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An Overview of Indoor Localization Technologies: Toward IoT Navigation Services

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Abstract: **Localization system is a process of monitoring any area or object using any known information gathered from different sources such as wired or wireless networks. Internet of Things (IoT) technology plays a more significant role, which directly affects our lives. Navigation IoT based system is becoming a very appealing research topic nowadays since it is used in various context-aware and localization-aware applications that cover many fields such as tracking, healthcare, or security. Moreover, this field has taken so much attention lately since there is continuous progress in sensing technologies and computing capabilities. This paper provides a brief review of the indoor localization technologies used for IoT-based navigation systems. This review gives fundamental guidelines for designing an intelligent indoor localization system.**

Keywords: IoT, indoor localization, navigation, positioning, tracking

I. INTRODUCTION

One of the main targets of today's communications systems' advancements is the availability of location information. The positioning systems could be used in either indoor and outdoor environments. The outdoor localization is mostly achieved by the use of the Global Navigation Satellite System (GNSS). However, this technology cannot be used for indoor positioning due to the propagation of waves. Those waves cannot penetrate through the walls of the buildings but are reflected instead [1]. So, non-line of sight, interference, and noise are the main reasons that make GPS inconvenient to be used for indoor positioning.

Regarding outdoor positioning, GPS has had a significant impact on today's navigation technology, providing very high precision and supporting many applications. Furthermore, there has been researching on adopting GPS-based approaches for indoor positioning as well. In [2], repeaters were used to direct the GPS waves into the indoor environment and detect the target's location. Even though the authors managed to obtain an average error of 2.7m, it is still not an acceptable type of error because missing the target with an error of 2.7 m in indoor positioning means to place the object totally in a different room. Moreover, repeaters' usage to adapt GPS for indoor positioning requires an enormous cost.

On the other hand, Indoor Positioning System (IPS) operates quite differently from GPS. It is mostly based on wireless communication such as Wireless-Fidelity (Wi-Fi), geomagnetism, Bluetooth, ultrawideband, ultrasound, sound, inertial sensors-based localization, etc. [3]. All these indoor positioning technologies are based on different methods. The most well-known one is the fingerprinting approach, which is based on the implementation of two phases, the online and offline ones. The offline phase consists of the collection and pre-processing of data, whereas the online phase applies a matching algorithm to the signals which are in real-time in order to calculate the position of the object. Received Signal Strength (RSS), Time of Arrival (ToA), Time Difference of Arrival (TDoA) and Channel State Information (CSI) are the main techniques in which IPSs are based. However, RSS may not have a better accuracy in indoor environments due to signal attenuation by multipath effects and significant power consumption [4, 5]. The other techniques mentioned above are inferior toward CSI-based approaches since the latter can provide more information and a better description of the signal's propagation path [6]. An IPS is a framework comprising a connected series of devices used to position objects or people in an indoor environment using the information received from wireless connections. In this study, we provide a review of localization technologies and discuss the advantages and disadvantages of each presented technology.

This paper focuses on descriptive information about indoor localization technologies used for tracking and navigation objects and humans. Besides, it compares different technologies in terms of accuracy range, techniques, advantages, and disadvantages. This brief survey provides the researcher's guidelines and an excellent platform to further their research in this survey's same scope.

II. LOCALIZATION TECHNOLOGIES

In this section, we present common localization technologies that use for object tracking in indoor environments. The localization technologies are divided into eleven categories as shown in Figure 1.

A. Wireless Local Area Network (WLAN)-WiFi

Wireless Local Area Network (WLAN) is the most well-known approach for IPS. It belongs to the group of IPS which are Radio

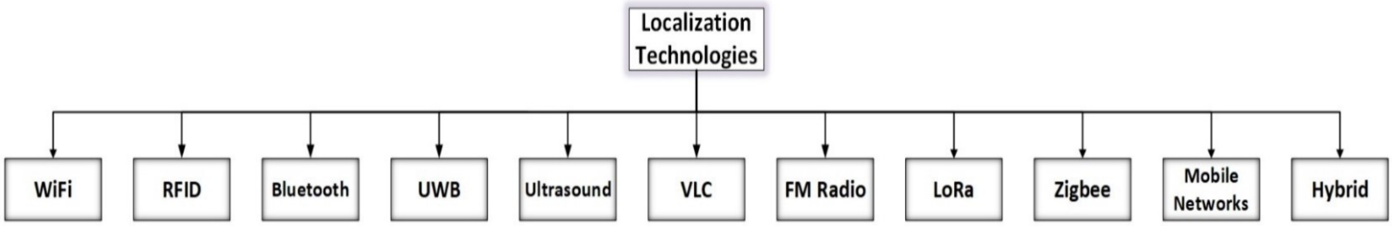

Figure 1. Localization technologies

Frequency (RF) based [7-9]. Much research has been conducted on WLAN since this localization technology does not require additional hardware implementation in the indoor environment. WLAN utilizes the Wi-Fi transmitters as tags to send packets to different access points in an indoor area. The most ubiquitous WLAN localization technique is RSS. However, other techniques such as TDoA, ToA, and Angle of Arrival (AoA) are utilized if a certain degree of complexity is added into the hardware [1].

The Wi-Fi infrastructure can support fingerprinting-based systems, which have been a research trend because it is much more accurate than triangulation technology [10]. The fingerprinting approach is mostly based on RSS, and it consists of two phases. The first phase is known as the offline (training) phase, and the second phase is known as the online (position) phase [11, 12]. During the offline phase, specific fingerprints (RSS samples) are collected at the desired locations, implementing the radio map. During the online phase, the RSS samples received from the Access Points (APs) will be transmitted to the positioning engine. This positioning engine will be responsible for the comparison between the samples collected in both phases. After the comparison, an approximate position will be calculated. This technique's main drawback is the offline phase, which is considered very time-consuming and tedious. Moreover, RSS Indicator (RSSI) based approaches are very prone to environmental changes and heterogeneity.

B. Radio Frequency Identification (RFID)

RFID is another technology that belongs to the group of RF-based IPS technologies. Just like WLAN, RFID uses many localization techniques such as AoA, ToA, and the most common one RSSI. RFID system consists of 4 parts: Tags, Reader, Antenna, and Reader Interface Layer. There are many tags and just one reader. The primary duty of the antenna is to energize the RFID tags. The tags emit data in the form of electromagnetic waves that are captured by the reader. RFID reader uses predefined protocols and RF in order to determine the data sent from the tags. The tags and the reader well know predefined protocols and RF. Reader Interface Layer is responsible for mapping the tag information. RFID systems consist of two types: Active and Passive RFID. Zafari et al. [1] stated that Passive RFID is not suitable for an IPS due to their limited range, thus restricting it only for communication. In contrast, active RFID is more convenient to be used in Indoor Positioning since its tags are capable of operating at a higher range from the reader. In [13] used active RFID tags based on RSSI to track moving objects' locations using an extended Kalman filter. Unlike work in [14] used passive RFID tags based on ultrahigh-frequency interference for localization in 2D and 3D indoor environments. The main drawback of RFID is its short-range operation, and in order to increase the accuracy and the range as well, many tags need to be densely distributed in an indoor area, thus raising the chances of collisions between the tags.

C. Bluetooth

Bluetooth is the third technology, which belongs to RF-based IPS technologies. Bluetooth comprises MAC and physical layer specifications for connecting wireless devices in a particular area [1]. The most advanced Bluetooth version is Bluetooth Low Energy (BLE), which is recently sponsored by Apple and is being distributed in the form of beacons. BLE can be used as an IPS using different localization techniques such as RSSI, Time of Flight (ToF), and AoA with RSSI being the most prevalent one. There are two categories of algorithms that comprise the BLE-based indoor positioning, such as ranging-based and non-ranging-based algorithms. In the former RSSI, TOA/AOA, TDoA positioning based algorithms are included, whereas in the later ones, fingerprinting algorithms are included [15]. Due to the dependence on RSSI, conventional BLE is not considered to be very precise. Moreover, BLE iBeacon-based systems are not perfect since there is a delay in the RSS reporting values to the user device.

D. Ultra-Wideband (UWB)

UWB technology is based on the transmission of RF signals in the form of very short pulses with a period of less than one ns. The pulses are transmitted over a considerable bandwidth with a low duty cycle [1]. Considering that UWB is immune to path loss and interference, researchers decided to concentrate a lot on this technology and expand its utilization beyond the scope of communication. The main technique that this technology utilizes in order to estimate the indoor positioning is ToA or TDoA . The position is estimated from RF waves traveling between the reference and target nodes, whose locations are well known [16]. This technology is preferred over Bluetooth and Wi-Fi when localization accuracy is the main target since it can provide precision at the centimeter level. The UWB using ToF approximation is capable of achieving a positioning accuracy up to 10 cm, whereas in [16], Yassin et al. state that it can reach an accuracy of 15 cm if it is based on ToA or TDoA. Even though this technology seems to be flawless, there are still issues such as varying indoor areas, short-range or high cost of implementing the complex hardware that has obliged the researchers to work and boost its performance further [17]. The accuracy of the UWB for indoor positioning was improved dramatically; however, a hybrid complex model was required.

E. Ultrasound

Ultrasound Indoor Positioning System (UIPS) is a very novel IPS technique that uses many wireless ultrasonic beacons that emit ultrasonic waves toward the targeted node such as a mobile device. By measuring ToF, which is the most prevalent technique in Ultrasound-based IPS, of the ultrasound wave that traveled between the nodes and by incorporating the measurements into complex signal processing algorithms such as trilateration algorithm capable of detecting at cm-based precision the target node. Unfortunately, UIPS requires more than one anchor node. Additionally, it requires synchronization and LoS between the nodes achieved using RF signals [1, 18]. De Angils et al. in [19] propose a model that can overcome the issue of LoS in UIPS; however, it requires a large number of beacons for high precision. Since this technology is highly dependent on the sensor's infrastructure, it is prone to distortions caused by Doppler effect and noise. This technology is becoming so ubiquitous in indoor positioning due to its ability to provide very high accuracy at a low cost. This comes from the fact that it can integrate itself very quickly into the today's communication technology such as cellular devices or embedded inertial sensors [20].

F. Visible Light

Visible Light Communication (VLC) is not restricted only for communication, but it also is used for indoor positioning. This kind of indoor localization technology utilizes Light Emitting Diodes (LED), which acts as iBeacons, in order to transmit signals to the receiver [1]. Usually, the receiver has to carry a sensor to detect the positions of the LEDs. There are multiple LEDs in a room to increase the technique's accuracy, but their emitted lights should not overlap with each other. The main techniques that are used by this IPS are RSS, AoA, TDoA, and ToA. Authors in [21] and [1] state that the most accurate ones are TDoA and ToA; however, the cost of systems based on those techniques is very high. The sensors at the receiver (usually a cellular phone), based on the technique mentioned earlier, extract the distance information about LED receivers and then utilizes trilateration or triangulation algorithms to find their exact coordinates. Unfortunately, this system requires a constant calibration of LEDs which makes it not flexible. Ghimire et al. in [22] proposed an IPS dependent on multiple LEDs which could transmit synchronized OFDM signals and each AP produces same symbols in order to convey data symbols.

G. FM Radio

FM Radio technology is considered to be one of the most advantageous IPS due to its wave characteristics. The indoor localization is usually performed using multiple FM transmitters that act as beacons and strike with FM waves the receiver, which is usually supposed to be a phone with FM sensors embedded in it [23]. FM signals have very high power and cover a very long range due to their low frequency in which they operate. That is why they are used for object tracking in indoor/outdoor environments and outdoor environments where GPS fails to provide an accurate result, such as the dense urban areas [24]. Moreover, FM does not need additional complex hardware and does not consume too much power, making it not a costly technology [25].

Additionally, FM Radio signals, in contrast to Wi-Fi signals, can be used for tracking even in hospitals since they do not interfere with other biomedical device signals due to their different frequency bands [23]. Their low frequency of operation makes it possible for them to be less sensitive to multipath fading or LoS [24]. However, Perekadan et al. disagree with that and state that FM Signals used alone are not reliable; thus, they deployed a hybrid system consisting of both FM and GSM signals. Despite multiple advantages, FM radio signals have some drawbacks such as their inability to carry timing information, thus making AoA, ToA and TDoA techniques inaccurate in FM technology [24].

H. Zigbee

Zigbee is a specification implemented upon IEEE 802.15.4 standard and is mostly concerned with MAC and physical layers [1, 26]. It is used to design Personal Area Networks (PAN) and boost short-range communication. It is preferred over Bluetooth and Wi-Fi due to its low cost of implementation, high scalability, high availability, and its ability to support dynamic routing topology [27]. Zigbee network topology consists of multiple reference sensors with known physical positions and one target node defined as the blind sensor. Due to the sensors' ability to reach each other, the radio signal strength obtained by the blind node is used for positioning [27]. The main technique used by Zigbee for indoor localization is the fingerprinting approach based on RSSI. In [28] a system based on Zigbee technology was established for Indoor Localization. It was proven that by using multiple algorithms instead of one, a higher accuracy could be obtained. The accuracy of this kind of technology is very high, but unfortunately, it is based on the types of algorithm being used and RSSI measurements prone to multipath fading. Additionally, this kind of technology is not very prevalent since it is not available on most user devices [1].

I. LoRa (Long Range)

LoRa Physical Layer has been designed for transmission mainly in the outdoor environments due to its ability to cover a very large range. LoRaWAN is the MAC layer on top of LoRa Physical layer and it is used to make possible the communication of many LoRa end devices through LoRa Gateway. It addresses all network protocols for devices that use LoRa. LoRa is based on Chirp Spread Spectrum Modulation (CSS), making it possible to reach very large communication ranges with very

Table 1. Summary of some the indoor localization systems with different technologies and techniques

Reference	Technology	Accuracy Range	Technique	Advantage	Disadvantage
[6]	Wi-Fi	>0.5 m	CSI	Accurate and cost-effective	Required a specific mobile device for CSI data collection
[13, 14]	RFID	>50 cm	RSSI	Efficient	Very short range is covered, requires multiple tags
[15]	Bluetooth	>0.8 m	RSSI	Efficient	Prone to noise and environment
[17]	UWB	10 cm	ToF	Very accurate and has low interference	Complicated and expensive hardware is required
[18]	UIPS	>10.2 mm	ToF	Accurate	Prone to noise and environment
[21]	VLC	>1.8 m	RSSI	Very precise	LoS and expensive hardware is required
[25]	FM	>2.5 m	RSSI	Cost-effective	No timing information is provided
[26]	Zigbee	0.51 m	RSSI	Accurate and cost-effective	Not available on every user device
[29]	LoRa	4.5 m	RSSI	Low energy and high efficiency	Not accurate
[30]	Mobile Networks	2.3 m	RSRP RSRQ	Flexible and very cost-effective	Prone to multipath fading
[31]	Hybrid	2-15 m	RSSI	Long- and short-range accuracy	A complex system is required

little power consumption [32]. CSS supports resilience against interference, Doppler Effect, and multipath. Due to the reasons mentioned above, CSS is considered advantageous for Indoor and outdoor positioning [1]. LoRa is considered a technology that provides a very long-range, low power consumption, low cost, and low data rate. LoRa cannot employ AoA, ToA, TDoA techniques since they all require very complex hardware, making RSSI the most appropriate one. Much research has been conducted lately regarding LoRa based on fingerprinting approaches using RSSI measurements for indoor localization. By utilizing this kind of system, in [29], Anjum et al. reached an accuracy up to 4.55 m. As can be seen, this technology's accuracy is not very high due to its bandwidth characteristics and due to its long-range between the server and the device.

J. Mobile Networks (GSM, 3G, 4G)

Mobile telephone networks such as GSM, 3G, 4G, and 5G, when programmed appropriately, can provide a very accurate indoor positioning at a low cost since no extra hardware equipment's is required. The main technique used by mobile networks, especially GSM and 3G, for indoor localization is the fingerprinting approach based on the RSS measurements gathered from the network. A few years ago, lots of research was being conducted in GSM mobile networks in order to be used as an IPS since 4G was not fully developed and ubiquitous, and 3G networks in relatively high frequency were not preferred due to low penetration [33]. Tian et al. proposed a system based on the measurements of RSS values on 548 GSM channels from a data acquisition device. Then, they used Sector Vector Machine (SVM) for their classification and a Bayesian filter to diminish the error and eventually achieve an accuracy of 98%. Indoor positioning in LTE was further enhanced, and it was introduced in REL 9. The LTE user equipment was determined based on a combination of cell identity, observed time difference of arrival, and A-GNSS. LTE positioning protocol proposed by 3GPP provides a significant boost in Indoor Location [34]. Poosmani and Rhee et al. [30] gathered the information from the physical layer of 4G Cellular Networks by using Received Signal Received Power (RSRP) and Received Signal Received Quality (RSRQ). They used RSRQ and RSRP for indoor localization since they overcome the issues of RSSI. By incorporating those values into their algorithm, they managed to provide a real time localization in the indoor environment. The error that they received was about 2.3 m. A novel method based on LTE system was proposed in [35] as well.

K. Hybrid

All the previous technologies have their own disadvantages and advantages regarding indoor positioning. Researchers have proposed using systems that can incorporate them with one another to diminish the drawbacks of those technologies. By integrating two, three, or more technologies with each other, the researchers could increase the overall accuracy, robustness, range, and effectiveness of the system. For example, in [31], a merge between BLE and Wi-Fi networks could increase the overall accuracy and the range of the system. As stated above, BLE provides higher accuracy than Wi-Fi, but it is restricted to only low ranges, whereas Wi-Fi could be used in wider areas; however, its performance is not very accurate. They managed to decrease the error up to 2-15 m and make their system useful in large areas such as airports. Table 1 displays a comparison summary of different technologies in terms of accuracy range, techniques, advantage, and disadvantage

III. CONCLUSION

This review paper summarized several IPS widely used today based on the latest research conducted on them. We discussed in detail their field of applications, accuracy, advantages, and disadvantages. As the complexity and cost of the implementation of these systems increases, the accuracy increases as well. However, researchers have tried to push as much as possible in IPS's performance by incorporating more than one of those systems with one another, thus making hybrid models the most efficient IPSs. Several algorithms are proposed during the online phase of the fingerprinting approaches; nevertheless, artificial intelligence-based algorithms achieve the best performance. Various algorithms are explained in detail in this survey, and we pointed out the upper hands and drawbacks of each of those algorithms. They have particular application scenarios and know which one to use where it is essential to get very high efficiency.

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