A review of Indoor Positioning Techniques

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Abstract
A great development has been appeared in wireless technologies and location based services and especially with appearance of open android operating system. In outdoor environments, Global Positioning System (GPS) can be used to get the position of smartphone users but GPS receiver is mostly inefficient in indoor environments. In this paper, several positioning systems have been reviewed which are used different technologies such as WLAN networks, cellular networks, infrared and ultrasound based system. Many comparison metrics between positioning techniques have been mentioned such as measurement type, accuracy, coverage, line of sight or non-line of sight, affected by multipath and cost and the best technique can be obtained through these metrics.

Keywords: IPS, GPS, Fingerprint, AoA, ToA.

1. Introduction

In the recent years, the development in mobile telecommunications and information technology allowed for appearance of several services based on user location in indoor environment. As well, various communication systems which based on the user position are developed. For example, security services, location based services, access control, etc. [1]. Recently, smartphones are evolved and their functionalities are increased through integrating different kinds of sensors like Global Positioning System ("GPS") receivers, Wi-Fi, Bluetooth and cameras etc. These sensors are utilized for various purposes such as communication, location-based services (LBS) and also entertainment. As for GPS is utilized to locate objects in outdoor environments but GPS's receivers are often inactive in indoor environments and satellite signal cannot penetrate obstacles. Thus, Indoor Positioning Systems (IPS) have been created by using other sensors; particularly Wi-Fi where the 802.11 Wi-Fi networks is widely available at the most buildings [2]. The important substitute to GPS is Indoor or Local positioning systems (LPS). LPS is unlike GPS because of LPS does not offer global coverage but it is more efficient system to local environments. Location based services (LBS) are one of the important services that take advantage of the user location. In the last
years, these services is received the growing attention and become utilized in various fields, such as health, social networks, work, etc. [3].
There are several positioning techniques which have been mentioned and reviewed and the comparison between them. Finally, positioning systems can offer various services, such services is classified into the following groups [4]:

- Positioning: Determining the location of an object.
- Tracking: Observing the movement of an object.
- Navigation: guidance user inside specific building such as museum, Mall.

2. Positioning Systems

There are many of existing systems used to determine a user's location in indoor and outdoor environments as shown in Figure .1

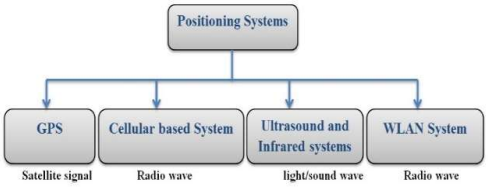

Fig 1. Different Positioning Systems

The Global Positioning System (GPS) and cellular positioning are examples of positioning systems used in outdoor environments, and positioning based on ultrasound and infrared and WLAN as examples of indoor positioning systems.

3. Indoor positioning Systems (IPS)

IPS is a system used in indoor environment to obtain users' position where GPS is ineffective because multipath and the satellite signal cannot penetrate walls. Many positioning techniques are utilized to determine the location information of a person or mobile clients and different levels of accuracy can be obtained for different applications.

3.1. Positioning Techniques

There are several techniques used to detect the location of mobile user as shown in Figure 2.

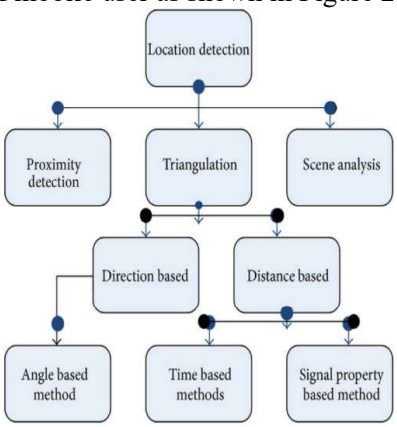

Fig 2. Classification of Positioning Techniques [5]

3.1.1. Proximity Detection Technique

Proximity detection or connectivity based Positioning is the simplest method for positioning. It provides symbolic relative location information. This method uses cell of origin (COO) method to determine the position of mobile client with known position and limited range [5,6]. Thus, if a receiver discovers a valid signal from a certain transmitter, the object must be within the coverage area of that transmitter [18]. When the mobile target detects more than one beacon, the nearest position is determined where the strongest signal is received. The accuracy of COO method bases on the density of beacon point deployment and signal range. There are several wireless positioning technologies which implement this method such as Bluetooth, infrared radiation (IR) based system, radio frequency identification (RFID) GSM (Cell-ID) and custom radio devices [7].

3.1.2. Triangulation

The triangulation method uses the geometric properties of triangles to identify the position of an object. In this method there are two derivations: lateration and angulation [5, 6, 8].

i. Angle Based Method

Angle of Arrival (AOA) or angulation technique defines the angle of arrival of the mobile signal received from a known location at multiple base stations. AOA method needs only two beacons when estimating position of object in a 2D dimension plane. Three beacons or more are needed to detect the location for improving accuracy. Then geometric relationships are used to determine the estimation location from the intersection of two lines of bearing (LoBs) at the known reference locations, as shown in Figure 3. [9, 10,11].

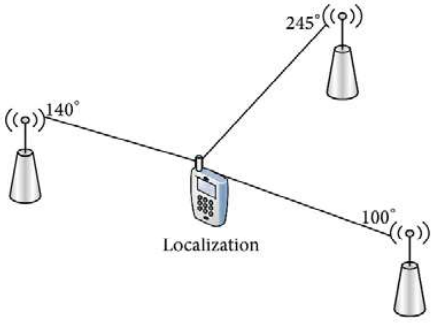

Fig 3. AOA positioning method [5]

ii. Time Based Methods

Lateration, Trilateration and Multilateration all indicate to a position identified from distance measurements. In lateration or trilateration the location of an object is determined by computing its distance from multiple reference

points. In the trilateration, the part "tri" refers to existence of three fixed points "Access Points AP" are required to obtain a position. In multilateration the position can be estimated by measuring the RSSs received from several APs. The lateration technique depends on the measurement of the propagation time system (such as TOA, RTOF, and TDOA and RSS-based and received signal phase methods) [10, 12].

Time of Arrival (TOA)/Time of Flight (TOF) techniques are depended on the synchronization of the arrival time of a signal transmitted from a mobile device to several receiving access points as shown in Figure 4. [10, 12].

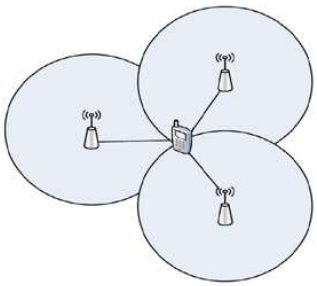

Fig 4. Positioning based on TOA/RTOF measurements [5].

In TOA technique, a time stamped signal is transmitted from the mobile device to receiving access points. Then, the distance between the mobile device and the receiving APs is computed from the delay of transmission time and the speed of the signal [9, 11]. As for the TDOA technique, Time Difference of Arrival are measured between multiple couples of reference points at known locations and relative time measurements are used at each receiving node in place of absolute time measurements as illustrated in Figure 5. [12].

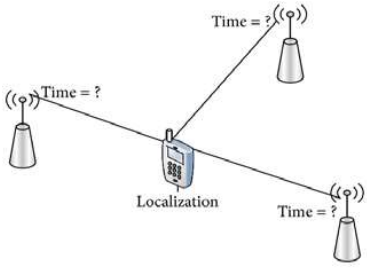

Fig 5. Time difference of arrival [5].

3.1.3. Trilateration for Indoor Positioning

The trilateration is a technique of the position estimation of mobile user in indoor and outdoor positioning. In GPS, the position of objects is determined by the receivers using this technique. It based on the computed distances of a user form at least three different points and its positioning coordinates.

This method uses Wi-Fi signal strength (SS) in indoor locations to get position of a user. At least three APs are required when implementing this technique as shown in Figure 6. [13].

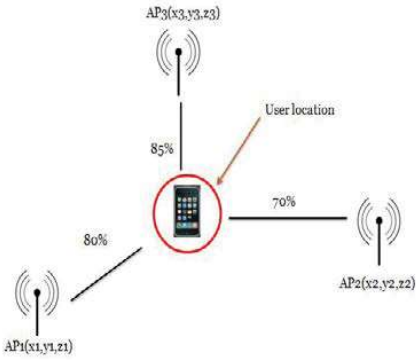

Fig 6. Signal Strength from three AP [14]

The percentage of signal strength obtained from the Wi-Fi access points are measured, and then the distance can be computed between a user and each AP based on these measurements using the following equation:

$$d_i = p(1 - m_i) \quad (1)$$

Where p is the maximum coverage of signal strength, m_i= is the percentage of SS and i = 1, 2, 3 is the number of access point. The signal strength forms three circles between the mobile device and each access point and intersects each other as shown in Figure 7.

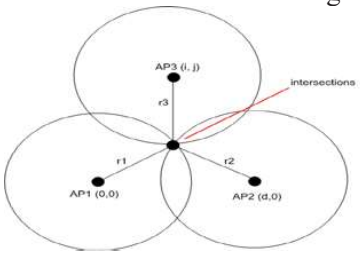

Fig 7. Intersections of 3 circles [14]

The position of user can be identified by the intersection of these three circles as shown in the following equation.

$$(x - x_i)^2 + (y - y_i)^2 = {r_i}^2 \quad (2)$$

Where (x_i, y_i) is the coordinates of each access point, r_i is the computed distance between the user and each AP and (x, y) is the coordinates of a user. Finally, the linear equation for 2 variables is solved and the positioning coordinates (x, y) is determined [14].

3.1.4. Signal Property Based Method

The wireless localization systems which used either timing information or angle based are affected by the multipath. Thus, the radio signal properties based method can be used to calculate the distance of unknown location to reference location from some sets of measuring units using the attenuation of emitted signal strength [5]. Mostly wireless based positioning systems which use properties of the received signal with received signal strength indicator "RSSI" is the most widely used signal-related feature. As for implementation this method, the system requires a server. These methods operate with the Wi-Fi technology and can operate using Wi-Fi access points which are least cost than Wi-Fi routers [15].

3.1.5. Dead Reckoning (DR)

In Dead Reckoning method, the current position can be estimated based on previous identified position and this position based on estimated speeds over elapsed time. There are several navigation and tracking systems which use dead reckoning method to offer very accurate positioning information and are very widely used [16]. The disadvantage of this method is the inaccuracy of the process that is cumulative, thus the deviation in position increases with time because of the new positions are computed entirely from previous positions. DR can be carried out in indoor localization systems [5, 17, 18].

3.1.6. Map Matching (MM)

Map matching is the method of identifying the location of a vehicle on a road network. This method combines the current positioning information with electronic map to determine the position of an object. Using maps is an efficient method instead of the installation of additional hardware [15]. MM technique includes three groups of algorithms which are topological analyses, pattern recognition and advanced algorithms e.g. hierarchical fuzzy inference algorithms [19].

3.1.7. Scene Analysis

Scene analysis technique based on RF signal and uses algorithms that first collect features (fingerprints) of a scene and then determine the location of an object by matching online measurements with the closest a previously location fingerprints. Fingerprinting method is commonly used in scene analysis [7].

4. Fingerprint Method

Fingerprinting is the most used method in indoor positioning and is based on the power level received by the mobile phone from each of the access points in the wireless network. This method does not need additional costs on infrastructure and no prior knowledge of the environment is needed, it can give better estimates of the user's locations for indoor environments [20, 21].

This technique uses the outputs of a standard Wi-Fi card, which is the RSSI from each access point. A list of RSSI coming from all the APs covering the area can be obtained where the laptop/mobile is moving. Using this available information, a Wi-Fi device in a WLAN environment is located by approximating its position by the position of the APs received at that location with the strongest signal strength, the main drawback of this method is its large estimation error. Fingerprinting includes signal power footprints or signatures that define a position in the indoor environment and these footprints are the received signal strengths from many APs that cover the environment .

A fingerprint is unique to a human, the properties of a signal are typical for the position where it is transmitted or received. So, a fingerprint in wireless positioning is the set of measurable signal characteristics that depend on the position of transmission or reception. However, there are further signal characteristics where it cannot have a simple analytical relationship because of a complex signal propagation environment. Fingerprinting method is done in two phases [20, 23]:

Offline phase or data collection phase is the training period that the positioning system used to collect RSS at the interest environment and process them to enable the system for determining the mobile device's position in the online phase [23, 24, 25].The goal of the training phase is to establish a fingerprint database. To build the database, collection of Reference Points (RP) are selected at interested the area [26]. Then the RSSs from all the APs are measured for locating a MS at all RP locations, and stored in the database [21, 27, 28] as shown in Figure 8.

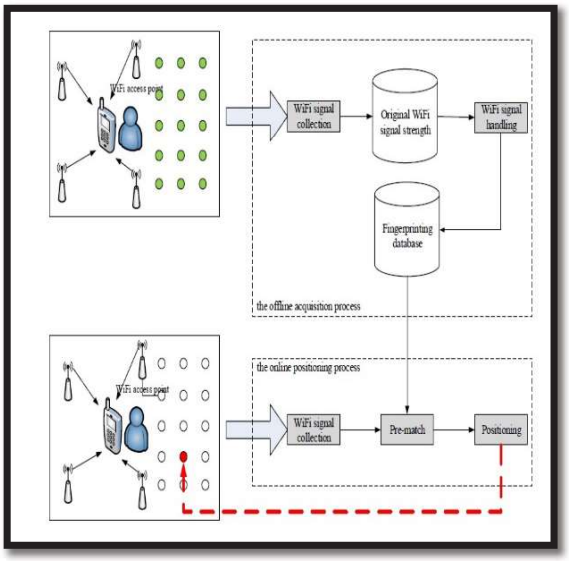

Fig 8. Methodology of Fingerprint Technique [29]

In the online phase or positioning phase, the mobile device measures RSSI at unknown location. The measurements (which include RSSs and SSIDs of the Aps) are compared with the stored data in the database using a matching algorithm. The best matching determines the location of the mobile [21, 30, 31].

5. Comparisons of Indoor Position Techniques

There are many comparison metrics between positioning techniques. The best technique can be obtained through measurement type, accuracy, coverage, line of sight or non-line of sight, affected by multipath and cost. The comparison metrics is shown in table 1.

Table 1. Comparisons of Indoor Position Techniques [5]

Method	Measurement Type	Accuracy	Coverage	LOS/NLOS	Affected By Multipath	Cost
Proximity	Signal type	Low to high	Good	Both	No	Low
Direction (AoA)	Angle of Arrival	Medium	Good	LOS	yes	High
Time (ToA, TDoA)	Time difference of arrival	High	Good	LOS	Yes	High
Fingerprinting	Received signal strength	High	Good	Both	No	Medium
Dead reckoning	Acceleration, Velocity	Low to medium	Good	NLOS	Yes	Low
Map matching	An algorithm based on algorithms based on projection and pattern recognition	Medium	Medium (indoor) Good (outdoor)	NLOS	Yes	Medium

6. Conclusions

In this paper, the existing positioning systems and the techniques used are described for estimating the position indoors. A summary of techniques currently used for indoor localization are present. Finally we compared several existing techniques for indoor localization through measurement type, accuracy, coverage, line of sight or non-line of sight, affected by multipath and cost.

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Conflicts of Interest

The authors have no conflicts of interest.

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