The most known system for this approach is the Global Positioning System (GPS) which can determine a devices position with an error less than 1 m. Using GPS modules may lead to additional cost and higher energy consumption, but in particular it is not feasible in most indoor scenarios, due to signal attenuation and multipath formation by the different materials.

For indoor localization there exists no solution yet that could be called state-of-the-art and the technical research direction varies as their use cases. In this paper we will discuss different approaches, use cases and their specific requirements for indoor localization and present some of todays representativ systems.

This paper is structured into five parts: this introduction is followed by a section giving an overview to different possible use cases, the requirements and how this influences the system design. In section 3 discuss the technical fundamentals of indoor localization and in section 4 we present some of the realized systems. Section 5 concludes this paper and gives a prospect to future research trend in indoor localization.

2. USE CASES
Indoor localization may be applied to a various spectrum of use cases as localization in general. The different utilizations have different requirements which have to be considered from the beginning.
The most popular use case might be indoor navigation espacially in large public buildings like a cathedral, mall or parking block. Visitors can then be guided by a service finding designated localitions or leading them out of a complex structure and back as well (e.g. to their car). Such navigation services often come along with additional location-based services like in a museum giving the user information that fits their current surroundings. But even in disaster scenarios navigation may become important as fire and rescue services could use this for finding shortest paths in large buildings, maybe with additional information e.g. finding sources of fire or of a raised alert.
Location-based services may of course also be used for convenience, as the term smart home becomes more and more reality. Localization services can optimize the usage of resources like heating, air-conditioning or lighting. But they may also create a new kind of autonomous control like adjusting the volume to a users position in home entertainment systems. And considering the urge for optimization such a system may facilitiate the realization of autonomous environments where robots navigate themselves like in a warehouse.

The previous examples were more or less initiated by a user localizing their own position or in a autonomous system the location of an actuator. But localization services may also enable tracking of people or objects and may be used with good or bad intentions. Having a surveillance system in e.g. a prison may be considered as right as it may help prevent attacks. But having the same system in a larger office to surveil your employees may be considered as wrong. So as in technical progress in general we have to consider ethical and maybe even legal aspects as the ability to track people leads to privacy issues.

This was just a brief overview of the variety of use cases for indoor localization and of course we cannot mention all possible scencarios. In general, indoor localization use cases can be divided into two parts regarded the major effort: either localizing yourself or localizing other ones or objects. Utilizations do partially intersect but they all have special requirements to the used technology, the system design, accuracy, the environment in which the system shall be realized and of course the cost factor.

2.1 Requirements

As already stated, the different use cases have different requirements. As it is in the nature of things, the cost factor always matters. But in some cases the cost of implementing a localization system may become one of the most important requirements. This espacially is the case in cost-benefit analysis when such a localization system shall reduce burden rate as an enterprise may want or need to decrease their employments. Considering the previous example of an surveillance system of detainees in a prison, this might reduce the required guards drastically and analog the cost. And maintenance of the system has to be considered as well as it may be a long-term cost factor.

Another important aspect is if the system has to be integrated into existing infrastructure or may not use specific technologies. Radio waves e.g. may not be applied in hospitals as they could interfere with medical systems. Or a system based on ambient sounds could not be applied in an environment with uncontinous noises, e.g. in a factory. Furthermore, adding additional hardware may also not be an option which may again come along with the cost factor. So there could be the constraint e.g. to use only the hardware of a standard smartphone, which restricts the possible technologies and methods.

The aim of acquiring a localization system itself already defines requirements. Localization can mean live tracking of an object, but it can also mean triggering actions by certain location-based events. This influences how the system architecture has to be designed. A surveillance system can not rely on interaction with the objects to be tracked, so such a system has to run passive and totally independent from the client. This is what we call a network-based localization system.
The opposite would be a client-based localization system where the system actively interacts with the object to be tracked or in fact maybe runs on the client stand-alone. Some use cases may require interaction with the client, in some it may be optional and could improve accuracy and reliability of the system. Espacially regarding privacy issues, a client-based system might be necessary.

As we can see, the requirements for building up an indoor localization system are strongly defined by the use cases it will be applied to. Some are technical, some are non-technical constraints and we can mereley take a look at a selection of them as they are highly individual. But they all have to be consider from the beginning as they define the system and not the other way around.

3. FUNDAMENTALS OF LOCALIZATION

In this section we will take a look at the technical background of indoor localization systems, what problems may be encountered and how they can be solved.

3.1 Technologies

To determine the location of an object you need reference signals from it. For that basically every kind of signal with a constant propagation speed that can again be captured can be used. We will only take a look at mechanical and electromagnetical waves as they are the most common for this approach [10].

Mechanical waves are bound to a medium and need e.g. air or water to propagate. A typical example of mechanical waves is ultrasound that propagates with the velocity of sound. A transmitter could generate sound signals and a receiver then exploits the signal. With additional information about the propagation speed of the signal the receiver retreives relative information about the transmitter, e.g. the distance between them.
Electromagnetic waves are not bound to a medium and propagate in vacuum as well as in matter, but are effected by reflection, absorption, refraction, interference and other phenomena as well. Examples for electromagnetic waves are light, radio and infrared. In general they all propagate with the speed of light, but the basic approach is the same as with mechanical waves, i.e. knowing the propagation speed a receiver can retreive the relative distance to the transmitter.

A different approach of using electromagnetic waves is ultra-wide band (UWB). In UWB no sine oscillations are being produced but impulses of a duration as short as possible. The width of the necessary frequency band is proportional to the impluse duration. UWB feature superb multi-path resistance due to the large frequency band [12]. Additonally, it is very energy efficient and provides a high bandwidth for communication.

Indoor localization systems mostly use ultrasound, infrared or radio waves. Approaches using ultrasound can easily be realized by just using a microphone and a sound generator and have the advantage that the hardware is cheap. Many devices are even already equipped with microphones like smarphones or laptops. As sound generator can serve a devices speaker as well as e.g. a human, so using ultrasound also has the advantage that is not only bound to technical devices.

Infrared is in usage similar to ultrasound. Many devices espacially older ones like cell phones are already equipped with infrared transmitters but for example human bodies also actively emit infrared signals which can be used for localization.

Typical applications of radio waves are ZigBee, Wi-Fi, Bluetooth or RFID.
ZigBee is a specification based on the IEEE 802.15.4 standard and operates in the 2.4 GHz frequency band. It is typically used in embedded systems and wireless sensor networks (WSN) and has been developd for low cost production [3].
Wi-Fi is a specification based on the IEEE 802.11 standard

and operates in the 2.4 and 5 GHz frequency band. Wi-Fi is the most common technology used for wireless local area networks (WLAN) [2].
Bluetooth was standardized as IEEE 802.15.1 for short range point-to-point communication between devices, often stated as wireless private area networks (WPAN) when compared to Wi-Fi. It was intended to remove wires typically from control devices like headsets or remote controls and has partially replaced the use of infrared. Bluetooth also operates in the 2.4 GHz frequency band [1].
For RFID exists no single unified specification and the frequency band differs from country to country. It was designed for very short range communication (up to 1 m) using tags which may have an own power source or be powered via electromagnetic induction by the reading device. Typically the tags are attached to objects for wireless identification. Nowadays, all named radio standards are wideley distributed, espacially Wi-Fi can be found in most indoor environments [11].
Light can be used as well, e.g. using cameras, but in contrast to the previous technologies this approach needs direct line of sight to the object to be localized.

A different approach to the previous ones is to use discrete events gained from sensors. An example would be the nowadays common sensors in smartphones like accelerometer and compass. These events can be match to predefined measured events. Using this you could recognize when a user carrying a smartphone moves and using the compass in which direction. So this approach would provide information about the users movement and is analog feasible for other scenarios.

3.2 Mathematics

The described technologies of signals do not suffice to finally determine the location of an object. First of all, the received signals or information have to be computed to actual valuable information and there are several methods for this [4] [8]:

Received Signal Strength (RSS)

The intensity of an electromagnetical wave is inverseley proportional to the square of the distance to its source, following the inverse-square law. Mechanical waves follow a similar behavior with a slight variation of the inverse-square law [7]. So the received signal strength is directly proportional to the distance between receiver and transmitter and can be computed from this. Using the RSS value is very error-prone to environmental effects on the signal like matter. As listed before, signals are effected by different phenomena like absorption unless there is a direct line of sight between transmitter and receiver.

Time of Arrival (ToA)

In ToA - sometimes also called Time of Flight (ToF) - a transmitter communicates it system timestamp to a receiver. The receiver then compares this timestamp to its own system time. Using this time difference combined with the prior known propagation speed of the signal, the receiver can estimate its distance to the transmitter. This method relies on highly synchronized system times of transmitter and receiver as this is very error-prone to time shifts.

Time Difference of Arrival (TDoA)

TDoA uses two ToA measurements. A transmitter emits two different types of signals at exactly the same time, e.g. ultrasound and radio. The receiver then computes the time difference these to signals arrive. From this time difference again combined with the propagation speeds, the receiver can estimate its distance to the transmitter. This method is less error-prone since it only relies on a single system clock and does not need time synchronization.

Angle of Arrival (AoA)

AoA - also called Direction of Arrival (DoA) - determines the angle a signal arrives at a receiver. This can either be done by directional hardware like antennas or microphones. Another way is to use two receiving devices with well known distance between them. Using again the TDoA at these two receivers and the velocity of the signal, these information can be converted to directional angle of receiver and transmitter. This method is very error-prone to reflection of signals.

After having relative information about the target object like the distance or the angle, we can finally determine the location by combining multiple of them:

Trilateration

This method uses the estimated distance and the geometry of circles or spheres to determine the location of the target object. Assuming a two-dimensional space, three anchor points with a measured distance to the target object are required. At each anchor point there is formed a circle using the distance value. From these circles the intersection can be determined by solving an equation system. Additional information may finally narrow down the location to a unique point.

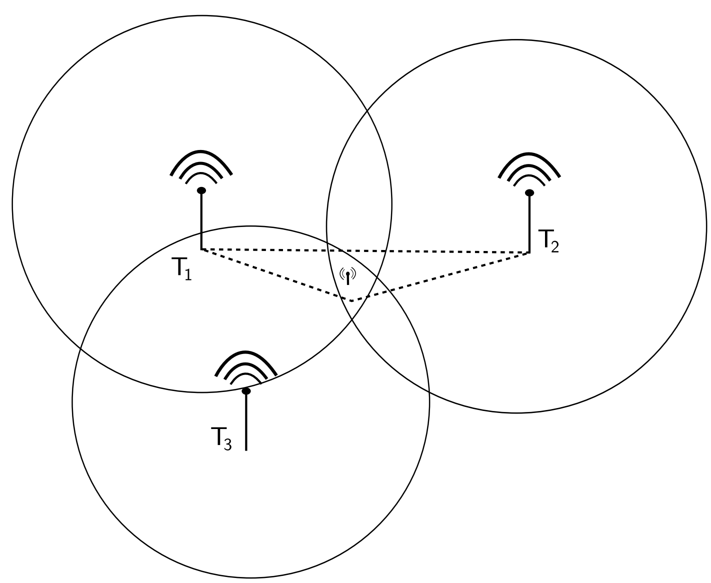

Figure 1: Average accuracy of the experimental test environment [8].

Multilateration

In contrast to trilateration, multilateration uses TDoAs instead of distances. Considering two receivers and a measured TDoA, the possible locations of the transmitter form one half of a two-sheeted hyperboloid. Adding a thrid receiver would create a second TDoA and thus a second hyperboloid. The two hyperboloids then intersect in a curve of possible locations. Introducing a fourth receiver, a third TDoA and hence a third hyperboloid would be formed intersecting with the two already found hyperboloids in a unique point.

Triangulation

Triangulation in contrast to Trilateration uses angles to determine the location. Assuming again a two-dimensional space, two measured angles suffice for this approach. From these angles and one known side a triangle can be formed with fixing the target object to one point using the law of sines.

Fingerprinting

In contrast to the previous methods, fingerprinting does not compute the location of the target object directly. In fingerprinting, a signal database of the target environment is build in advance, e.g. measuring the RSS value of radio frequencies at different points. This is often called offline or preprocessing phase. In the actual localization phase, the measured values are then mapped to the database and the best match is chosen as location.

Discrete Events

Using discrete events is similar to fingerprinting. These events have to be measured before and then the retreived sensor data can be matched against the database of events. Such events could be as already mentioned steps or rotations by a human captured by an accelerometer and compass, but can also be characteristic temperature, noise and other measurements or even a combination. These events then match either a specific predefined location bounded to this event or a modification relative to the previous state.

The shown methods in general only determine relative locations. To localize a target object physically it suffices if only one anchor knows about its physical position. Ensuing from this anchor using the determined relative location of the target object, its trivial to determine its physical position as well.

3.3 Accuracy and Error Containment

Using the method of discrete events, the accuracy obviously depends on the amount and the correctness of the pre-measured data. But as already mentioned, mechanical and electromagnetic waves effected by various physical phenomena like reflection, absorption, refraction, interference and other. Absoprtion or interferences change the signal strength so that the computed distance from the RSS value may be corrupt. Reflection leads to a multiplication of the original signal so that there arrive multiple signals of the originally emitted one. This is often called multipath and results in corrupt distance values as well. Using then corrupt values in e.g. trilateration may lead to multiple determined locations. When there is a direct line of sight between transmitter and receiver available, these phenomena may be minimized and can be neglected. But in indoor environments you usually have walls, furniture and moving people in between and even small changes in the surrounding environment like if a window is open or closed may lead to differences in the measurements. Hence, usually you will not be able to determine an objects location accurately.

The resulting error in the determined regarding the actual real location of the target object can in general be mathimatically described as a cost function, so optimizing the parameters minimizes the error. There are various approaches and solutions in the field of mathematical optimzation and stochastics and they all achieve more or less different results in accuracy. Typical methods are the least-square method, bayesian inference or gaussian process. But covering the methods closer goes beyond the scope of this paper.

Summarizing the fundamentals of indoor localization, it is in general not possible to determine absolutely correct location of an object and the various approaches may acheive different results in accuracy in different environments.

4. APPLICATIONS

In this section we will discuss some of todays indoor localization systems, what technologie they use and what use case they have been designed for.

LOSNUS

LOSNUS stands for LOcalization of Sensor Nodes by Ultrasound and has been presented by H. Schweinzer and M. Syafrudin from Vienna University of Technology [9]. It primary has been designed for WSN locating numerous static devices in three dimensional indoor environments and uses as the acronym says ultrasound as its source technologie. LOSNUS challenges the aspects of cost and locating efficiency, signal coordination and privacy of devices.

The system consists of four components: one location server, one activation unit, several ultrasound transmitter units and the target devices which are to be located. An overview of the system is shown in figure 2. It is assumed but not closer considered, that the system is connected via a network, e.g. located devices via WLAN respectiveley sensors via a WSN with the location server.

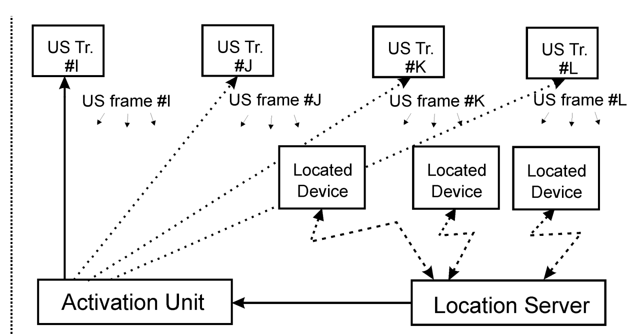

Figure 2: System overview of LOSNUS [9].

The activation unit coordinates the ultrasound transmitters. Since the signals would overlap and collisions would make the signals useless, the activation unit supplies the transmitter units with individual codes in a predefined sequence to create delays between two ultrasound transmissions.
The ultrasound transmission units are sequentially activated by the activation unit and have well-known positions. The ultrasound signals are send as structured frames containing a lead-in, time mark and an individual transmitter code, see figure 2.

The start for recording the frame at the target located

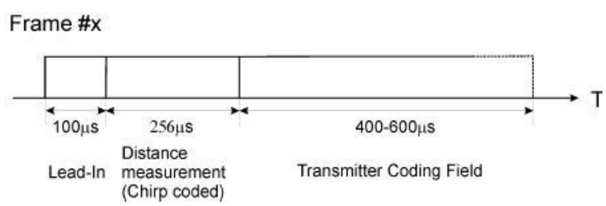

Figure 3: Ultrasound signal frame format [9].

devices is marked by a data bit within the lead-in phase. The position of this data bit encodes the time stamp at the clock of the transmitter and is used to determine the position of the chirp part. The received data of the frame is then forwarded to a central location server which then finally computes the locations. Located devices are not intended to calculate their own locations due to security and energy efficiency reasons. But they might preprocess the received data with the purpose to eleminate disturbing signals or mutltiple reception of the same frame and reducing the forwarded amount of data. In the presented test environment elemination of multiple frame reception is done by assuming that the first received frame with a new transmitter code is the signal send by the direct line of sight, so further frames with the same transmitter code are being discarded.
The central location server communicates to the activation unit and initiates the locating sequence. After receiving the ultrasound frame data from the located devices, the location server finally determines the location using TDoA values considering the given transmitter delays and using a pseudo-trilateration algorithm. It subsequently then sends the calculated location back to the relating node.

The system also deals with further physical error influences like missing signals or multipaths and security issues. Due to the system design, introducing additional nodes can easily be achieved automatically by the node and localization server. LOSNUS is advertised to offer high accuracy of around 10 mm and a locating rate up to 10 cycles/s. Further work addresses the need for pre-calibration of the system and construction of a security concept.

An Indoor Location-Based Service Using Access Points as Signal Strength Data Collectors

Kao et al. prensted a network-based respectively infrastructure-based approach using WLAN access points (AP) collecting RSS data of WLAN clients to determine the clients location [6]. This system aims for an easy to deploy and low-cost indoor localization system using the fact that WLAN infrastructures are often already present in many indoor environments, so that typically no specific additonal hardware has to be installed.

The system contains of three major components as shown in figure 4. Numerous APs serve as RSS data collectors

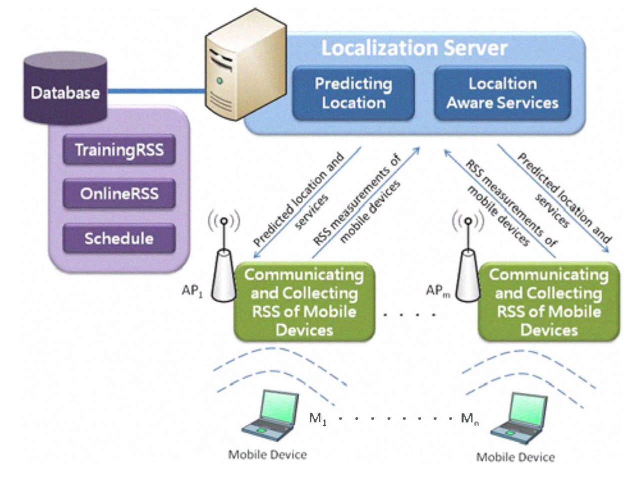

Figure 4: System architecture overview using APs and a localization server [6].

and simultaneously handle the network communication. In the presented test environment ASUS WL500 AP were used running the open-source AP operating system OpenWRT [?] which allows to install additional software and gives advanced configuration access. To collect the RSS data, a slightly modified version of the open-source monitoring tool Kismet is used which records the RSS data and client information to a database.
The localization server runs a MySQL database server to which the RSS data is saved. Furthermore the localization server calculates performs the actual localization using fingerprinting. This comprises two phases: a so called offline phase to collect RSS data of the predefined environmnet and create a RSS map. And an online phase in which the RSS data is gathered and then compared to the pre-collected data. The location is finally determined as the minimum result of the Euclidean distance function regarding the mean of RSS values. Additionally in the presented test environmnet, the localization server runs a webserver providing the location-based content and a webpage which serves as subscription unit for the clients. Only clients that access this webpage will be tracked by the system. The third part is the target client that will be located. There is no additional soft- or hardware necessary so that a client can be located by the system but a running WLAN module. As already mentioned, in the presented test environment a client is only been tracked after accessing a provided webpage. But this is no technical restriction to the presented system as a client could also been tracked all the time whlie it is in range. In the example application, content like files and information according to location and time are then provided to the user via the webpage.

In the experiments, the accuracy has been evaluated at different locations in the test environment. Three AP have been deployed on the same floor covering the whole area.

The pre-collected RSS data has been measured each time at the center of each room. The accuracy then has been evaluated taking measurements at the center of each room, at the corners, at one floor above and again at the center of each room using a different mobile device than the pre-collected RSS data has been recorded with. The achieved average accuracy ranges between 91% at the corners and 98% at the centers. Even at one floor above, the average accuracy is about 93%. Full results are shown in figure 5.

Room Number	On center of class rooms	On corners of class rooms	On center with different device
701	100%	95%	94%
702A	95%	90%	92%
702B	100%	93%	82%
703	100%	90%	98%
721	94%	94%	98%
722	99%	86%	100%
723	99%	92%	100%
Average	**98%**	**91%**	**95%**

Figure 5: Average accuracy of the experimental test environment [6].

Future research on this work addresses the communication performance and a more sophisticated prediction algorithm.

UWB Localization Systems in Home-Entertainment Applications

R. Zetik et al. from the Technische UniversitÃď't Ilmenau presented an evaluation of a test scenario using UWB localization systems in home-entertainmnet applications [12]. In this approach, the aim is to localize a person by the reflection of electromagnetic waves from his body, so that no tag or other device is required to determine the persons location. From this an entertainment system might use such an approach to automatically optimize the volume level and further settings according to the users position.

In this presented system, a frequency band from 3.5 GHz to 10.5 GHz were used and is based on the movement of the target person. A transmission antenna emits the signal and several receiving antennas obtain the reflected signal. Movements can in general still be detected even when the person is sitting, due to small movements through twitching or breath activity which can still be detected.

The detection of movements is based on background subtraction in which time variant background signals are subtracted from the measured Channel Ipulse Response Function (CIRF) and depends highly on different factors like the number of persons, their activity and environmental conditions. In order to detect a person correctly, scenario specific dynamic range, which is the ratio between the largest and smallest values of the signals, has to be achieved according to again scenario specific hardware (e.g. the space between the antennas). The dynamic range is measured in dB and a high dynamic range is the basic requirement to detect weak signals scattered back from a person. The minimum dynamic range is determined by a defined parameter signal to clutter ratio (SCR). SCR describes the realtion between the signal strength of the electromagnetic wave that is scattered back from the person and the signal strength that propagates on direct line of sight from the transmitting to the receiving antenna.
The other basic challenge is the stability with low jitter which defines the success of the background subtraction. That may lead to misinterpretations of the background subtraction as movements when measuring with high jitter.

The actual localization process is then been done by using the ToAs from the electromagnetic waves scattered back from the movements and the mean of the last square method. In the presented scenario, various measurements have been evaluated like walking different paths or sitting at different places in the test environment and were mapped to a two-dimensional position. In figure 6 are shown the travelled paths in figure 7 the result of a localization process, according to the blue dashed track in figure 6. The position estimations have additionally been smoothed by different filters. Moreover the presented research deals with further influences on the electromagnetic signals like electromagnetic shadows and others to improve the correct movement detection.

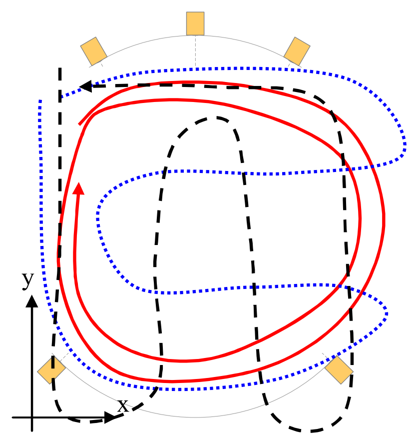

Figure 6: Different travelled paths in the test environment [12].

Summerizing, the presented approach of using reflections of electromagnetic waves highly depends on the application scenario, environment, hardware and proper background subtraction. Besides, the test application comprised a delay which might be applicable in home-entertainment systems, but considering time critical applications this might not be feasible. However, in the given test scenario, this system might be applicable to accomplish the aim of automatically adjust the settings in a home-entertainment system.

Self-Contained Indoor Positioning on Off-The-Shelf Mobile Devices

Gusenbauer and Isert from the BMW Group Research and Technology in Munich collaborative with Kroesche from the

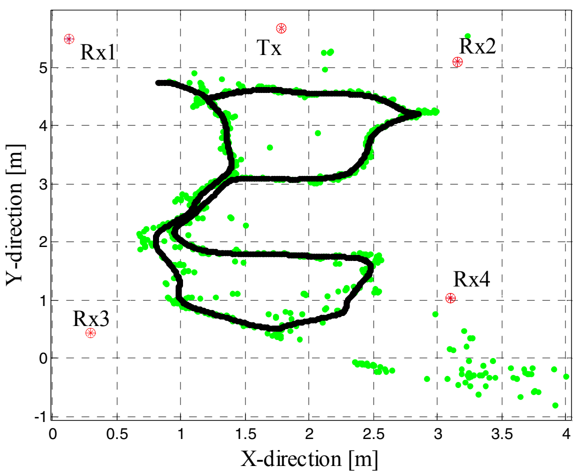

Figure 7: Estimated location of a moving scenario [12].

Upper Austria University of Applied Sciences in Hagenberg presented a self-contained indoor positioning system for mobile devices using common sensors to evaluate movement activities [5]. The system aims for espacially environments where no additional infrastructure like WLAN is available and would not make sense to deploy, like in a parking garage. The system uses primary the method of Pedestrian Dead Reckoning (PDR) based on the accelerometer and compass of the mobile device. Due to the not fixed connection between a person and the device, basic assumptions of device oriantation were made. It is assumed that the person holds the device in his hand in front of him towards his line of sight. Furthermore it is assumed, that the person will move according to his line of sight and not in other directions like sideways. A basic overview is shown in figure 8.

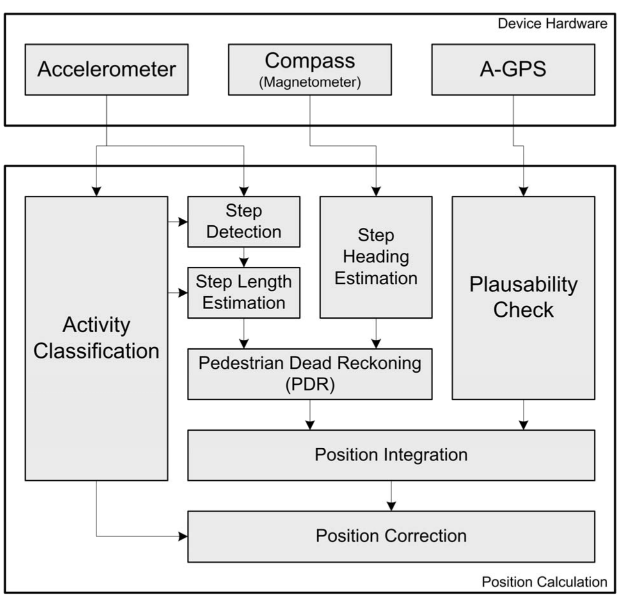

Figure 8: An overview of the system components [5].

The PDR process is at first based on the accelerometer measurements. From this the system recognizes different activity patterns as an example measurement is illustrated in figure 9. According to the recognized activity, the movements

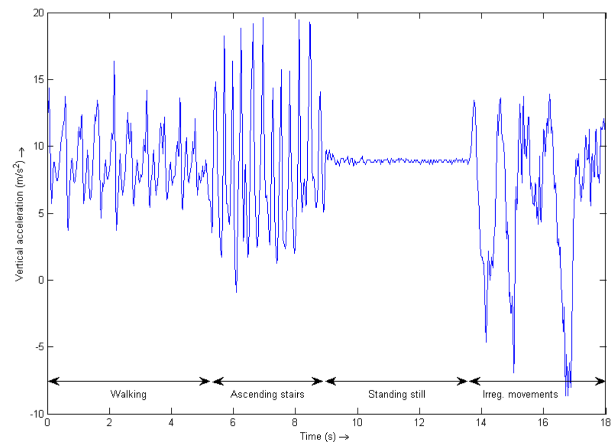

Figure 9: Example measurements from the accelerometer with the relating activity [5].

are evaluated. In activities with a location shift like walking or running, espacially steps have to be extracted from the measured data to define a step frequency. The step length then is estimated individually and for each detected step seperately linearly influenced by the step frequency due to the assumption that the length is e.g. larger when running than when walking. The parameters of the length calculation are continuously calibrated and additionally GPS data is used for this when available using linear curve fitting.
The second used sensor measurement is the heading extracted from the azimuth readings of the compass. In the given test scenario this is simultaneously the primary source of error because of the use of an electromagnetic compass which can be effected by magnetic disturbances.

Additional calibration comes from an activity based map matching strategy. One major weakness is the missing ability of vertical movements, e.g. in an elevator. When the acitivity pattern is detected as using an elevator, the position is rectified to the nearest elevator according to a prebuild map. Furthermore the map can be used for simple visualization.

The last major data needed for localization is a starting position. In the presented application this is achieved either again from available GPS data or from the persons car that communicates its location then to the users mobile device.

Furthermore the presented application applies several filter and optimization optimizing correct step detection, length calculation using stochastic methods and further filters and compensating noises in the measurements.

Figure 10 shows an example measurement of the application in a parking garage at Munich Airport. The example shows an error in the heading direction at starting point A which results in a wide variance between the calculated and real location. We can also see the use of the activity based map

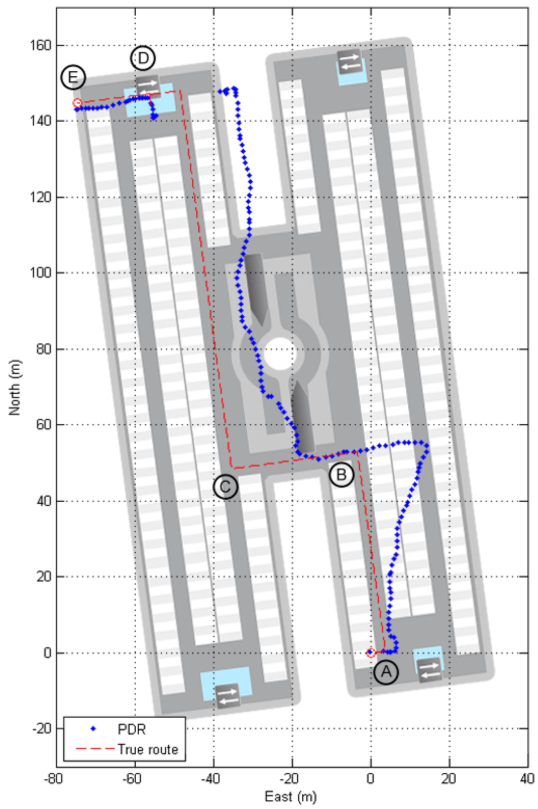

Figure 10: Example localization in a parking garage at Munich Airport [5].

matching at point D, where an elevator were used. Although of the intermediate high error, the destination location were reached with an error of 3.6 m. Several other test scenarios resulted in an average distance error of 4%.

Summerizing, the presented approach using PDR shows a feasible way of indoor localization where no additional infrastructure is available or would make sense to deploy for the use of localization. It offers a self-contained application for off-the-shelf mobile devices and provides possbilities for further improvements as using a gyroscope in addition to the compass for more accurate heading estimation. Moreover with a barometer even vertical movement estimation becomes possible which again would improve the accuracy according to three-dimensional environments. And finally the method of activity based map matching can be improved taking walls and other objects into account.

5. CONCLUSION

We discussed several possible approaches for indoor localization and took a look at different technologies, uses cases, requirements and mathematical models. Indoor environments have numerous error sources for the accuracy of localization, due to the different influences of objects and environmental changes on the technologies. But there are numerous possible counter measures as well to decrease the resulting error in accuracy. In the end, the specific use case defines the need for more or less sophisticated models to minimize this error.

We also presented four indoor localization applications which all use various technologies and methods and aim for different use cases. The first one was based on ultrasound signals and used additional hardware to emit and receiv the signals. It used a sophisticated protocol to coordinate the signal transmission, challenged the term of privacy and was mainly designed for WSN.

The second application was a network-based approach using a WLAN infrastructure, so that deployment might be easy and cost efficient in environments that are already covered by such an infrastructure. It used the RSS values from the network communication and was already able to achieve relatively high accuracy with simple methods. In the presented scenario, content like files or information was distributed according to the time and the location of the accessing user.

The third application was based on UWB and aimed for automatically adjusting preferences of a home-entertainment system according to a persons location. The system used the reflection of the UWB by the human body, so no tag or other additional hardware at a person was needed. The presented work showed that this approach is highly dependend on the environment and used hardware and hence highly error-prone. But nevertheless, the position of a person could be achieved so that it would be applicable in real entertainment systems.

The last presented application was a self-contained application for mobile devices using discrete events measured by accalerometer and compass. This approach required no additional infrastructure so it can easily be applied in infrastructure free environments like a parking garage.

All four applications offered chances for improvements using either more sophisticated mathematical models or additional and more reliable hardware.

5.1 Future Prospect

In our analyses it loomed that the trend in the research field of indoor localization systems goes towards applications that are easy to deploy without the of additional hardware if feasible. Many applications use RSS and fingerprinting due to the fact that radio frequency applications are widely spread like Wi-Fi or ZigBee. This eleminates the need for deploying specific hardware and hence reduces the cost factor. UWB is an arising used technology because of its major resistence against multipath formation and further advantages.

Furthermore research in self-calibrating systems increases to again decrease the required maintenance effort. By now the most approaches are designated to specific use cases as each use case defines special requirements. However, research in designing indoor localization systems that are feasible to as many as possible scenarios increase as well. Nowadays, this field offers new possibilities of location-based services, but some day indoor localization might become ordinary as GPS or telecommunication techniques like GSM already are.

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