State of the Art of Non-vision-Based Localization Technologies for AR in Facility Management

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Abstract. Augmented reality (AR) applications for indoor purpose mostly use vision-based localization systems. However, even with AI-based algorithms, reachable accuracies are quite low. In the field of facility management an important functionality is the possibility to go for a high localization accuracy to display information, warnings or instructions at the correct position, if necessary. Simple vision-based solutions, like QR codes, are widely used. However, they show a high effort during installation and the advantages of using AR are limited. Thus, a state-of-the-art review for non-vision-based indoor localization technologies was carried out. Moreover, an evaluation with respect to usability for augmented reality applications was done. A scenario of the application of AR in the facility management environment is described based on the review results. For use-cases with high accuracy, tracking systems like infrared-based camera systems are a preferable solution. Also, ultrasonic could be a cheap solution for a medium accuracy tracking. For a simple room-based localization Bluetooth beacons and other hybrid indoor position technologies are preferred.

Keywords: Indoor localization · Augmented reality · Facility management

1 Introduction to Indoor Positioning

Indoor positioning technologies (IPT), also known as indoor positioning systems (IPS), are used to track humans or devices in an indoor environment. For outdoor positioning, satellite-based radio navigation technologies are widely used, such as the Global Positioning System (GPS) technology. Thus, satellites equipped with very stable atomic clocks continuously transmit a radio signal containing the current time and data about its position. It works with the so-called transit time methodology (Time of Flight, ToF). Accuracies between 30 cm and 5 m are reachable and with additional base stations and a correction of the received signals, accuracies below 1 cm can be reached (e.g. for surveying and mapping). This system is called Differential Global Positioning System (DGPS). However, a direct line-of-sight to four or more GPS satellites is necessary for a correct positioning. This limits the applicability for indoor positioning. For this reason,

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other technologies were developed for application cases such as indoor navigation, robot navigation and – what we focus on within this paper – augmented reality (AR).

Some extensive literature reviews have been carried out over the last years. One of the most recent was done by Mendoza-Silva et al. 2019. A very comprehensive survey including technologies, mathematics and hybrid IPS was carried out by Oguntala et al. 2018. They focused on the application of IPS working with IoT devices. Liu et al. 2007 did a comprehensive survey of wireless indoor positioning techniques and systems. Alarifi et al. 2016 gave a comprehensive overview about the actual state of the art and technologies, and the UWB technology in particular. Mrindoko and Minga 2016 carried out a review on the performance metrics and the localization techniques in general. Viani et al. 2011 did an extensive review on wireless sensor networks. They identified some key issues: environmental and working conditions are difficult to predict, the accuracy can vary strongly and must be considered, and the overall costs for sensors and calibration are not scalable.

2 Location Detection Techniques and Algorithms

2.1 Proximity

If only presence needs to be recognized, the proximity technology can be used. Depending on the used devices (e.g. RFID or Bluetooth) different 'presence areas' can be defined. Proximity is widely used and very simple to implement. It is only necessary to determine if, e.g., the user is logged into a specific Wi-Fi access point to check its presence. Also, magnetic positioning technologies use this approach. For example, in an industrial area it can be recognized which people are in which building. Moreover, in case of evacuations, proximity can be used to check the absence of single persons. However, if a user is logged into two nodes at the same time, it is unclear in which area it is.

2.2 Trilateration with Received Signal-Strength (RSSI)

In radio-based technologies the received signal strength can be measured very easily. Depending on the signal strength, a distance in meters can be approximated by trilateration. This technology is called Received Signal-Strength Index (RSSI). However, there is not a simple correlation between signal strength and distance, because objects, like walls, furniture and even people have a great impact on the signal strength. Also, temperature and humidity must be considered (density of the air). Depending on the used technology, calibrations can be carried out to improve the accuracy. To get a unique position, at least three stations with known coordinates must be used. The uncertainty strongly depends on the used technology, the calibration and the environment. To achieve an accuracy of less than a meter, various techniques have to be used or combined with trilateration.

2.3 Angle of Arrival (AoA)

Technologies using the Angle of Arrival (AoA) method, determine the direction of the emitted signal and solve mathematically a triangulation problem. It is also called

Direction of arrival (DoA). One common method in IPS is to calculate the AoA measuring the time difference of arrival (TDOA) between individual elements of an antenna array. With the AoA method, accuracies around 10 cm can be reached. The method will play a main role in future indoor positioning technologies, as it can already be seen i.e. in the new Bluetooth 5.1 definition (Suryavanshi et al. 2019).

2.4 Time of Arrival (ToA)

The Time of Arrival method (ToA) – also known as Time of Flight (ToF) – bases on trilateration. However, compared to the RSSI method, all stations must be synchronized in time. GPS is the most-known localization technology that uses ToA. The satellites are equipped with atomic clocks to reach the necessary accuracy. For indoor localization purpose, two-way ranging is used. The position is determined by sending a radio signal, which is mirrored back and received again. This increases the accuracy and an accurately synchronized time is less important. However, for this kind of system a direct line of sight is necessary.

3 Performance Metrics

In Alarifi et al. 2016 six metrics (key performance indicators) have been defined to classify the indoor positioning technologies. Table 1 shows an overview of the results of these metrics.

Table 1. Performance metrics (Alarifi et al. 2016).

Metric	Definition
Accuracy	The closeness of agreement between a measured quantity value and a true quantity value of a measure
Availability	The positioning service availability in terms of time percentage
Coverage area	The area covered by an IPS
Scalability	The degree to which the system ensures the normal positioning function when it scales in one of two dimensions: geography and number of users
Cost	Can be measured in different dimensions; money, time, space, and energy which can be affected at different levels of the system: system installation and maintenance, infrastructure components, and positioning devices
Privacy	Strong access control over how users' personal information is collected and used

4 Indoor Positioning Technologies for AR

4.1 Overview

Table 2 gives an overview about the available technologies and their advantages and disadvantages based on the presented performance metrics. Bartoletti et al. 2019 did a classification on the accuracy and the coverage area, based on the survey of Liu et al. 2007. The privacy is not rated, because it depends strongly on the application case. In the following sections, more detailed descriptions and literature sources are given.

Table 2. Indoor positioning technologies (Farid et al. 2013; Alarifi et al. 2016; Mrindoko and Minga, 2016) (Own sources)

Technology	Algorithms	Accuracy	Availability, Latency	Scalability	Costs	Energy demand
Wireless local area network (Wi-Fi)	Proximity, RSSI	1–15 m	Overloaded frequency band	Very high, because it is building equipment	Low	High
Bluetooth (BLE)	Proximity, RSSI, AoA (BLE 5.1)	1–3 m	Overloaded frequency band, <0.5 s	Middle, new equipment, but quite cheap and battery supplied	High	Very low
Ultra wideband (UWB)	ToA	10–30 cm	Requires LOS, wide frequency range	Very low, very expensive equipment	Very high	Very high
Radio frequency identification (RFID)	Proximity, RSSI, (ToA), (AoA)	Passive: object size Active: 1 m	Requires almost object contact in case of passive RFID	Very low for IPS	Passive: low Active: high	Passive: Very low Active: high
ZigBee	Proximity, RSSI	5–80 cm	Overloaded frequency band	Very high in combination with IoT	Low	Very low
Li-Fi	Proximity	>0.1 m	Requires LOS, no penetration of obstacles, < 0.2 s	Very high, because it is building equipment	Middle	Low
Ultrasonic (Ultrasound)	ToA	1–3 cm	Neglectable penetration of obstacles, 0.1–3.0 s	Low, expensive equipment	High	Middle
Magnetic positioning	Sensors, maps	1–5 m	Magnetic field depends on environmental conditions	Very high, because need no stations, only mapping	Low	Low

(continued)

Table 2. (*continued*)

Technology	Algorithms	Accuracy	Availability, Latency	Scalability	Costs	Energy demand
Infrared (IrDA)	Proximity, ToA	0.1–90 cm	No penetration of obstacles <0.2 s	Low due to limited range and high effort	Medium	Low
GSM based	Proximity, RSSI	20 m	Low to high impact of environmental conditions	Very low, only works on area level	Use of existing stations	High
Dead reckoning (inertial navigation)	Sensors, maps	5–15 m	Re-targeting necessary	High	Very low	Very low
Pseudolites	ToA	10–80 cm	Requires LOS	Low, expensive equipment	Very high	High

4.2 Wireless Local Area Network (WLAN, Wi-Fi)

Utilizing WLAN for indoor positioning was first investigated by Youssef 2004 which proposed the HORUS method, that bases on the RSSI approach.

A lot of research followed to improve the localization accuracy. Mazuelas et al. 2009 applied Wi-Fi RSSI to calculate the distance between a mobile station and an Access Point (AP) by an online estimated propagation model. Yet, the resolution of RSSI-based approaches is not satisfactory. Other metrics were adopted to further improve the localization performance. Gjengset et al. 2014 developed a so-called array phaser, that upgrades a multi-antenna commodity Wi-Fi AP to a phased array signal processing platform for AoA estimation. To avoid using a complicated antenna array, Kumar et al. 2014 proposed *Ubicarse*, that facilitates handhold Wi-Fi devices to emulate large antenna arrays using a synthetic aperture radar (SAR) technique. Vasisht et al. 2015 proposed a very different method by using a frequency mitigation technique to utilize Wi-Fi's 2.4 GHz and 5 GHz spectrums as a whole in combating multipath effect. They achieved sub-nanosecond ToF with commodity Wi-Fi cards. Fingerprint-based approaches compare the current features of ambient signals with those already recorded in a fingerprint database, to correlate the newly collected signals to pre-defined locations. This method is widely used for IPS based on WLAN. Wu et al. 2013 explored the frequency diversity of the subcarriers in OFDM systems and leveraged the Wi-Fi channel state information (CSI) to build a fingerprinting system. Sen et al. 2012 demonstrated PHY layer-based WiFi localization and observed an 89% mean accuracy for a spot-detection of a 1 m/1 m area. Rai et al. 2012 developed a crowdsourcing technique Zee to gather Wi-Fi fingerprints in the area of interest.

Summarizing, WLAN-based IPS can reach accuracies in the range of one meter only in mapped environments, which are frequently updated, and in very optimistic scenarios. Otherwise the accuracy is in the range of 5 to 15 m. For augmented reality cases this accuracy is not sufficient enough.

4.3 Bluetooth, Bluetooth Low Energy (BLE)

Bluetooth Low Energy devices operate in the 2.4 GHz license-free band, and so share the same indoor propagation characteristics as 2.4 GHz Wi-Fi transceivers. The beaconing, or advertising mode, permitted in the BLE standard enables a very short, unsolicited message at very flexible update rates. These messages can be used to allow a device to detect close proximity to a specific location, based on the Received Signal Strength (RSS). In this way, location specific triggers, adverts, vouchers and information can be provided to the user. BLE advertising beacons are particularly attractive to retailers because of the promise of long battery lives of many years, and thus low maintenance requirements. Long battery lives are expected to require low radio power output and/or low beaconing rates. While this does not affect their use for proximity detection, it does affect their usefulness for providing fingerprint-based positioning throughout an entire indoor environment (Faragher and Harle 2014).

Yapeng Wang et al. 2013 demonstrated the principles of using RSSI and triangulation methods first available in the Bluetooth standard 2.1 and stated first results.

Faragher and Harle 2014 investigated as first the impact of Bluetooth Low Energy devices in advertising/beaconing mode on fingerprint-based indoor positioning schemes. They demonstrated that the low bandwidth of BLE signals compared to Wi-Fi, is the cause of significant measurement error when coupled with the use of three BLE advertising channels. They proposed a multipath mitigation scheme and determined, that the optimal positioning performance is provided by 10 Hz beaconing and a one second multipath mitigation processing window size. They investigated that a steady increase in positioning performance with fingerprint size occurs up to 7 ± 1, above this, there is no clear benefit to extra beacon coverage.

Paterna et al. 2017 followed more complex assumptions by considering channel diversity, weighted trilateration and applied Kalman filtering. They stated an improvement in the precision of the system, which goes up to 1.82 m in 90% of the time for a device moving in a middle-size room and 0.70 m for static devices. Furthermore, they have proved that the system is scalable and efficient in terms of cost and power consumption. Castillo-Cara et al. 2017 carried out an empirical study of the transmission power setting for Bluetooth based indoor localization. Following a holistic approach, they started by assessing the capabilities of two Bluetooth sensor/receiver devices. Consequently, they evaluated the relevance of the RSSI fingerprint reported by each BLE beacon operating at various transmission power levels using feature selection techniques. Based on this, they used two classification algorithms in order to improve the setting of the transmission power levels of each of the BLE beacons. With this method, they were able to improve the accuracy by 13% based on a positioning within a 1 m/1 m sector. However, real application of this method seems difficult.

Suryavanshi et al. 2019 described the new direction-finding capability in the Bluetooth 5.1 standard. The Bluetooth Core Specification provided by Bluetooth Special

Interest Group (SIG) added direction finding feature in the Low Energy (LE) standard. This feature enables a tracker to find the target by estimating the relative angle between the tracker and target. It uses either Angle of Arrival (AoA) or Angle of Departure (AoD) method with multiple antennas switching for direction estimation. Lehtimäki 2019 described the new standard from the viewpoint of the software implementation.

The direction-finding capability of Bluetooth 5.1 promises accuracy in the range of 1–3 cm. Until now there is no measurement data available, which could be able to prove this marketing numbers. However, it seems a very promising technology and can have the capability to be a game changer in IPS for augmented reality applications.

4.4 Ultra-Wideband (UWB)

Ultra-Wideband (UWB) technology exploits the diverse interactions between electromagnetic fields and matter, operating on the principle that images, gained from scattering of electromagnetic waves, provide a detailed geometrical dimension of the surrounding environment, since wavelengths are smaller compared to the real size of objects (Sachs 2012). Although, electromagnetic scattering does not reveal detailed information of certain objects, for example, opaque and hidden objects. UWB is designed to operate in the microwave frequency occupying a very large bandwidth of more than 1.5 GHz (Foerster et al. 2001), thereby giving the technology an exceptionally high resolution but low penetrating power especially to most non-metallic materials for easy detection of hidden objects. In addition, the higher bandwidth of microwave frequency enables UWB-based location identification to achieve higher object resolution in the decimeter, centimeter, and millimeter range, and better object recognition capabilities than narrow-band technologies (Oppermann et al. 2004; Pinhasi et al. 2004; Sachs 2012). Moreover, since UWB operates by sending ultra-short pulses with low duty cycle across many frequencies (Ingram et al. 2004), this enables the technology to provide accurate ToA positioning information even in the presence of multipath. Other desirable features of UWB include high data rate, that is short-range at very low power density (Rahayu et al. 2008). However, the large bandwidth of UWB causes inevitable interference in the presence of other devices, thereby necessitating a strict low power consumption limit, which makes the technology a conservative approach and impractical for many location identification applications (Radunovic and Le Boudec 2004). Cirulis 2019 investigated the potential of UWB in augmented reality environments.

However, UWB technology is still quite expensive and seems not to be an adequate technology for AR purpose.

4.5 Radio Frequency Identification (RFID)

The RFID technology positioning system usually consists of antennas, tags, readers and positioning algorithms. Each tag is uniquely identifiable and able to transmit stored data, which may be read-only or writable. Active tags are equipped with an inbuilt battery, while passive tags do not have inbuilt batteries, but backscatter the signal received from the base station. Semi-active tags, although they do backscatter the carrier signal received from a base station, also have an inbuilt battery, which powers the circuitry, thereby giving it the flexibility to function in dense environments (Cook et al. 2014).

Research on the applicability of RFID for indoor positioning scenarios was carried out e.g. by Bouet and dos Santos 2008, Chon et al. 2004, Li et al. 2009, Saab and Nakad 2011, Ting et al. 2011. RFID offers other desirable advantages which include high data rate, adaptability to various environment, availability in non-line-of-sight (NLOS), wireless capability, wireless zero-power sensors and low maintainability (Bai et al. 2012; Chen et al. 2011; Khan and Antiwal 2009). RFID technology, however, suffers from several limitations arising from the issue of operating frequency standardization, invasive nature, and requirement of additional infrastructure in location identification techniques like proximity (Kaur et al. 2011). Furthermore, improved accuracy and higher resolution often require the deployment of several tags around the coverage area of interest, which sometimes results in high computational cost.

Latest research was carried out by Xu et al. 2018 or Magnago et al. 2019 using UHF tags and quite large antennas. First authors achieved accuracies below 30 cm in 74% of the cases and below 50 cm in 99% of the cases.

For AR applications RFID can be useful to define an accurate target or anchor, but for a real-time tracking, the technology needs UHF tags and large antennas, which are expensive and do not reach very high accuracies.

4.6 ZigBee

ZigBee is a wireless standard defined by a set of communication protocols designed for wireless personal area networks, thereby making it a short-range technology. Wireless devices using ZigBee operate in the 868 MHz, 915 MHz, and 2.4 GHz ISM band. The effective signal range of ZigBee is up to 100 m in free space, and typically 20 to 30 m in indoor environments (Baronti et al. 2007). The coordinating ZigBee device forms the root of the network by initiating a connection between other networks and nodes of up to 255 nodes, whereas the node receives data from the coordinator (Kanwar and Khazanchi 2012).

ZigBee offers several desirable advantages as described in the literature by several researchers Amutha and Nanmaran 2014, Larranaga et al. 2010, Tadakamadla 2006. However, ZigBee suffers from some drawbacks as well, as the operating frequency of ZigBee, which lies in the unlicensed ISM band, makes the technology prone to interference from signals operating at the same frequency. In addition, since the technology is only suitable for short-range applications with low-data-rate, the range of applications is limited.

However, it could be a feasible (license-free and cheap) solution for augmented reality purposes.

4.7 Li-Fi

Li-Fi is a light communication system that is capable of transmitting data at high speeds over the visible light, ultraviolet, and infrared spectrums. In its present state, only LED lamps can be used for the transmission of visible light. Visible light communications (VLC) works by switching the current to the LEDs off and on at a very high speed, too quick to be noticed by the human eye, thus, it does not present any flickering.

Zhuang et al. 2018 did a literature review on positioning systems using visible LED lights. Islim and Haas 2016 reviewed several modulation techniques, which is one of the main research field right now. The systems should be able to be in operation, even if artificial light is not wished. The high-frequency flickering still needs to be optimized, that human beings are no affected.

The technology is promising for many indoor localization scenarios, but for using it with augmented reality the accuracy is too low, and determination of the orientation is not trivial in many scenarios.

4.8 Ultrasonic (Ultrasound)

Ultrasound is an acoustic sound inaudible for the human ear. Time of flight methods are used; hence high positioning accuracies can be reached.

A literature review specifically on this top was carried out by Ijaz et al. 2013. Yazici et al. 2011 suggested to use Time Difference of Arrival (TDOA) technique and reported of positioning errors of below 20 mm for moving targets. Qi and Liu 2017 suggested a new time domain method to extract the envelope of the ultrasonic signals in order to estimate the ToF. They were able to improve the accuracy below 1 mm for non-moving objects and 10 mm for a moving target. Hazas and Hopper 2006 identified that current ultrasonic location systems suffer from limitations due to their use of narrowband transducers. They investigated the use of broadband ultrasound for indoor positioning systems. They reached a localization accuracy if 2 cm with an increased noise robustness. A. De Angelis et al. 2015 developed a portable ultrasonic positioning system. This could be an interesting solution if a higher localization accuracy is only required in individual cases, e.g. maintenance work.

For the use with augmented reality an advantage is the high accuracy. However, this technology has high investment costs, but portable systems could be used, if higher accuracy is necessary.

4.9 Magnetic Positioning

Due to the presence of large steel components inside building, the geomagnetic field is affected and distorted. Such changes in magnetic field are used for indoor localization. Magnetic positioning can offer pedestrians with smartphones an indoor accuracy of 1–2 m with 90% confidence level, without using the additional wireless infrastructure for positioning. Un-optimized compass chips inside smartphones can sense and record these magnetic variations to map indoor locations.

Lee et al. 2018 proposed a method using deep learning (AMID) to recognizes magnetic sequence patterns using a deep neural network. Features are extracted from magnetic sequences, and then the algorithm is used for classifying the sequences by patterns generated by nearby magnetic landmarks. Locations are estimated by detecting the landmarks. With a probability of 80% they could detect a landmark. Bhattarai et al. 2018 were generating magnetic map to localize the position of a smartphone with built in sensors. They reached a positioning accuracy below 2 m during 70% of the experimental time. G. De Angelis et al. 2015 realized a system using off-the-shelf components based on inductive coupling between resonating coils. They reached an accuracy below 10 cm in a simple room. In complex geometrical conditions they reached accuracies below one meter.

Due to the low accuracies this technology is not recommended using it in augmented reality applications.

4.10 Infrared (IrDA)

Infrared-based indoor localization systems use infrared light pulses to locate signals inside a building. IR receivers are installed in every room, and when the IR tag pulses, it is read by the IR receiver device. Also, CCD or CMOS image sensors are used. They can also be categorized as such systems because they use dedicated markers, even if they use vision-based equipment. One of the largest restrictions is that the infrared spectrum is near to the visible light spectrum. Thus, the accuracy can be greatly influenced by natural light.

Yasir et al. 2016 proposed to use multiple optical receivers and reached an accuracy of 6 cm with a motion speed of 1.3 m/s. Raharijaona et al. 2017 tackled the problem of natural light by using flickering infrared LEDs and reach accuracies around 2 cm for a distance of 2 m. With three sensors they were also able to determine the orientation. Wang et al. 2017 proposed a novel localization-accuracy optical wireless based indoor localization system, based on the use of the mechanism that estimates background light intensity. They reached a localization accuracy of 2.5 cm.

One of the main challenges if the use if infrared is the necessary line of sight and the very small area coverable by one sensor. However, for indoor localization with the purpose of augmented reality, flickering infrared LEDs could be an interesting option. If high accuracy is needed for the use in facility management, such solutions are recommended, also because they could be used as a mobile equipment.

4.11 GSM Based

Using GSM as indoor localization is not wide-spread due to the technical limitations and the low accuracy.

Zhang et al. 2017 reviewed recent literature relating to localization in 5G networks, and emphasizes the prospect for implementing cooperative localization, which exploits the location information from additional measurements between mobile terminals.

Also, 5G is not going to be a recommended technology for indoor positioning purposes. However, low latency and high data rate allow new use cases (e.g. cloud support) for AR applications in the field of facility management.

4.12 Pedestrian Dead Reckoning (Inertial Navigation)

Using data from inertial sensors embedded in smartphones a relative indoor positioning can be carried out called Pedestrian Dead Reckoning (PDR). Kang and Han 2015 proposed a system only based on Smartphone sensors. Li and Ning 2018 showed, that using low-cost sensors in combination with a map and calibration routines can increase the positioning accuracy dramatically. However, a practicable application is not indicated.

Zhang et al. 2018 proposed a novel PDR indoor localization algorithm combined with online sequential extreme learning machine to increase the accuracy. They reached in their experiments a localization error of 1.7 m instead of 5.1 m without an algorithm.

However, for augmented reality applications the errors are still too high, and anchors needs to be used for acceptable results.

4.13 Pseudolites

Pseudolites are ground-based transmitters sending GPS compatible signals. As an independent system for indoor positioning, pseudolites technique can be explored for a wide range of positioning and navigation application where the signal of satellite GNSS can't be received.

Kim et al. 2014 proposed a pseudolite-based positioning system that can be used with unmodified legacy GPS receivers. Wan and Zhan 2011 analyzed the near-far problem in indoor pseudolite positioning systems and the near far ratio. Further, they evaluated different methods of time synchronization based on different structure of pseudolite positioning systems. In combination with PDR Gan et al. 2017 reached a localization accuracy of below 0.5 m. Recently, Li et al. 2019 developed a not algorithm based on a robust estimation and partial ambiguity resolution method to increase the accuracy without need of other IP technologies. They reached a positioning error of almost 0.10 m.

However, for augmented reality applications the necessary technology is quite expensive but could be an alternative in the future.

5 Hybrid Indoor Positioning Technologies

As already mentioned, for certain application cases the combination of different indoor positioning technologies can increase the accuracy significantly. Commonly used methods to fusion the different sensor data are Kalman or particle filters and all kind of machine learning algorithms. This can also be called hybrid IPS. The main technology used is inertial navigation (PDR), in particular because of the cheap sensors and the availability in smartphones. Kuang et al. 2018 proposed using PDR in combination with magnetic field matching and reached an accuracy of 0.64 m in an office environment and 2.34 m in a shopping mall environment. Yucel et al. 2012 proposed a combination of ultrasonic and infrared signals and reached a maximum positioning error of 0.02 cm. However, that could not show how such a system can be scaled up to e.g. building level. House et al. 2011 used passive RFID tags and IMU sensor in the formfactor of a wearable and reached a positioning accuracy of around 50 cm. They used the RFID tags as anchor to reposition the correct absolute position. Januszkiewicz et al. 2016 presented a similar methodology, but used infrared beacons instead of RFID anchors. Ruotsalainen et al. 2011 introduced a visual-aided two-dimensional indoor pedestrian navigation system integrating measurements from GNSS, Bluetooth, WLAN, self-contained sensors, and heading change information obtained from consecutive images. The integration was performed by using an extended Kalman filter. Compared to the indoor positioning without visual-aiding the system reached a 26% higher accuracy. Fu et al. 2018 combined IMU-based indoor navigation with visual-aiding and reached a 90% higher accuracy compared to using only the IMU sensor. Coronel et al. 2008 proposed to use IMU sensors and Bluetooth beacons by applying Kalman filtering. Yu et al. 2019 proposed a Wi-Fi and pedestrian dead reckoning (PDR)-integrated localization approach based on unscented Kalman filters. They showed that their approach may improve traditional approaches in terms of reliability and localization accuracy. Wang et al. 2016 studied map information of a given indoor environment, analyzed variations of Wi-Fi received signal strength (RSS), defined several kinds of indoor landmarks, and then utilized these landmarks to correct accumulated errors derived from PDR. This fusion scheme, called Landmark-aided PDR (LaP), was proved to be light-weight and suitable for real-time implementation. They achieved an average accuracy of 2.17 m.

For AR applications sensor fusion and hybrid indoor positioning technologies are necessary. Not only to achieve higher accuracy, but more important to achieve a higher robustness of the overall system. Combining different technologies can also help to prevent a completely wrong indoor navigation, i.e. if a hardware error occurs.

6 Scenario for Indoor Positioning Systems in AR for Facility Management

Based on this comprehensive literature review a scenario was developed to condense the results and to find the best solutions for the use of AR in facility management scenarios. Figure 1 shows such a feasible scenario in an office environment. Both operators wear AR glasses and can see actual information about the state of e.g. the escalator or a room.

The indoor positioning is carried out on three different levels of detail. This approach has the best scalability and allows to upgrade an existing building with this new system very quickly, easily and with cheap components.

With Bluetooth beacons the actual room is recognized. This means, when the operator enters the room, different states and information can be displayed in its AR glasses. The accuracy than can be reached by using Bluetooth beacons is sufficient for this task. However, using Wi-Fi fingerprint data and a Kalman filter the accuracy and the localization speed could be increased further.

To see specific information, i.e. the next necessary maintenance of a fire-extinguisher, visual markers can be used. A QR code can be mounted to such infrastructure and with image-based technology it can be identified, and information is shown in the glasses, as long as the equipment is in the operators' field of vision.

In more complex rooms, like the plant room or a conference room with many technical equipment, a tracking system based on infrared could be installed. The AR glasses can be equipped with so-called markers (see Fig. 2 for a first prototype).

This system can provide a higher accuracy for detecting the operators position and by using three or more infrared tracking cameras. With five markers on the AR glasses, the position and orientation of the head can be determined. With this information and an accurate 3D B.I.M. model no additional landmarks (like QR codes) are necessary. The information of a specific equipment appears when the operator focuses on it for longer than a specific period of time.

Fig. 1. Scenario for AR in facility management and indoor positioning technology (modified design of macrovector/Freepik)

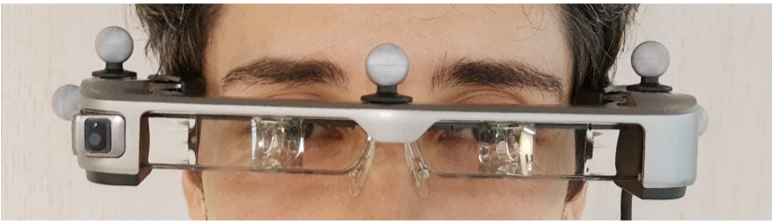

Fig. 2. AR glasses with markers

7 Conclusion

A huge number of different technologies useable as non-vision-based localization techniques can be identified. For application where a high accuracy is necessary, tracking systems like infrared-based camera systems are a preferable solution. However, this technology is quite expensive, line-of-sight is necessary and natural light has an influence on the accuracy. Such systems are also widely used in the field of robotics, where interesting synergies to the facility management occur. Also, ultrasonic could be a cheap solution for a medium accuracy tracking. This technology is widely used in environments like hospitals. One main advantage of this technology is that it does not use the overloaded electromagnetic spectrum. For a simple room-based localization Bluetooth beacons and other hybrid indoor position technologies are preferred. They are very cheap and already widely used. However, missing opensource standards and use of the overloaded 2.4 GHz radio frequency are considerable disadvantages.

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References

Alarifi, A., et al.: Ultra wideband indoor positioning technologies: analysis and recent advances. Sensors **16**, 707 (2016)

Amutha, B., Nanmaran, K.: Development of a ZigBee based virtual eye for visually impaired persons. In: 2014 International Conference on Indoor Positioning and Indoor Navigation (IPIN). Presented at the 2014 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Busan, South Korea, pp. 564–574. IEEE (2014)

Bai, Y.B., Wu, S., Wu, H.R., Zhang, K.: Overview of RFID-based indoor positioning technology. In: GSR (2012)

Baronti, P., Pillai, P., Chook, V.W.C., Chessa, S., Gotta, A., Hu, Y.F.: Wireless sensor networks: a survey on the state of the art and the 802.15.4 and ZigBee standards. Comput. Commun. **30**, 1655–1695 (2007)

Bartoletti, S., Conti, A., Dardari, D., Giorgetti, A.: 5G Localization and Context-Awareness. Whitepaper (2019)

Bhattarai, B., Hwang, S.-S., Pyun, J.-Y.: An efficient geomagnetic indoor positioning system using smartphones. In: 3rd International Conference on Next Generation Computing (ICNGC2017b), Taiwan (2018)

Bouet, M., dos Santos, A.L.: RFID tags: positioning principles and localization techniques. In: 2008 1st IFIP Wireless Days. Presented at the 2008 1st IFIP Wireless Days, pp. 1–5 (2008)

Castillo-Cara, M., Lovón, J., Rocca, G., Orozco-Barbosa, L., García-Varea, I.: An empirical study of the transmission power setting for Bluetooth-based indoor localization mechanisms. Sensors **17**, 1318 (2017)

Chen, X.Q., Alfadhl, Y., Chai, K.K.: An indoor item finder with active RFID tags. In: IET International Conference on Communication Technology and Application (ICCTA 2011), Beijing, China (2011)

Chon, H.D., Jun, S.-B., Jung, H., An, S.W.: Using RFID for accurate positioning. J. Glob. Position. Syst. **3**, 32–39 (2004)

Cirulis, A.: Ultra wideband tracking potential for augmented reality environments. In: De Paolis, L.T., Bourdot, P. (eds.) AVR 2019. LNCS, vol. 11614, pp. 126–136. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-25999-0_11

Cook, B.S., et al.: RFID-based sensors for zero-power autonomous wireless sensor networks. IEEE Sens. J. **14**, 2419–2431 (2014)

Coronel, P., Furrer, S., Schott, W., Weiss, B.: Indoor location tracking using inertial navigation sensors and radio beacons. In: Floerkemeier, C., Langheinrich, M., Fleisch, E., Mattern, F., Sarma, S.E. (eds.) IOT 2008. LNCS, vol. 4952, pp. 325–340. Springer, Heidelberg (2008). https://doi.org/10.1007/978-3-540-78731-0_21

De Angelis, A., et al.: Design and characterization of a portable ultrasonic indoor 3-D positioning system. IEEE Trans. Instrum. Meas. **64**, 2616–2625 (2015a)

De Angelis, G., et al.: An indoor AC magnetic positioning system. IEEE Trans. Instrum. Meas. **64**, 1267–1275 (2015b)

Faragher, R., Harle, R.K.: An analysis of the accuracy of Bluetooth low energy for indoor positioning applications. In: Proceedings of the 27th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2014). Presented at the International Technical Meeting of the Satellite Division of the Institute of Navigation, Tampa, Florida, pp. 201–210 (2014)

Farid, Z., Nordin, R., Ismail, M.: Recent advances in wireless indoor localization techniques and system. J. Comput. Netw. Commun. **2013**, 185138:1–185138:12 (2013). [WWW Document]

Foerster, J., Green, E., Somayazulu, S., Leeper, D.: Ultra-wideband technology for short- or medium-range wireless communications. Intel Technol. J. Q2, 11 (2001)

Fu, W., Peng, A., Tang, B., Zheng, L.: Inertial sensor aided visual indoor positioning. In: 2018 International Conference on Electronics Technology (ICET). Presented at the 2018 International Conference on Electronics Technology (ICET), Chengdu, pp. 106–110. IEEE (2018)

Gan, X., Yu, B., Heng, Z., Huang, L.: Indoor positioning technology of Beidou/GPS pseudolites correction PDR. In: International Conference on Indoor Positioning and Indoor Navigation (IPIN), vol. 4 (2017)

Gjengset, J., Xiong, J., McPhillips, G., Jamieson, K.: Phaser: enabling phased array signal processing on commodity WiFi access points. In: Proceedings of the 20th Annual International Conference on Mobile Computing and Networking - MobiCom '14. Presented at the 20th Annual International Conference, Maui, Hawaii, USA, pp. 153–164. ACM Press (2014)

Hazas, M., Hopper, A.: Broadband ultrasonic location systems for improved indoor positioning. IEEE Trans. Mob. Comput. **5**, 536–547 (2006)

House, S., Connell, S., Milligan, I., Austin, D., Hayes, T.L., Chiang, P.: Indoor localization using pedestrian dead reckoning updated with RFID-based fiducials. In: 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 7598–7601 (2011)

Ijaz, F., Yang, H.K., Ahmad, A.W., Lee, C.: Indoor positioning: a review of indoor ultrasonic positioning systems. In: 2013 15th International Conference on Advanced Communications Technology (ICACT). Presented at the 2013 15th International Conference on Advanced Communications Technology (ICACT), pp. 1146–1150 (2013)

Ingram, S.J., Harmer, D., Quinlan, M.: UltraWideBand indoor positioning systems and their use in emergencies, In: Position Location and Navigation Symposium (IEEE Cat. No. 04CH37556), PLANS 2004. Presented at the PLANS 2004. Position Location and Navigation Symposium (IEEE Cat. No.04CH37556), pp. 706–715 (2004)

Islim, M.S., Haas, H.: Modulation techniques for Li-Fi. ZTE Commun. **14**, 29–40 (2016)

Januszkiewicz, Ł., Kawecki, J., Kawecki, R., Oleksy, P.: Wireless indoor positioning system with inertial sensors and infrared beacons. In: 2016 10th European Conference on Antennas and Propagation (EuCAP). Presented at the 2016 10th European Conference on Antennas and Propagation (EuCAP), pp. 1–3 (2016)

Kang, W., Han, Y.: SmartPDR: smartphone-based pedestrian dead reckoning for indoor localization. IEEE Sens. J. **15**, 2906–2916 (2015)

Kanwar, A., Khazanchi, A.: ZigBee the new bluetooth technology. Int. J. Eng. Comput. Sci. **1**(2), 67–74 (2012)

Kaur, M., Sandhu, M., Mohan, N., Sandhu, P.: RFID technology principles, advantages, limitations & its applications. Int. J. Comput. Electr. Eng. **3**, 151–157 (2011)

Khan, M.A., Antiwal, V.K.: Location estimation technique using extended 3-D LANDMARC algorithm for passive RFID tag. In: 2009 IEEE International Advance Computing Conference. Presented at the 2009 IEEE International Advance Computing Conference, pp. 249–253 (2009)

Kim, C., So, H., Lee, T., Kee, C.: A pseudolite-based positioning system for legacy GNSS receivers. Sens. Switz. **14**, 6104–6123 (2014)

Kuang, J., Niu, X., Zhang, P., Chen, X.: Indoor positioning based on pedestrian dead reckoning and magnetic field matching for smartphones. Sensors **18**, 4142 (2018)

Kumar, S., Gil, S., Katabi, D., Rus, D.: Accurate indoor localization with zero start-up cost. In: Proceedings of the 20th Annual International Conference on Mobile Computing and Networking - MobiCom '14. Presented at the 20th Annual International Conference, Maui, Hawaii, USA, pp. 483–494. ACM Press (2014)

Larranaga, J., Muguira, L., Lopez-Garde, J.-M., Vazquez, J.-I.: An environment adaptive ZigBee-based indoor positioning algorithm. In: 2010 International Conference on Indoor Positioning and Indoor Navigation. Presented at the 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Zurich, Switzerland, pp. 1–8. IEEE (2010)

Lee, N., Ahn, S., Han, D.: AMID: accurate magnetic indoor localization using deep learning. Sensors **18**, 1598 (2018)

Lehtimäki, S.: Bluetooth Angle Estimation for Real-Time Locationing. Silicon Labs (2019). [WWW Document]. https://www.silabs.com/whitepapers/bluetooth-angle-estimation-for-real-time-locationing. Accessed 1 July 2020

Li, W., Wu, J., Wang, D.: A novel indoor positioning method based on key reference RFID tags. In: Computing and Telecommunication 2009 IEEE Youth Conference on Information. Presented at the Computing and Telecommunication, pp. 42–45 (2009)

Li, X., Huang, G., Zhang, P., Zhang, Q.: Reliable indoor pseudolite positioning based on a robust estimation and partial ambiguity resolution method. Sensors **19**, 3692 (2019)

Li, Y.-S., Ning, F.-S.: Low-cost indoor positioning application based on map assistance and mobile phone sensors. Sensors **18**, 4285 (2018)

Liu, H., Darabi, H., Banerjee, P., Liu, J.: Survey of wireless indoor positioning techniques and systems. IEEE Trans. Syst. Man Cybern. Part C Appl. Rev. **37**, 1067–1080 (2007)

Magnago, V., et al.: Robot localisation based on phase measures of backscattered UHF-RFID signals. In: 2019 IEEE International Instrumentation and Measurement Technology Conference (I2MTC). Presented at the 2019 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), pp. 1–6 2019

Mazuelas, S., et al.: Robust indoor positioning provided by real-time RSSI values in unmodified WLAN Networks. IEEE J. Sel. Top. Sig. Process. **3**, 821–831 (2009)

Mendoza-Silva, G.M., Torres-Sospedra, J., Huerta, J.: A meta-review of indoor positioning systems. Sensors **19**, 4507 (2019)

Mrindoko, N.R., Minga, D.L.M.: A comparison review of indoor positioning techniques. Int. J. Comput. **21**, 9 (2016)

Oguntala, G., Abd-Alhameed, R., Jones, S., Noras, J., Patwary, M., Rodriguez, J.: Indoor location identification technologies for real-time IoT-based applications: an inclusive survey. Comput. Sci. Rev. **30**, 55–79 (2018)

Oppermann, I., Hämäläinen, M., Iinatti, J.: UWB Theory and Applications UWB Theory and Applications. Wiley, Hoboken (2004)

Paterna, V., Calveras, A., Aspas, J., Bullones, M.: A bluetooth low energy indoor positioning system with channel diversity, weighted trilateration and Kalman filtering. Sensors **17**, 2927 (2017)

Pinhasi, Y., Yahalom, A., Harpaz, O., Vilner, G.: Study of ultrawide-band transmission in the extremely high frequency (EHF) band. IEEE Trans. Antennas Propag. **52**, 2833–2842 (2004)

Qi, J., Liu, G.-P.: A robust high-accuracy ultrasound indoor positioning system based on a wireless sensor network. Sensors **17**, 2554 (2017)

Radunovic, B., Le Boudec, J.-Y.: Optimal power control, scheduling, and routing in UWB networks. IEEE J. Sel. Areas Commun. **22**, 1252–1270 (2004)

Raharijaona, T., et al.: Local positioning system using flickering infrared LEDs. Sensors **17**, 2518 (2017)

Rahayu, Y., Rahman, T.A., Ngah, R., Hall, P.S.: Ultra wideband technology and its applications. In: 2008 5th IFIP International Conference on Wireless and Optical Communications Networks (WOCN '08). Presented at the 2008 IFIP International Conference on Wireless and Optical Communications Networks - (WOCN), Surabaya, Indonesia, pp. 1–5. IEEE (2008)

Rai, A., Chintalapudi, K.K., Padmanabhan, V.N., Sen, R.: Zee: zero-effort crowdsourcing for indoor localization. In: Proceedings of the 18th Annual International Conference on Mobile Computing and Networking - Mobicom '12. Presented at the 18th Annual International Conference, Istanbul, Turkey, p. 293. ACM Press (2012)

Ruotsalainen, L., Kuusniemi, H., Chen, R.: Visual-aided two-dimensional pedestrian indoor navigation with a smartphone. J. Glob. Position. Syst. **10**, 11–18 (2011)

Saab, S.S., Nakad, Z.S.: A standalone RFID indoor positioning system using passive tags. IEEE Trans. Ind. Electron. **58**, 1961–1970 (2011)

Sachs, J.: Handbook of Ultra-Wideband Short-Range Sensing: Theory, Sensors, Applications, pp. 1–30. Wiley, Hoboken (2012)

Sen, S., Radunovic, B., Choudhury, R.R., Minka, T.: You are facing the Mona Lisa: spot localization using PHY layer information. In: Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services - MobiSys '12. Presented at the 10th international Conference, Low Wood Bay, Lake District, UK, p. 183. ACM Press (2012)

Suryavanshi, N.B., Viswavardhan Reddy, K., Chandrika, V.R.: Direction finding capability in Bluetooth 5.1 standard. In: Kumar, N., Venkatesha Prasad, R. (eds.) UBICNET 2019. LNICSSITE, vol. 276, pp. 53–65. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-20615-4_4

Tadakamadla, S.: Indoor Local Positioning System for ZigBee, Based on RSSI. Mid Sweden University, Sundsvall, Sweden (2006)

Ting, S.L., Kwok, S.K., Tsang, A.H.C., Ho, G.T.S.: The study on using passive RFID tags for indoor positioning. Int. J. Eng. Bus. Manag. **3**, 8 (2011)

Vasisht, D., Kumar, S., Katabi, D.: Sub-Nanosecond Time of Flight on Commercial Wi-Fi Cards. arXiv: arXiv:1505.03446 [Cs] (2015)

Viani, F., Rocca, P., Oliveri, G., Trinchero, D., Massa, A.: Localization, tracking, and imaging of targets in wireless sensor networks: an invited review. Radio Sci. **46**, 1–12 (2011)

Wan, X., Zhan, X.: The research of indoor navigation system using pseudolites. Procedia Eng. **15**, 1446–1450 (2011)

Wang, K., Nirmalathas, A., Lim, C., Alameh, K., Li, H., Skafidas, E.: Indoor infrared optical wireless localization system with background light power estimation capability. Opt. Exp. **25**, 22923 (2017)

Wang, X., Jiang, M., Guo, Z., Hu, N., Sun, Z., Liu, J.: An indoor positioning method for smartphones using landmarks and PDR. Sensors **16**, 2135 (2016)

Wu, K., Xiao, J., Yi, Y., Chen, D., Luo, X., Ni, L.M.: CSI-based indoor localization. IEEE Trans. Parallel Distrib. Syst. **24**, 1300–1309 (2013)

Xu, H., Wu, M., Li, P., Zhu, F., Wang, R.: An RFID indoor positioning algorithm based on support vector regression. Sensors **18**, 1504 (2018)

Wang, Y., Yang, X., Zhao, Y., Liu, Y., Cuthbert, L.: Bluetooth positioning using RSSI and triangulation methods. In: 2013 IEEE 10th Consumer Communications and Networking Conference (CCNC). Presented at the 2013 IEEE 10th Consumer Communications and Networking Conference (CCNC), Las Vegas, NV, pp. 837–842. IEEE (2013)

Yasir, M., Ho, S.-W., Vellambi, B.N.: Indoor position tracking using multiple optical receivers. J. Light. Technol. **34**, 1166–1176 (2016)

Yazici, A., Yayan, U., Yücel, H.: An ultrasonic based indoor positioning system. In: 2011 International Symposium on Innovations in Intelligent Systems and Applications. Presented at the 2011 International Symposium on Innovations in Intelligent Systems and Applications, pp. 585–589 (2011)

Youssef, M.: HORUS: A WLAN-based indoor location determination system. Department of Computer Science, University of Maryland (2004)

Yu, J., Na, Z., Liu, X., Deng, Z.: WiFi/PDR-integrated indoor localization using unconstrained smartphones. EURASIP J. Wirel. Commun. Netw. **2019**(1), 1–13 (2019). https://doi.org/10.1186/s13638-019-1365-9

Yucel, H., Edizkan, R., Ozkir, T., Yazici, A.: Development of indoor positioning system with ultrasonic and infrared signals. In: 2012 International Symposium on Innovations in Intelligent Systems and Applications. Presented at the 2012 International Symposium on Innovations in Intelligent Systems and Applications, pp. 1–4 (2012)

Zhang, M., Wen, Y., Chen, J., Yang, X., Gao, R., Zhao, H.: Pedestrian dead-reckoning indoor localization based on OS-ELM. IEEE Access **6**, 6116–6129 (2018)

Zhang, P., Lu, J., Wang, Y., Wang, Q.: Cooperative localization in 5G networks: a survey. ICT Exp. **3**, 27–32 (2017)

Zhuang, Y., et al.: A survey of positioning systems using visible LED lights. IEEE Commun. Surv. Tutor. **20**, 1963–1988 (2018)