Survey Of Indoor Positioning Techniques And Systems For Mobile Nodes

S.Sundar , Harish M. Kittur

Abstract: Wireless indoor positioning frameworks are extremely well known as of late. The positioning systems are being useful in successful implementation of applications like inventory management, fire rescue operations in a building etc... This paper provides a review of existing algorithms, techniques and metrics followed in wireless positioning system and endeavors to arrange different calculations and frameworks. Three area estimation plans, for example, proximity/closeness, scene investigation and triangulation are discussed. We analyzed the usage of finger printing method in recent systems extensively as it is used in many systems. Then we examined various properties on evaluating the algorithms and using these evaluation schemes for the survey of existing systems. We also used parameters like accuracy, position error, etc. for comparing the performance of recent algorithms.

Index Terms: Bluetooth, Fingerprinting, Proximity, RSSI, Scene analysis, UWB, Wi-Fi ,Zigbee

1 INTRODUCTION

The growth of new generation of mobile devices and wide usage of wireless hot spots in various private and public places, has forced large amount of development in Indoor Positioning Systems (IPS) using various wireless technologies [1]. Indoor positioning is characterized as, any framework that gives exact data inside the shut condition [2]. The core of position innovations is to discover the mobile client's movement activity. It is useful in many real world applications like, location discovery of items in a warehouse, area recognition of salvage people in a structure ablaze, area location of restorative individual or equipment etc. The essential advancement in indoor area detecting frameworks has been made during a decade ago, there are many research works are being carried out by both industry and academia in IPS for improving the performance of the system. This survey paper aims to give comprehensive view of several wireless location sensing techniques/algorithms useful in indoor applications. In positioning frameworks there are four unique topologies are existing [3, 4]. Remote situating is where here, the transmitter is versatile and estimating units are fixed and get the transmitter's sign. All the received signals are collected and with that, the transmitter is located. In the second method, the measuring unit is mobile and it receives signals from various transmitters. From the received signals, the measuring unit is capable of computing is location and this method is called as self-positioning. Indirect positioning is the third method and in this, the measured signals from the self-positioning method are transmitted to a remote device through wireless[3].The fourth strategy is named as indirect self-positioning where here the deliberate information from a remote unit is sent to a mobile unit through remote information connect.

- *Dr.S.Sundar is working as Assistant Professor(Selection Grade)at VIT,Vellore,India PH-04162202726. E-mail: sundar.s@vit.ac.in*
- *Dr.Harish M. Kittur is working as Professor in VIT,Vellore,IndiaPH-04162202410.E-mail:kittur@vit.ac.in*

2 CLASSIFICATION OF LOCATION DETECTION TECHNIQUES & POSITIONING ALGORITHMS

In positioning systems, traditionally methods like proximity, triangulation, and scene analysis are used for locating the target device. In this section, these algorithms are discussed. As each of these have unique advantages and drawbacks, utilizing beyond one algorithm simultaneously can enhance the performance [3].

2.1 Proximity

Proximity algorithms are also called as range-free algorithms and these can provide only relative coordinate of the target [5, 6]. There are different methods are in use and in one method, thick framework of antennas (each fixed in a notable position) are utilized for following a gadget/target [3]. At the point when an objective is identified by a single antenna then it is gathered from it and on the off chance that more than one receiving antenna is recognizing, then one with strongest signal will be gathered. This can be actualized by strategies like Infra Red(IR) and Radio Frequency Identification(RFID).In another method, it uses Cell of Region (CoO) in which by utilizing data on which cell site the hub is at given time, the surmised situation of the objective is determined[7].

2.2 Triangulation

In this method, by applying simple trigonometry the position of the device will be calculated. It has two arrangements: lateration and angulation. In lateration, the position of the object is evaluated by estimating its distances from different reference focuses. Here in trilateration, the term "tri" indicates at least three fixed reference points are required for estimation [8]. Tracking techniques based on Time of Arrival (TOA), Time Difference of Arrival (TODA) Received Signal Strength (RSS), and received signal phase methods are all lateration techniques [2, 9]. TOA/TOF (Time of Flight) is an example of ranging method where, it quantifies the appearance time among transmitter and beneficiary [10]. The separation between the portable focuses to the estimation framework is legitimately identified with propagation time. In this methodology, numerous transmitters send sign to beneficiary. At the point when it is gotten, the collector quantifies the appearance time all things considered and make correlation at the beneficiary framework. In any case, this methodology requires every one of the transmitters are to be accurately synchronized with the collector framework.Estimation methods, for example, Direct Sequence Spread-Spectrum

(DSSS) or Ultra-Wide Band (UWB) can be utilized for TOA estimations [3, 11]. TOA is the most exact technique in indoor condition since it sift through the multipath impacts [12].
Least square calculation is another technique used to process the situation of the objective. It is by limiting whole of squares of nonlinear expense function[3,13,14].[3] Let the node is located at (x_0, y_0) that sends a signal at the time t_0 and there are N base stations discovered at $(x_1, y_1), (x_2, y_2), \dots (x_N, y_N)$ receive the signals at time t_1,t_2,…,t_(N) at that point the cost capacity can be framed by condition (1),

$$M(x) = \sum_{i=1}^{N} \alpha_i^{-2} m_i^{2}(x) \quad (1)$$

Where, α_i is the chosen parameter which reflects the reliability of the signal received and $m_i(x)$ is given as,

$$m_i(x) = c(t_i - t) - \sqrt{(x_i - x)^2 + (y_i - y)^2} \quad (2)$$

Where c is the speed of light, and $x = (x, y, t)^T$. By carefully choosing the values of x, y and t, the term $m_i(x)$ in (2) can be made zero. The location is estimated by minimizing the cost function $M(x)$ in (1).

TDOA is an improved version of TOA where, it does not need synchronized time source of transmission and also it does not have packet loss problems [15]. In this, a transmitter is required to send two distinct sign with various spread rates and when these two sign are gotten at the collector, the distinction of appearance time is estimated and this is actually proportionate to engendering time of a sign. Localization using TDOA is an example of multilateration [8].

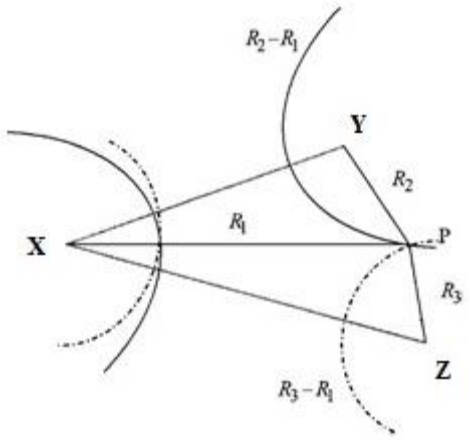

Figure.1 *Positioning based on TDOA [3]*

Every distinction of appearance time estimation produce a hyperbolic bend as appeared in figure.1[3, 8].The condition of hyperboloid is given as,

$$R_{ij} = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2}$$

(3)

Where, (x_i, y_i, z_i) and (x_i, y_i, z_i) represents fixed beneficiaries i and j and coordinate of target is represented by (x, y, z) [4].The exact solutions to (3) are through nonlinear regression, the basic method to linearize the condition is utilizing Taylor-arrangement extension to make an iterative calculation [16].
In Round-Trip Time of Flight (RTOF)/Round Trip Time (RTT), it gauges the hour of trip of the sign heading out between transmitter to the estimating unit and back [3]. In TOA, synchronization issue exists because of utilization of two neighborhood checks in ascertaining delay in the two hubs though in RTT, it utilizes just a single hub to record the transmitting and appearance times. Because of this, the synchronization issue is explained somewhat. Yet, one of the disadvantages of this strategy is, for extend estimations to various gadgets that should be completed at the same time cause's dubious latencies [8].This latency would be more when devices move quickly. The positioning algorithms used in TOA are directly applicable to RTOF [3]. A calculation is proposed in [17] to quantify RTOF of remote LAN parcels with estimation mistake of hardly any meters. In Received Signal Phase Method, the received signal phase differences (or carrier differences) is utilized for evaluating the range. [3]In this case, if all the transmitting stations emits sinusoidal wave with same frequency f (with zero phase offset), the receiver needs a finite delay (transit delay) to decide the phase of signals received at n objective point. The delay is denoted by wave length of the signal in equation, $S_i(t) = \sin(2\pi ft + \theta_i)$, where c represents speed of light and $i \in (P, Q, R, S)$. We can get the range estimation $D_i = (c\theta_i)/(2\pi f)$, for whatever length of time that the transmitted sign wavelength is longer than the askew of the cubic space (building). At that point, we can utilize a similar situating calculations utilizing in TOA estimation. To improve the performance, algorithms like TOA/TDOA and RSS can be used along with this method. The principle disadvantage of this stage move strategy is it requires LOS in indoor condition to limit the error. In Angulation /Angle of Arrival Technique (AOA estimation), it decides the area of an objective by the crossing point of a few sets of edge of appearance of the portable sign from a base station or guide station. It requires two beacons to determine the target in two dimension plane. To improve the accuracy, it requires three or more beacons for location estimation. Scene investigation alludes to sort of calculations that first gather unique mark of a scene and afterward by coordinating with the online estimations with the gathered area fingerprints, an article will be foundDuring the disconnected stage, a site study is performed in a domain by gathering area facilitates and signal qualities from close by base stations [18]. During the on line phase(run time), location positioning techniques uses the currently collected signal strength information's with the offline collected data's to estimate the object. The mainstream area fingerprinting-based situating calculations which uses design acknowledgment strategies are: k-Nearest-Neighbor (kNN), neural networks, Support Vector Machine (SVM), and Smallest M-vertex Polygon (SMP) [3, 19]. kNN utilizes online RSS to look through k nearest matches of known areas from the effectively constructed database as per root mean square (RMS) mistake guideline [3]. The normal of these k areas with or without adjusting signal space as loads, the assessed area is acquired either by weighted kNN or unweighted kNN. Here; k is the picked parameter for better execution. In neural network based positioning problems, one hidden layer is used in a Multi-Layer Perceptron (MLP) network [3]. For preparing the neural systems, the disconnected information like RSS and area facilitates are utilized as data sources. Appropriate weights are obtained at the end of the training. These weights

are multiplied with signal strengths and if bias value is chosen, then it is added with the result. This outcome is utilized in the exchange capacity of the shrouded layer neuron. The prepared shrouded layer lattice is increased with move work result and whenever concealed layer predisposition esteem is picked then it will be included. SVM is another procedure for information characterization and relapse [3].It is widely utilized for scope of utilizations like science, building and drug [20, 11]. SMP utilizes online RSS qualities to look through article areas with every transmitter independently. Assume M transmitters are utilized, at that point by picking one up-and-comer from every transmitter, M-vertex polygons are framed. The area estimation is then the averaging directions of vertices of littlest polygon.

3 CLASSIFICATION OF SYSTEMS AND SOLUTIONS

3.1 Radio Frequency Identification (RFID)

The essential parts in RFID framework incorporate per users and RFID labels. It enables one way non-contact wireless communication between the reader and tags. The tags are either active or passive. The passive tags are smaller, cheap, less weight and do not require a battery to operate. The typical range of passive tags is varying from1m to 2m. It operates in low (125 KHz), high (13.56MHz), ultra-high (433,868-915MHz) and microwave frequencies (2.45GHz, 5.8GHz) [3]. Dynamic RFID labels are with littler reception apparatus and works in a lot of long range (several meters) contrasted with aloof labels. Active tags operate in low and high frequency ranges. SpotON is the well-known RFID technology for location sensing systems [21]. The received RSS value can be used in SpotON tags for estimating the inter tag distance.

3.2 Ultra Wide Band (UWB)

It is a link with a limited range of high bandwidth [8].UWB are operates on multi bands of frequencies (3.1GHz to 10.6GHz) contrasted with RFID frameworks which are work on single groups of radio range [22]. UWB tags are also consumes less power compared to RFID tags. A run of the mill UWB has radio wave generator and beneficiaries for catching the spread and dissipated wave. The equipment is expensive, henceforth UWB based framework is utilized in applications requiring exactness of 20-30 cm. UWB depends on sending ultra-short heartbeats (<1 ns), with a low obligation cycle (1: 1000) [3].These brief length beats are anything but difficult to channel so as to separate which sign are right and which are from multipath reflections Wireless LAN (WLAN)/ (Wi-Fi) Wi-Fi based positioning systems are compatible (not requiring any software installations) and does not require LOS [10]. Due to these, it is quite popular in indoor localization. WLAN positioning the devices based on RSS and it has many attractions. It doesn't require any extra foundation/equipment as Network Interface Cards (NICs) to quantify signal quality qualities [8]. It means, signals needed for positioning can be used from the existing NICs in hand held computing devices. Scalability is another advantage of WLAN.

3.3 Bluetooth

It is a wireless standard (IEEE 802.15) operates in 2.4GHz ISM band. Bluetooth has numerous focal points like low power, minimal effort, and high security and littler in size empowers it utilizing for restriction. [8] But latency (10-30s) is the main issue [8].Kotanen et al. presents Bluetooth based Local Positioning Application (BLPA) [23]. In this, they utilize Extended Kalman Filter (EKF) to figure 3-D position gauge with the revealed exactness of 3.75 m.

3.4 Zigbee

It is valuable for short and medium range correspondences from 20m to 30m [24].The main attractions of Zigbee are low power consumption and not requiring large data throughput. It operates in unlicensed ISM and it uses RSSI values to calculate the distance. The Zigbee based localization is proposed in [7, 25].In these, [25] Fernandez et al. proposed indoor localization based on RSSI of an ad hoc Zigbee network.

3.5 Others

Frequency Modulation (FM) is another popular method. Band ranges and separation of channels in FM differ from region to region [8]. Indoor positioning based on FM radio signals is presented in [26, 27]. [28, 29]Hybrid Positioning Systems (HPS) are working by combining many positioning technologies to locate a device. There are positioning systems works well in indoor environments but less accurate in outdoor positioning. Hence the concept of HPS is proposed where it works well for both indoor and outdoor localization problems. [8]Popular examples for HPS are, Combain Mobile, Navizon, SkyHook, Xtify, and Google Maps for Mobile.

4 REVIEW OF RECENT DEVELOPMENTS IN IPS

As IPS based research is growing fast, there are many research works have been proposed by many people. As covering all these developments are not feasible, this section is planned by covering few sample works proposed in recent years. Light sensor based positioning and navigation is proposed in Adrian David Cheok et. al. [30]. In this work, fluorescent light is utilized as the medium to transmit data and it is encoded by beat recurrence regulation method. This proposition is for detecting and following the portable and wearable PCs in indoor condition. The system is portable and lightweight .The main advantages of this method is, if the user wears this along with the wearable tracking GPS, it can also allow for tracking in outdoor environment. [31]Shih-Hau Fang et al. presents a structure for ZigBee indoor situating with an outfit approach. The outcome shows that the outfit calculation beats the fingerprinting strategy. The improvement is because of that the proposed calculation allows the coordination of various methodologies in the situating procedure. This empowers abusing the various examples of sources of info and the reciprocal favorable circumstances of every calculation are misused adequately.Light Emitting Diode (LED) based indoor positioning addressed in [32] – [34]. [32] Yong-Yuk Won et al. used three LEDs in the form of triangular optical wireless zone and each allotted with location code. The intensity of the received location is interesting at all reference focuses. When the area codes are apportioned to the directions of all reference focuses, their spatial conveyance map is arranged. Utilizing a calculation dependent on the spatial conveyance map, the 3D position of the article is situated. In [33], white LEDs are utilized for indoor situating. The adjusted sign transmitted by the LEDs are utilized as premise of TOA based separation estimation. For extending gauges, creators have determined articulations for the Cramer-Rao bound (CRB) in light of power of adjusted sign transmitted by LEDs. In [34], the proposition is for indoor

situating framework dependent on Visible Light Communication [VLC].The creators have utilized light sensor and accelerometer prepared PDA is at collector side to quantify the got light force and direction of the cell phone. The receiver position is then estimated by applying the measured values in a low complexity algorithm. In IPS, correct placements of wireless access points (WAP) are vital for better accuracy in locating a device/node. [1] Massimo Ficco et al. presented an approach to select the best deployment schema for WAP. They have utilized multi-objective genetic algorithm to distinguish the best passageway position.For commercial applications like pedestrian tracking, there are two techniques are popular. One is by WLAN and other is by Pedestrian dead reckoning (PDR). The quality of PDR ought to dispose of the downsides of WLAN and bad habit versa.[35] Lyu-Han Chen et al. proposed an intelligent algorithm which fuses a PDR system and Wi-Fi system. It is smart on the grounds that, the underlying client area and the underlying client moving heading data's are consequently determined by the proposed strategies without requiring any client contribution to progress. Time reversal (TR) is another technique useful in achieving centimeter level accuracy in the presence of multipath in IPS. In TR, it ready to center the vitality of the transmitted sign in just on to the proposed area and tis is otherwise called spatial centering impact. [36] Zhung-Han Wu et al. proposed TR based indoor situating framework (TRIPS) for single AP working in NLOS. It includes two stages; the first is disconnected stage, where channel motivation reaction (CIR) database is constructed. This is to outline physical geological area into the consistent area in the CIR space. The subsequent stage is web based situating stage where the assessed CIR of the terminal gadget (TD) is coordinate with the CIR database to limit the TD. For accurate positioning at reduced cost, coded ultrasonic indoor positioning is useful. [37]Alejandro Lindo et al. proposed two novel multiband waveform combination techniques for ultrasound-based indoor situating frameworks. One is, M-channel trans multiplexer for complimentary set of sequences (CSS) and the other one is Interlace of BPSK (IBPSK). By concurrent transmission of the CSS, the principal conspire takes out the requirement for utilizing full scale arrangements which are utilized in customary ultrasonic nearby position frameworks. The IBPSK plot protects the connection properties of the non-unitary arrangements, (for example, Generalized Pairwise Complementary codes) and to identify them in non-cognizant structure. Dong Li, et al [38] displayed Feature-Scaling-based k-closest neighbor (FS-kNN) to improve the precision of limitation. They have demonstrated that the inaccuracy caused in calculation of signal distance in traditional kNN, is improved by using RSS level based scaling. Guido De Angelis et al [39] proposed a simple and cost effective ranging positioning .It is based on application of particle filter on distance measurement using RTT measurements from an UWB system. In their study, along with particle filter they have also compared the performance classical least square estimator and Kalman filter on detecting a slowly moving target in the presence of noise. But they have concluded that usage of particle filter will lead to increasing the computational complexity.The example of Magnetic Field Intensity (MFI) variety can be utilized as unique mark for indoor field situating. But this method is prone to expensive computation as well as the presence of Ferro magnetic may affect the accuracy of the system. [40] Binhee Kim and Seung-Hyun Kong offered a novel solution to the said problems. It is a low power consumption technique which uses vertical and horizontal magnetic differences to improve the robustness and also it provides superior computational efficiency.The significant points of all the discussed techniques are given in table 1.

TABLE 1

RECENT APPROACHES IN POSITIONING

Scheme	*Positioning systems*	*Accuracy*	*Remarks*
Light sensor based[30]	*Similar like IR*	*Accuracy varies with light intensity*	*Economical and useful for smaller area. Not suitable for virtual reality applications.*
Enhanced Zigbee[31]	*RSSI*	*Within 1.25m for 98.67% of time*	*Gives preferred situating exactness over any individual technique and a multi-master approach.*
3-D optical[32]	*IR*	*Accuracy varies with light intensity*	*A Positioning Error (PE) for 2D is < 3 cm at a physical separation between two adjoining reference purposes of 5 cm. For 3D PE of around 10 cm was seen in the 3D space, with vertical layers at interims of 10 cm.*
Visible Light[33]	*TOA(RSSI)*	*In the order of millimeters or centimeters.*	*Position estimation precision relying upon the geometry of the room, the recurrence and intensity of the transmitted sign and the properties of the LED and the photograph collector.*
Visible Light and Accelerometer [34]	*Light Intensity based*	*Few centimeters*	*Does not require information of receiver's height and requirement of the transmitter and the receiver be aligned to the ceiling. The average PE of less than 0.25 m.*
Calibrating IPS[1]	*Wi-Fi(RSS)*	*For 45 samples accuracy varies from 1.4m to 1.8m*	*A predictive analysis is used in the proposed approach which can be used to facilitates the positioning system planning at pre-deployment stage.*
PDR[35]	*Wi-Fi(RSS)*	*Preferred situating Accuracy over the PDR framework or Wi-Fi situating*	*The fundamental test is that the following mistake aggregates after some time.*

		framework alone.	
TR[36]	*RSSI*	*10-cm localization accuracy (within 0.9 m by 1 m area)*	*Indeed, even just with a solitary AP under the NLOS condition and a solitary acknowledgment of online estimations, this plan can in any case accomplish 100% limitation exactness.*
IBPSK[37]	*Ultrasound*	*Accuracy depends on correlation properties determined by the spreading sequences.*	*Contrasted with BPSK waveform length, in IBPSK, the transmission span is diminished in to 37.44%. This decreases the power utilization from the producers without debasing running exactness.*
FSkNN[38]	*RSSI*	*Within 1.69 m in 50% of the time.*	*The normal location error is as low as 1.70 meter. It is valuable in the provisioning of numerous indoor IoT applications.*

5 CONCLUSIONS

This paper reviews the ongoing advances in IPS and strategies. Different wireless positioning solutions and navigation techniques are discussed. Each of these systems/techniques has their own characteristics in terms of scalability, availability and measurable performance when applied in real time environments. It is clear that, the choice of algorithm/technique/system plays an important role on granularity and accuracy of location information and to detect them in non-coherent form. Other than different techniques accessible for IPS, still the present arrangements can't adapt to the exhibition level prerequisite of various applications. In general, most of the applications requirements are improved accuracy, availability and coverage with low cost implementations. A decent measure of research both from industry and the scholarly community are required to accomplish these requests. A portion of things to come drifts in remote IPS are as per the following:

1) New hybrid solutions for IPS and tracking estimation in 4G with existing positioning frameworks [8].

2) Need for building a new robust hybrid positioning system for integrating both indoor and outdoor localization.

3) Need for cooperative mobile localization. If group of nodes are detected then, developing application like formation of mobile ad hoc network on the located nodes could be another area for to explore.

4) Channel State Information (CSI) is a rising strategy to supplant RSSI. It achieves higher robustness in fingerprinting methods than RSSI. As current smartphones are only supports Wi-Fi enabled, specialized infrastructure is needed in existing systems [41-43].

5) The motion sensing [41], sound detection [44] techniques are available to enable the physically challenging people in accessing the IPS. More optimization in terms of usage, cost and accuracy this regard is needed.

6 REFERENCES

[1] Massimo Ficco, Christian Esposito, and Aniello Napolitano, “Calibrating Indoor Positioning Systems with Low Efforts”, IEEE Transactions on Mobile Computing, April 2014, Vol.13, No.4.

[2] Zhang, D., Xia, F., Yang, Z., et al., “Localization technologies for indoor human tracking”, Proceedings of the 5th International Conference onFuture Information Technology (Future Tech 10), May 2010.

[3] Hui Liu, Houshang Darabi, Pat Banerjee., et al., “Survey of Wireless Indoor Positioning Techniques and Systems”, IEEE Transactions on Systems, Man and Cybernetics—Part c: Applications and Reviews, November 2007, Vol. 37, No. 6.

[4] Drane, C., Macnaughtan, M., Scott, C., “Positioning GSM telephones”, IEEE Commun. Mag , Apr. 1998, vol. 36, no. 4, pp. 46–54, 59.

[5] He, T., Huang, C., Blum, B.M., et al., “Range-Free Localization and Its Impact on Large Scale Sensor Networks”, ACM Trans. Embedded Computing Systems, November 2005, vol.4, no.4, pp. 877–906.

[6] Nakajima, N., “Indoor Wireless Network for Person Location Identification and Vital Data Collection”, ISMICT, Oulu, Finland, December 2007.

[7] Hu, X., Cheng, L., Zhang, G., “A Zigbee-based localization algorithm for indoor environments”, Proceedings of the International Conference on Computer Science and Network Technology (ICCSNT ’11), December 2011, pp. 1776–1781.

[8] Zahid Farid, Rosdiadee Nordin, and Mahamod Ismail, “Recent Advances in Wireless Indoor Localization Techniques and System”, Hindawi Publishing Corporation Journal of Computer Networks and Communications, Volume 2013, Article ID 185138.

[9]Ismail, M.B., Boud, A.F.A., Ibrahim, W.N.W, “Implementation of location determination in a wireless local area network (WLAN) environment”, Proceedings of the 10th International Conference on Advanced Communication Technology (ICACT ’34), February 2008, pp. 894–899.

[10] Mak, L.C., Furukawa, T., “A ToA-based Approach to NLOS Localization Using Low-Frequency Sound”, ACRA, Auckland, New Zealand, December 2006.

[11] Correal, N.S., Kyperountas, S., Shi, Q., et al., “An ultra-wideband relative location system”, Proc. IEEE Conf. Ultra Wideband Syst.Technology, Nov. 2003, pp. 394–397.

[12] Gu, Y., Lo, A., Niemegeers, I., “A survey of indoor positioning systems for wireless personal networks”, IEEE Communications Surveys and Tutorials, 2009, vol. 11, no. 1, pp. 13–32.

[13] Fang, B., “Simple solution for hyperbolic and related position fixes”, IEEE Trans, Aerosp, Electron Systems, Sep 1990, Vol 26, no 5, pp. 748–753.

[14] Kanaan, M., Pahlavan, K., “A comparison of wireless geolocation algorithms in the indoor environment”, Proc IEEE Wireless Commun, Netw Conf., 2004, vol 1, pp. 177–182.

[15] Najar, M., Vidal, J. “Kalman Tracking based on TDOA for UMTS Mobile Location”, PIMRC, September 2001, pp. B45–B49, San Diego, California, USA.

[16] Torrieri, D., “Statistical theory of passive location systems”, IEEE Trans, Aerosp, Electron, Syst, Mar 1984, vol. 20, no. 2, pp. 183–197.

[17] Gunther, A., Hoene, C., “Measuring round trip times to determine the distance between WLAN nodes”, in Proc. Netw. 2005, Waterloo, ON, Canada, May 2005, pp. 768–779.

[18] Kaemarungsi, K., Krishnamurthy, P., “Properties of indoor received signal strength for WLAN location fingerprinting”, MobiQuitous, 04, 2004, pp. 14-23.

[19] Cristianini, V., Shawe-Taylor, J., “An introduction to support Vector Machines: and other kernel-based learning methods”, Cambridge Univ Pr, 2000.

[20] Li, X., Pahlavan, K., Latva-aho,M.,et al., “Comparison of indoor geolocation methods in DSSS and OFDM wireless LAN”, Proc. IEEE Veh. Technol. Conf, Sep 2000, vol. 6, pp. 3015–3020.

[21] Hightower, R., Want, Borriello, G., “SpotON: An indoor 3D Location sensing technology based on RF signal strength”, Univ. Washington, Seattle, Tech. Rep. UW CSE 2000–02-02, Feb. 2000.

[22] Gezici, S. Z., Tian, G. V., Giannakis, H., et al., “Localization via ultra-wideband radios: A look at positioning aspects for future sensor networks”, IEEE Signal Process. Mag., Jul. 2005, vol. 22, no. 4, pp. 70–84.

[23] Kotanen, A., Hannikainen, M., Leppakoski, H.,et al., “Experiments on local positioning with Bluetooth”, Proc. IEEE Int.Conf. Inf. Technol.: Comput. Commun., Apr 2003, pp. 297–303.

[24]“ZigBeeTechnology”, http://www.zigbee,org/About/AboutTechnology/ZigBeeTechnology.aspx, 2013.

[25] Fernandez, S., Gualda, D., Garcıa, J. C., et al., “Indoor location system based on ZigBee devices and metric description graphs”, Proceedings of the 7th IEEE International Symposium on Intelligent Signal Processing (WISP’11), September 2011, pp. 4–8.

[26] Popleteev, A., Osmani, V., Mayora, O., “Investigation of indoor localization with ambient FM radio stations”, Proceedings of the IEEE International Conference on Pervasive Computing and Communications (PerCom ’12), 2012.

[27] Moghtadaiee, V., Dempster, A. G., Lim, S., “Indoor localization using FM radio signals: a fingerprinting approach”, Proceedings of the International Conference on Indoor Positioning and Indoor Navigation (IPIN ’11), September 2011.

[28] Zirazi, S., Canalda, P., Mabed, H., et al. “Wi-Fi access point placement within stand-alone, hybrid and combined wireless positioning systems”, Proceedings of the 4th International Conference on Communications and Electronics (ICCE ’12), 2012, pp.279–284.

[29] Mehmood, H., Tripathi, N. K., “Hybrid Positioning Systems: A Review”,LAP Lambert Academic Publishing, 2011.

[30] Adrian David Cheok, Li Yue, “A Novel Light-Sensor-Based Information Transmission System for Indoor Positioning and Navigation”, IEEE Transactions on Instrumentation and Measurement, January 2011,Vol. 60, no. 1.

[31] Shih-Hau Fang, Chu-Hsuan Wang, Ting-Yu Huang., “An Enhanced ZigBee Indoor Positioning System with an Ensemble Approach”, IEEE communications letters, April 2012, Vol. 16, no. 4.

[32] Yong-Yuk Won, Se-Hoon Yang, Dong-Hyeon Kim, “Three-dimensional optical wireless indoor positioning system using location code map based on power distribution of visible light emitting diode”, Published In IET Optoelectronics, doi: 10.1049/iet-opt.2013.0006.

[33] Thomas, Q., Wang, Y., Ahmet Sekercioglu, et al., “Position Accuracy of Time-of-Arrival Based Ranging Using Visible Light with Application in Indoor Localization Systems”, Journal Of Light wave Technology, October 15, 2013, Vol. 31, No. 20.

[34] Muhammad Yasir, Siu-Wai Ho, Badri, N. Vellambi., “Indoor Positioning System Using Visible Light and Accelerometer”, Journal Of Light wave Technology, October 1, 2014,Vol. 32, no. 19.

[35] Lyu-Han Chen, Eric Hsiao-Kuang Wu, Ming-Hui Jin, et al.,“Intelligent Fusion of Wi-Fi and Inertial Sensor-Based Positioning Systems for Indoor Pedestrian Navigation”, IEEE Sensors Journal, November 2014, Vol. 14, N0. 11.

[36] Zhung-Han Wu, Yi Han, Yan Chen, et al., “A Time-Reversal Paradigm for Indoor Positioning System”, IEEE Transactions On Vehicular Technology, April 2015, Vol. 64, No. 4.

[37] Alejandro Lindo, Enrique García, Jesús Ureña, et al., “Multiband Waveform Design for an Ultrasonic Indoor Positioning System”, IEEE Sensors Journal, December 2015, Vol. 15, No. 12.

[38] Dong Li, Baoxian Zhang,and Cheng Li, “ A Feature-Scaling-Based k-Nearest Neighbor Algorithm for Indoor Positioning Systems”, IEEE Internet of Things Journal, Vol. 3, No. 4, August 2016.

[39]Guido De Angelis, Antonio Moschitta and PaoloCarbone, “PositioningTechniquesin Indoor Environments Based on Stochastic Modelling of UWB Round-Trip-Time Measurements”, IEEE Transactions on Intelligent Transportation Systems,Vol.17,No.8,August 2016.

[40]Binhee Kim and Seung-Hyun Kong, “A Novel Indoor Positioning Technique Using Magnetic Fingerprint Difference”, IEEE Transactions on Instrumentation and Measurement, Vol.65, No.9, September 2016.

[41] Suining He, S.-H., Gary Chan, “Wi-Fi Fingerprint-based Indoor Positioning: Recent Advances and Comparisons”, IEEE Communications Surveys & Tutorials, Volume: 18, Issue: 1, August 2015.

[42] Yang, Z., Zhou, Z., Liu, Y., “From RSSI to CSI: Indoor localization via channel response” ,ACM Computing Surveys, Dec. 2013, vol. 46, no. 2,pp. 25.

[43] Wu, K., Xiao, J., Yi, Y., et al., “FILA: Fine-grained indoor localization”, in Proc. IEEE Infocom, Mar 2012, pp. 2210–2218.

[44]Shangguan, L., Yang, Z.,Zhou, Z., et al., “CrossNavi: Enabling real-time crossroad navigation for the blind with commodity phones”,Proc. ACM UbiComp, 2014, pp. 787–798.