Survey on Indoor Positioning Techniques and Systems

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Abstract. Navigating different devices and human beings in indoor scene has become very crucial for number of tasks specially in automated system. The efficiency of outdoor positioning has become excellent due to the development of GPS. However lots of mass market applications require very excellent positioning capabilities in almost every environments. As a result, indoor positioning has attracted the researchers attention and has been a focus of research during the past decades. This paper presents an overview of the four typical indoor localization schemes namely triangulation, trilateration, proximity and scene analysis are analyze and discussed. Moreover it gives a detailed survey of different positioning systems which are being both research-oriented solutions and commercial products and also attempts to classify the different systems into different groups based on the technology used. We categorized all 11 sighted wireless indoor positioning systems into 6 distinct technologies namely Infrared signals, radio frequency, ultrasound waves, vision-based analysis, electromagnetic waves, and audible sound and explains the measuring principles of each. These approaches are characterized and their key performance parameters are quantified individually. For a better understanding, these parameters are briefly compared in table form for each system so as to outline the trade-offs from the viewpoint of a user.

Keywords: Indoor positioning systems · Positioning techniques
Wireless positioning technology · Wireless localization

1 Introduction

An Indoor positioning system (IPS) is a continuous and real-time system which can decide the position of someone or something in a physical space (i.e. gymnasium, hospital, school, etc.) [1]. IPs has been widely researched study area for many years now. As a service, IPs has still not attain through global use as broadly compared to outdoor positioning services. Outdoor positioning is usually based on GPS satellite signals. In GPS [2], the location is approximated by computing the transit time of the signal from satellite to client device. When time and satellite position is known, the scheme can then compute the distance between user and satellite. In indoors, situation

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is more complicated. Because GPS signals cannot penetrate through building walls good enough for accurate indoor positioning, other technologies has to be used or combined with the GPS system. Those other technologies include: WLAN, Bluetooth, Radio Frequency Identification (RFID) and more. Indoors is a very dynamic environment, with lot of moving people and in some places even obstacles tend to move a lot. There are some basic techniques and technologies used in indoor positioning. These include trilateration, triangulation (angle of arrival), RSS based positioning, time of arrival and fingerprinting. An overview of different existing technology options for the design of an positioning scheme As an example Infrared, ultrasound, RFID, WLAN, sensor networks, Bluetooth, UWB, vision analysis, magnetic signals and audible sound are explained in [1, 3]. Considering these key technologies, different localization systems have been formulated by different companies, higher institutions and research departments. This paper introduced and explained various research-oriented and commercially available indoor positioning systems. We also discussed the techniques and principles of these IPSs and made a comparison between them by considering a number of evaluation criterias such as cost, privacy and security, performance, complexity, robustness, user preferences, availability in commercial areas and drawbacks.

2 Survey on Wireless Indoor Positioning/Localization Techniques and Systems

There have been a number of surveys by different researchers about indoor positioning techniques and systems in the literature. This section describes literatures on indoor positioning, technologies, techniques and systems. Moreover various rating criterions are considered to examine the different indoor positioning systems for the services demanded by the users/required by the client.

2.1 Wireless Indoor Positioning Techniques

2.1.1 Triangulation

This algorithm is used find out the position of the target having the geometrical concepts of triangles and the target place can be estimated/computed by using the locations of three or more access points. Whenever the target devices receives the signals from one or more access points, the TOA, AOA and RSS of the signals will be utilized to estimate the distances between the target and the access points. The angle defines the estimated position of the target as illustrated in Fig. 1 below.

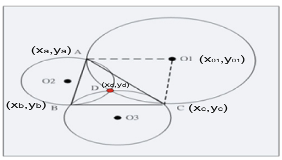

Fig. 1. Triangulation positioning techniques [3]

To calculate the value of the unknown nodes shown in Fig. 3 can be given as

$$\alpha = \angle AO_1C = 2\pi - 2\angle ADC$$

$$\left\{ \begin{array}{l} \sqrt{(x_{01} - x_a)^2 + (y_{01} - y_a)^2} = r_1 \\ \sqrt{(x_{01} - x_c)^2 + (y_{01} - y_c)^2} = r_1 \\ (x_a - x_c)^2 + (y_a - y_c)^2 = 2r_1 - 2r_1 \cos\alpha \end{array} \right\}$$

2.1.2 Trilateration

This approach [3, 4] determines the location of the target by measuring its distances from multiple reference points. The object in the field is located by creating a system which uses radio frequency signals. This RSS (radio frequency signal strength) is measured between the tagged object and the readers that are positioned in the field. Then the signal strength will be converted into a distance using the distance formula shown in Eqs. (1), (2) and (3) and plugged into a system known as trilateration. By using this approach we can determine the tagged object on the x, y plane (2D lateration) as well as x, y and z plane (3D lateration).

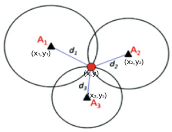

Fig. 2. 2D trilateration positioning techniques [3]

The equations for 2D trilateration [3] are as follows:

$$(x - x_1)^2 + (y - y_1)^2 = d_1^2 \tag{1}$$

$$(x - x_2)^2 + (y - y_2)^2 = d_2^2 \tag{2}$$

$$(x - x_3)^2 + (y - y_3)^2 = d_3^2 \tag{3}$$

The x and y coordinates are found using Cramer's rule [3].

$$x = \frac{\begin{vmatrix} (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) & 2(y2 - y1) \\ (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) & 2(y_3 - y_1) \end{vmatrix}}{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \end{vmatrix}} \tag{4}$$

$$y = \frac{\begin{vmatrix} 2(x_2 - x_1) & (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) \\ 2(x_3 - x_1) & (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \end{vmatrix}}{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \end{vmatrix}} \tag{5}$$

The equations for 3D trilateration [3] are as follows:

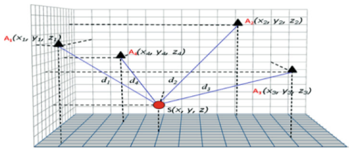

Fig. 3. 3D trilateration [3]

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = d_1^2 \tag{6}$$

$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = d_2^2 \tag{7}$$

$$(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2 = d_3^2 \tag{8}$$

$$(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2 = d_{(9)}^2 \tag{9}$$

Now, the x, y and z components using Cramer's rule [3].

$$x = \frac{\begin{matrix} 2(d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) - (z_1^2 - z_2^2) & (2(y_2 - y_1) & 2(z_2 - z_1) \\ 2(d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) - (z_1^2 - z_3^2) & (2(y_3 - y_1) & 2(z_3 - z_1) \\ 2(d_1^2 - d_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) - (z_1^2 - z_4^2) & (2(y_4 - y_1) & 2(z_4 - z_1) \end{matrix}}{\begin{matrix} 2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & 2(z_4 - z_1) \end{matrix}} \tag{11}$$

$$y = \frac{\begin{matrix} 2(x_2 - x_1) & 2(d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) - (z_1^2 - z_2^2) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & 2(d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) - (z_1^2 - z_3^2) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & 2(d_1^2 - d_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) - (z_1^2 - z_4^2) & 2(z_4 - z_1) \end{matrix}}{\begin{matrix} 2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & 2(z_4 - z_1) \end{matrix}} \tag{12}$$

$$z = \frac{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) & (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) - (z_1^2 - z_2^2) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) - (z_1^2 - z_3^2) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & (d_1^2 - d_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) - (z_1^2 - z_4^2) \end{vmatrix}}{\begin{vmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) & 2(z_3 - z_1) \\ 2(x_4 - x_1) & 2(y_4 - y_1) & 2(z_4 - z_1) \end{vmatrix}} \tag{13}$$

2.1.3 Scene Analysis

A principle of positioning approach in which first acquire/gather fingerprints of a scene and then determines an object position by matching with the information existing in the database [4]. The offline and online phases are the two phases of fingerprinting technique [5]. Strengths from access points are collected at reference points during the training phase, while in the tracking phase, user's surrounding access point signal strengths are compared/analyzed with the RP dataset collected in the 1^{st} phase for matching.

2.1.4 Proximity

This approach investigates the location of an object with respect to a distinguished position by sensing its location [3]. Moreover, this approach requires a connection between the mobile and fixed node to track the target so that the tracked target is considered/assumed as in the proximity area.

2.2 Range Measurement Techniques

(1) *Received Signal Strength:* This scheme can achieve a maximum value when the gap between transmitter and receiver is smaller so as to investigate the distance. This scheme is used to locate the space/distance of the subscriber unit from other set of measurement units by using the attenuated output of emitted signal strength for calculating the signal loss.

(2) *Time of Arrival:* The propagation time of signal is approximately equal to the distance between the measurement units and the targeted object. A precise synchronization of all the transmitters and receivers and at least three measurement units are required to obtain 2D lateration.

(3) *Time Difference of Arrival:* This Technique estimates the relative position of the mobile transmitter by determining the difference of the signal arival time at number of measurement units. For example, 3 fixed receivers can give two TDOAs, which estimates position of the targeted object.

(4) *Phase of Arrival:* This technique estimates the distance of a target using the signal delay which is expressed as the fraction of signal wavelength. In this technique, the transmitters are needed to be placed at particular locations to perform the location of the target based on phase measurements.

(5) *Angle of Arrival:* Use antennae arrays at the receiver side to estimate the angle at which the transmitted signal impinges on the receiver by calculating TDOA at individual elements of the antennae array. It requires the measurement of at least two angles with direction oriented or array of antennas to estimate the 2D location of a target.

2.3 Criterias for Evaluating Wireless Indoor Positioning Systems

(1) *Privacy and Security: One of the evaluation criteria for a good IPS is its* security and privacy because both of them are very important [6] for Private as well as Social activities for controlling the positioning information and history. To improve privacy in IPS location as well as information should be controlled from the software or system architecture side [3].
(2) *Cost:* The most important factors which can determine the cost of a positioning system are money, time, space, weight and energy [3]. Installation and maintenance are related to time factor. Mobile units may have weight and tight space constraints. The final important factor of a system cost is energy.
(3) *Performance: For evaluating the performance of an IPSs* precision and accuracy are very important. The success probability of position localization with respect to predefined accuracy is precision. Accuracy is the average error distance [3]. Other performance parameters are calculated positioning delay of targeted object, measurement transformation of targeted object and scalability.
(4) *Fault Tolerance and Robustness: Even though* some equipments in the system are not working or have a dead battery energy, a robust IPS should able to operate and tolerable during the occurrence of faults in the system [3].
(5) *Complexity:* A good IPS is a system with optimum performance (accuracy), easily used software platforms and an existed infrastructure devices for the users [7]. The users device computational time for determining their position is another aspect which indicates complexity.
(6) *User Preference: A good* IPSs always assumes the clients' requirement of the targeted equipments, the infrastructures and the software. If the devices are lightweight, wireless, small, lower power consumption and computationally powerful, the system has a chance to be preferred by the user.
(7) *Commercially existed: From* the developed IPSs which are discussed in Sect. 2.4, some of them are existing in the market and others are still researching.
(8) *Limitations:* The medium which are used for position sensing is the fundamental limitations of IPSs. For example, WLAN technology can reuse the existing infrastructure. However, position sensing based on radio frequency has multiple-path and has a reflection effects which result in maximum error.

2.4 Types of Wireless Indoor Positioning Systems

2.4.1 Infrared (IR) Positioning Systems

Active Badge: This system is the first indoor localization systems developed by AT&T Cambridge. This system needs an IR technology to make location sensing so as to place persons in its desired area by computing the position of the badges using a unique IR transmitted signal [8]. One or more sensors should be fixed in a room to be detected by the IR signal, which are sent by a system so as to locate the device. The targeted active badges position data are forwarded to a central server for specifying the position. A room level accuracy is provided by the system and the signal can be affected by any light.

Firefly: This system is an IR based tracking scheme developed by Cybernet Corporation [9]. It uses IR technology that offers high accuracy about 3.0 mm. The system comprises tags, a tag controller of tags and one camera. The controller a tag is a small, lightweight and battery-powered which can be carried by a tracked person. An emitter which has been supported by controller of tags attached on different targeted parts and 3 cameras are installed on a 1 m bar to receive the IR signals and estimate 3D position. Even though, tags and tag controllers are small and easy to hold, they are not suitable/comfortable to be worn due to their cables. The coverage area is limited with in 7 m.

2.4.2 Ultra-Sound Positioning Systems

Active Bat: This scheme is developed by AT&T Cambridge and can offer 3D positioning for the tracked tags [10]. In this system ultrasonic technology receivers is required to compute the 3D location of the tag by multiple-lateration and triangulation. A tag frequently broadcasting pulse of ultrasound that will be catched by a matrix of receivers at an acknowledged position. The distance measurement is obtained by the ultrasonic signal TOA. The system acquires installing 720 receivers to the ceiling to cover a 1000 m^2 area. The system has 3 cm accuracy for 75 tracked tags.

Cricket: This system uses ultrasound system as infrastructure mounted on the walls/ceilings at acknowledged location and receiver are attaching on the individual targeted object [11] for using TOA method and triangulation technique to identify the targeted object. This approach offers privacy for the client by accomplishing all the location triangulation computation of targeted object so as to own its location information. This scheme offers 10 cm accuracy.

Sonitor: This system is developed by Sonitor Technologies Inc. for indoor positioning and tracking solution based on an ultrasound technology [12]. The system can offer location identification and tracking of peoples and equipments any-time and providing proximity positional information with room level accuracy due to the ultrasound signal (i.e. Ultrasound signal cannot penetrate walls and does not need LOS transmission). Thus the scheme is used for detecting and tracking hidden targets.

2.4.3 Radio Frequency (RF) Positioning Systems

(I) *WLAN:* These scheme/technology has been deployed in public areas (i.e. hospitals, train stations, universities, etc.). The followings are some of the WLAN technology based IPSs..

Radar: This system is suggested by a Microsoft research group as tracking method using WLAN infrastructure [13]. The system utilizes signaling strength and SNR with the triangulation. The Radar system can offer 2D information.

Compas: This system takes an advantages/merits of existing WLAN technology/infrastructures and digital compasses to give high and accurate services with considerable cost for a client holding a WLAN-based equipments [14]. Estimating/calculation the position is depend on the measurement of the signal strength from different APs. This scheme uses the fingerprint method determine/estimate the position of a client [14].

(II) *UWB:* The UWB offer higher accuracy because its [15] pulses have short duration (less than 1 nano seconds) and this pulses are used for filtering the reflected signals from the original signal. Ubisense is an UWB based scheme as discussed below.

Ubisense: This system is designed by AT&T Cambridge, which offers a real-time scheme [16]. In this system the triangulation technique is employed by taking advantages of both the TDOA AOA to provide flexible location sensing. This scheme cannot be affected by a complicated environment (i.e. walls, doors, etc.) [16]. The accuracy offered is about tens of centimeters.

2.4.4 Magnetic Positioning System

MotionStar Wireless: This system is designed by Ascension Technology Corporation, which is used to track the targeted object with a pulsed DC magnetic fields for locating sensors within 3 m area/coverage [17]. This scheme offers accurate motion tracker by the measurement of different sensors attached on the body of a person. The system tracks multiple targets (120 sensors) at a time in real time.

2.4.5 Vision-Based Positioning System

Easy Living: This system is vision based and developed by Microsoft research group [18]. Two cameras (stereo) attaching on the ceiling of a room is needed and the entire part of the room is covered by one camera. Two 3D cameras (real-time) can cover the measuring area and offer real-time visions (which can be used as an input for location estimations). Then the computer receives the photos from the cameras and process the raw data. After that Easy Living scheme creates a “person creation zone” just near to the entrance of the room (a place where the stereo module creates the vision instance of the person). Thus, when a person gets in to the room, the scheme tracks the motion of the person and publish the information of the person.

2.4.6 Audible Sound Positioning System

Beep: This system is an audible sound based technology and designed as a cheap 3D IPS method [19]. This scheme uses Triangulation technique with a standard 3D multiple lateration based on TOA.

3 Comparison of Wireless Indoor Positioning Systems

In this section, the aforementioned different existed IPSs are evaluated from the point of view of the client interest. IPSs are compared considering the evaluation criterias which has been discussed in Sect. 2.3 Table 1 shown below depicts evaluation and comparison results and thus results are important so as to to easily identify the best location methods.

Table 1. Comparison of IPSs based on security and privacy, cost, performance and commercial existence

IPSs with security	IPSs with expensive cost	IPSs with room level accuracy	IPSs which uses WLAN infrastructure	IPSs which are commercially available
Cricket	Firefly	Active Badge	Compass	Firefly
Beep	Activebat	Sonitor	Active Bat	Sonitor
	Ubisense		Senitor	Ubisense
				Easyliving

4 Conclusion

From this paper, readers can get a detailed understanding of the different existed IPSs, especially the 11 IPSs explained in this paper. The existing IPSs are classified into 6 categories based on the main technology used to sense the location. Moreover, the system architecture and working principles are presented. Eight have been proposed to so as to and compare the IPSs from the point of view of the client.

5 Recommendation

From this paper, we have seen that each technology used in position determination has its own drawbacks. None of them can fulfill the system demand. Therefore we recommend that instead of using a single medium to estimate the locations of the targets, It will be good combining some technologies so as to enhance the quality of services rather using a single technology. For instance WLAN and UWB. Where WLAN t cover large area and UWB can give highly accurate calculation.

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