A Survey on Indoor Positioning Technologies

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Abstract. Location-aware service is one of the most important parts of the internet of things. And how to obtain the location information is the key point of location-aware service. This paper investigates some key technologies and algorithms of indoor positioning and analyzes their advantages and disadvantages in the terms of the positioning range, accuracy and cost. Finally some issues need to be resolved in future are discussed.

Keywords: Location-aware service, positioning technology, Infrared, WLAN, Ultrasonic, RFID.

1 Introduction

Location-aware services have become more and more popular with the development of modern communication and internet of things. Indoor positioning applications show huge prospect in areas such as location-based network management and security, medicine and health care, personalized information delivery, and context awareness [1].

Well-known example of the earliest modern positioning system is Global Positioning System (GPS) [2], [3]. GPS receiver measures satellite signals from 5-24 satellites and utilizes the time difference of arrival (TDOA) to estimate the position. The highest positioning accuracy of GPS in outdoor environments can reach 5m [4]. In reality environments, however, the coverage of GPS is limited. Because of GPS satellites radio signals can not penetrate most of the buildings or dense vegetation, GPS can not react in high-rise urban areas or building where people often work and locate. In recent years, the cellular network-based location technology [5] also made rapid development as the promulgation of E-911 which had generally positioning accuracy of 50 meters for outdoor applications [6], [7], [8]. The 50-meter positioning accuracy, however, is not satisfied for indoor application [9]. The users desire to control the indoor positioning within several meters.

The location estimation accuracy of GPS or the cellular network-based location technology is often inadequate for indoor environment. In order to improve the accuracy of indoor positioning application, the research on indoor positioning technologies has attracted more and more scholars and research institutes.

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2 Paper Preparation

At present, many technologies can be used for indoor positioning, such as infrared, ultrasonic, computer vision and radio frequency (RF). And the RF could be divided into four technologies by different specifications: ZigBee, Radio Frequency Identification (RFID), Ultra Wideband (UWB), and Wireless Local Area Networks (WLAN).

2.1 Infrared Positioning Technology

Infrared positioning technology firstly need to yield a certain time interval transmitting infrared signals by a emitter, then measure the position of the object according to the receiving time of infrared signals. The representative of infrared indoor positioning systems is the Active Badge location system which developed by W. Roy and others [10]. To use Active Badge, each user needs to carry small infrared marking equipment. The marking equipment sends a globally unique identification number every 15 seconds. The infrared sensors fixed in the building collect the data then transmit to a central server which accomplishes the positioning process. Active Badge is low cost and easy to use, but it is vulnerable to the impact of fluorescent and sunlight. In addition, the effective transmission range of this positioning technology is only a few meters since the poor penetration of infrared.

2.2 Ultrasonic Positioning Technology

Ultrasonic positioning technology used mainly reflective distance method to determine the location of the object. Active Bat system [11] is an ultrasonic indoor positioning system researched by AT&T Labs. When positioning, the central controller sends a request packet by radio, Active Bat shows a response by sending ultrasonic pulses to the signal receiver distributed in the ceiling upon receipt of request packets. The receiver on the ceiling is able to measure the time interval and calculate the distance between the receiver and Active Bat tag. Local controller transmits the measured distance information to the central controller which calculates the user's location technology using geometry. The system can control the positioning error within the 9cm. Ultrasonic positioning system requires large-scale layout with many of receiver hardware, and the positioning result is very sensitive with the environment.

2.3 Computer Vision Positioning Technology

Computer vision positioning technology estimates the location of objects by using image processing. Easy Living system is developed by Microsoft Research using computer vision technology [12]. Easy Living uses two real-time three-dimensional color camera Digiclops to locate, which can identify the status of multiple users by processing images. The accuracy of Easy Living is high. Positioning technology of computer vision can only locate in the line of sight (LOS), which is difficult to overcome the occlusion problem by the walls, obstacles. So the coverage of such systems is limited. The cost computer vision positioning technology is high because of needing the three-dimensional camera.

2.4 ZigBee Positioning Technology

ZigBee is a short distance, low-rate wireless network technology. This technology achieves positioning with the coordination of communications by thousands of tiny sensors. These sensors require very little energy to relay the data passing between the sensors adopted by radio waves, so the communication is very efficiently. Wireless Dragon positioning system is a representative ZigBee positioning system developed by Chengdu Wireless Dragon Communication Technology Co., Ltd. Wireless Dragon can be used for large areas by using CC2431 and CC2430. Because of the positioning accuracy of ZigBee positioning system is limited, C.Hyunggi proposed a maximum likelihood estimation method [13].

2.5 RFID Positioning Technology

Radio Frequency Identification (RFID) is a non-contact automatic identification technology, which automatic target recognition and access to relevant data radio through frequency signal. LANDMARCE positioning system is a RFID-based indoor positioning system developed by Michigan State University and the Hong Kong University of Science and Technology [14]. The system introduces the concept of reference tags. Reference tag placed in a fixed position, RFID readers compare the signal strength from the target and reference tags to determine the nearest reference tag from the target tag. Then the nearest reference tag gets a higher weight. The Location can be determined by the higher weight and the reference tag. G.Y. Jin, et al has been improved LANDMARC from the perspective of system energy consumption and system costs [15]. The disadvantage of such positioning systems is the RF signal influenced by the antenna, the role of proximity does not have the communications capabilities, positioning coverage is small, and not easily integrated into other systems.

2.6 UWB Positioning Technology

UWB location technology mainly utilizes the time of arrival (TOA) or the time difference of arrival (TDOA) of the RF signals to get the distance between the target and the reference point. Ubisense positioning system [16] is a UWB real-time positioning system developed by Cambridge University. Ubisense overcomes the constraints of line of sight (LOS) because of the UWB signal has a strong penetration. Ubisense can achieve real-time location positioning system utilizing the millisecond response time [17]. However, there are many issues of technical theory to be researched. UWB technology is not widely used on account of the high cost of UWB equipment. The research of the UWB location technology presently focuses on reducing the error of NLOS [18], [19] and improving the positioning accuracy [20].

2.7 WLAN Positioning Technology

WLAN positioning technology exploits received signal strength (RSS) or signal to noise ratio (SNR) for positioning. This positioning technology uses the WLAN client (laptop, PDA or smart phone) to get the RSS or SNR from wireless network interface card [21]. As wireless LAN is widely used in business districts, universities, airports and other public areas, WLAN positioning technology is becoming to the hottest indoor localization application for which can take full advantage of these existing resources [22], [23], [24]. Horus positioning system is a representative WLAN-based indoor positioning system which designed by the University of Maryland [25]. Horus is a probability distribution based positioning system for wireless local area network, which in the offline stage stores the probability distribution histogram of RSS for each AP at the reference point in the database, and in the online positioning stage some certain matching algorithms are used to get the optimal estimating position. Horus proposed a method of clustering the location sets in the radio map to improve the searching speed and reduce the computation. Horus requires collecting large amounts of RSS at the reference locations in offline phase though the system is accurate.

3 Indoor Positioning Algorithm

Indoor positioning algorithm can be divided into four types according to the signal measurements: Time of Arrival (TOA), Time Difference of Arrival (TDOA), Arrival of Angle (AOA) and Received Signal Strength (RSS).

3.1 TOA Algorithm

TOA algorithm needs firstly to measure the signal transmission time between the receiver and the transmitter. The distance of the receiver and the transmitter can be got from the speed and the measured time of the signal. Then the location of target estimates by using triangulation [26]. If he distance of the target to the base station (BS) i is R_i, ($i=1,2,3$), as shown in Fig. 1(a), the target must be in a circle. The center of the circle is the ith BS and the radius of the circle is R_i . Then the intersection of the circles is the position of the target. Suppose (x_0, y_0) and (x_i, y_i) represent the locations of the target and the ith BS respectively. They must meet the formula (1).

$$(x_i - x_0)^2 + (y_i - y_0)^2 = R_i^2 \ , i = 1,2,3 \tag{1}$$

Where i means the number of base stations involved. This method requires precise synchronized clock between the transmitter and receiver, which is high cost.

3.2 TDOA Algorithm

TDOA algorithm measures the propagation time difference among the target and the multiple base stations, and gets the distance difference from the time difference by multiplying the speed of the signal [27]. Let $R_{21} = R_2 - R_1$ is the distance difference between the target to BS1 and BS2, as shown in Fig. 1(b), the target must be located in the hyperbola which focuses on these two base stations. The target also locates in the hyperbolas which focus on BS1 and BS3 in a similar way. Then the intersections of two hyperbolas are likely to be the location of the target. That is, the locations of the target and base stations must meet the formula (2).

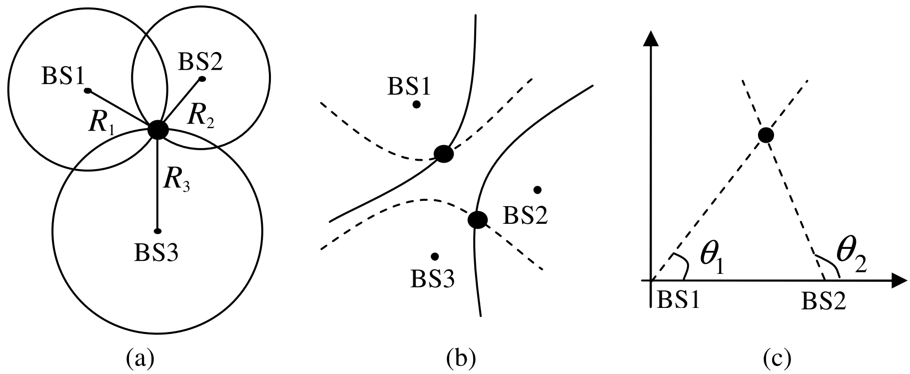

Fig. 1. Indoor positioning algorithms. (a) TOA algorithm. (b) TDOA algorithm. (c) AOA algorithm.

$$R_{i1}{}^2 = \left(\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} - \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2}\right), i = 2,3 \tag{2}$$

This algorithm only needs synchronize the base stations participated in the positioning, without the precise synchronization between the target and the base station described in TOA. There are two solutions obtaining from formula (2), which corresponding to the two intersections of two hyperbolas. However, only one intersection is representative of the real location of the target, it needs some prior knowledge to distinguish true solution to eliminate the position ambiguity.

3.3 AOA Algorithm

AOA algorithm needs to detect the arrival of angle of incidence launched by the target wave through the base station antenna array. A radial attachment forms from the base station to the target, which is namely the azimuth line [28]. Using the angles offered by two or more than two base stations determines the azimuth lines. The intersection is the estimated position for target. The AOA algorithm is shown in Fig. 1(c). Assuming θ_1 and θ_2 represents the arrival of angles detected by the antenna of BS1 and BS2, respectively, then obtaining formula (3):

$$\tan\theta_i = (y_i - y_0)/(x_i - x_0)\ , i = 1,2 \tag{3}$$

By solving the above nonlinear equations can get estimated position of the target. AOA positioning technology needs to use the directional antennas, such as intelligent antenna array, which realizes complexly and costs greatly.

3.4 RSS Algorithm

RSS Algorithm estimates the position according to the Received Signal Strength (generally refers to radio frequency signal). RSS localization method can divide into two tepes: propagation model method algorithm and fingerprinting algorithm.

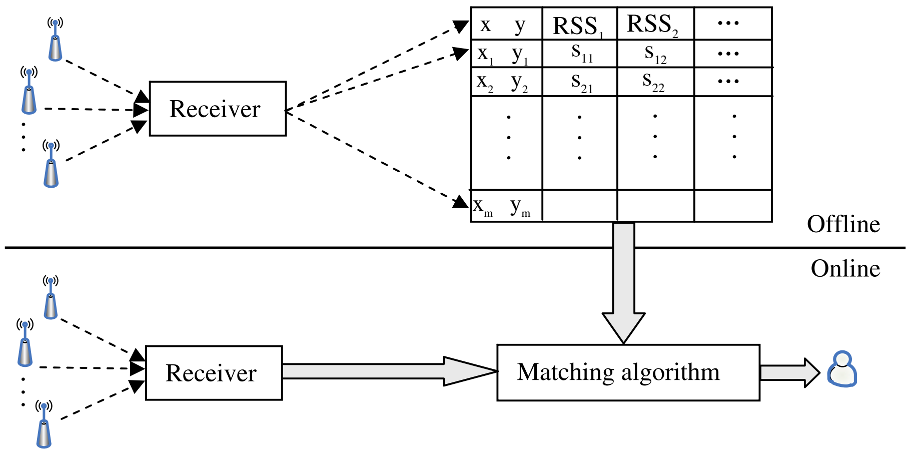

Fig. 2. Fingerprinting positioning method

Propagation model algorithm (PMA) needs to establish the model between RSS and the distance [29], [30]. Generally, the lager of the RSS values the closer from the access point (AP). In the open free space, attenuation of signal strength is inversely proportional to the distance from AP. But the indoor environment is very complex, the furniture, equipment windows and doors may cause multiparty propagation, such as reflection, refraction diffraction. And different structure of the obstacles may cause the different attenuation coefficient for RF signals. So the establishment of accurate indoor propagation model is very difficult.

Fingerprinting algorithm has two stages: offline phase for training and online phase for positioning [31]. Offline phase determines some reference locations, and stores the pre-recorded RSS and position coordinates in a database called Radio Map. Online phase estimates the location of the user by comparing the obtained RSS values to the radio map. The fingerprinting positioning algorithm is shown in Fig. 2. Fingerprinting algorithm needs not to establish the complex propagation model, but the workload is huge [32] and RSS values change susceptibly by multipath in the indoor environment [33]. Shihhau F. has proposed a dynamic system approach into the fingerprinting module to exploit the characteristic of the multipath effect [34], where the location is estimated from the state instead from RSS directly. The state is reconstructed from the temporal sequence of RSS samples by incorporating a proper memory structure. Because of the impact of the temporal variation due to multipath is considered a more accurate state location correlation is estimated.

4 Comparison of Indoor Positioning Technologies

The indoor locating technologies above have the advantages and disadvantages in coverage, location accuracy and system cost. All sorts of positioning technologies coexistence are possible in the future. The user may choose suitable positioning system according to his/her own needs. The comparison of indoor positioning technology is shown in Table 1.

Table 1. Comparison of indoor positioning technologies

Technology		System	Range	Accuracy	Algorithm	Cost
Infrared		Active Badge	5m	7cm	TOA/TDOA	Low
Ultrasonic		Active Bat	30m	9cm	TOA/TDOA	Moderate
Computer Vision		Easy Living	Rome Scale	10cm	Image Process	High
RF	**ZigBee**	Wireless Dragon	40m	3~5m	RSS- PMA	Moderate
	RFID	LANDMARCE	35m	2~5m	RSS-Fingerprinting / PMA	Moderate
	UWB	Ubisense	20m	10cm	TOA/TDOA	High
	WLAN	Horus	50m	2~3m	RSS-Fingerprinting / PMA	Low

5 Summary and Outlook

Location-based service is a very important basic link for Internet of Things and Smart City. Well-known positioning systems such as GPS and cellular network based systems can not be used effectively in indoor environments, motivating the research of other positioning technologies such as infrared, ultrasonic, computer vision and radio technologies. This paper analyzes the key technologies and algorithms of indoor positioning. The analysis shows that the different positioning technologies have their own advantages and disadvantages. On the whole, a breakthrough improvement of positioning accuracy is difficult to obtain from any of the single positioning technology. To achieve higher positioning accuracy, there must be appearing some systems fuse different positioning technologies considering the cost in future. In addition, the security of the positioning systems have little regarded currently. Although security is not the unique requirements of indoor positioning systems, security is a factor that must be considered, which makes sure the systems beyond attack. Thus the security issues of positioning systems will also be an important direction of indoor positioning research.

References

1. Hightower, J., Borriello, G.: Location Systems for Ubiquitous Computing. IEEE Computer Mag. 34(8), 57–66 (2001)
2. Mingfeng, L., Baohong, F., Sanzhi, L.: GPS positioning technology and application. National Defence Industry Press, Beijing (2006)
3. Enge, P., Misra, P.: Special issue on GPS: The Global Positioning System. Proceedings of the IEEE 87(1), 3–15 (1999)
4. Kaplan, E., Hegarty, C.: Understanding GPS: Principles and Applications. Artech House, Boston (2005)
5. Pingzhi, F., Ping, D., Lin, L.: Cellular wireless location. Electronic Industry Press, Beijing (2002)

6. FCC Docket No. 94-102: Revision of the Commission Rules to Insure Compatibility with Enhanced 911 Emergency Calling Systems. Federal Communications Commission Tech. Rep. RM–8143 (1996)
7. Zagami, J.M., Parl, S.A., Bussgang, J.J.: Providing Universal Location Services Using a Wireless E911 Location Network. IEEE Communications Magazine 36(4), 66–71 (1998)
8. FCC, Wireless 911 Services, `http://www.fcc.gov/cgb/consumerfacts/wireless911srvc.html`
9. The Definitive Wireless E-911 Reference Guide 2005. Mind Commerce (2005)
10. Want, R., Hopper, A., Falcao, V.: The Active Badge Location System. ACM Transactions on Office Information Systems (TOIS) 10(1), 91–102 (2003)
11. Ward, A., Jones, A., Hopper, A.: New Location Technique for the Active Office. IEEE Personal Communications 4(5), 42–47 (2004)
12. Microsoft Research. Easy living, `http://www.research.microsoft.com/easyliving`
13. Hyunggi, C., Myungseok, K., Jonghyuk, P., Byungsung, P., Hagbae, K.: Performance Analysis of Location estimation algorithm in ZigBee networks using received signal strength. In: 21st International Conference on Advanced Information Networking and Applications Workshops/Symposia, AINAW 2007, Niagara Falls, pp. 302–306 (2007)
14. Ni, L.M., Liu, Y.H., Lau, Y.C.: LANDMARC: Indoor Location Sensing Using Active RFID. Wireless Networks 10(6), 701–710 (2004)
15. Jin, G.Y., Lu, Y., Park, M.: An Indoor Localization Mechanism Using Active RFID Tag. In: Proceedings of the IEEE International Conference on Sensor Networks, Ubiquitousand Trustworthy Computing, Taichung, pp. 4–8 (2006)
16. Steggles, P., Cadman, J.: A Comparison of RF Tag Location Products for Real World Applications. Technical report, Ubisense Limited (2004)
17. Gezici, S., Tian, Z., Giannakis, G.B.: Localization Via Ultra Wideband Radios: A look at positioning aspects of future sensor networks. IEEE Signal Processing Magazine 22(4), 70–84 (2005)
18. Angela, H., Ruben, B., Juan, C., Ignacio, A., Antonio, V.: Accurate Indoor Wireless Location With IR UWB Systems: A Performance Evaluation of Joint Receiver Structures and TOA Based Mechanism. IEEE Transactions on Consumer Electronics 54(2), 381–389 (2008)
19. Chinder, W., Chihsheng, H.: NLOS Mitigation With Biased Kalman Filters for Range Estimation in UWB Systems. TENCON 2007 IEEE Region 10 Conference, October 30-November 2, pp. 1–4, Taipei (2007)
20. Shaohua, W., Qinyu, Z., Naitong, Z.: NLOS error reduction methods in UWB dense multipath environment. Chinese of Journal Electronics 36(1), 39–45 (2008)
21. Azadeh, K., Konstantinos, N., Anastasios, N.: Venetsanopoulos. Intelligent Dynamic Radio Tracking in Indoor Wireless Local Area Networks. IEEE Transaction On Mobile Computing 9(3), 405–419 (2010)
22. Hamid, M., Nitin, K.T., Taravudh, T.: Indoor Positioning System Using Artificial Neural Network. Journal of Computer Science 6(10), 1219–1225 (2010)
23. Yinsen, F., Taichi, W., Shihyu, C., Hsipin, M.: Location Estimation in Indoor Wireless Networks by Hierarchical Support Vector Machines with Fast Learning Algorithm. In: International Conference on System Science and Engineering, Taipei, pp. 321–326 (2010)
24. Jaegeol, Y., Seunghwan, J., Kiyoung, G., Jaehun, J.: Improvement of Kalman filters for WLAN Based Indoor Tracking. Expert Systems with Applications 37, 426–433 (2010)
25. Youssef, M., Agrawala, A.: Handling Samples Correlation in The Hours System. IEEE Infocom (2004)

26. Zhao, F., Yao, W., Logothetis, C.C.: Comparison of Super-resolution Algorithms for TOA Estimation in Indoor IEEE 802.11 Wireless LANs. In: Proceedings of the International Conference on Wireless Communications, Networking and Mobile Computing, Wuhan, pp. 1–5 (2008)
27. Tao, H., Xiaochun, L., Qi, L.: Pattern Recognition Based Kalman Filter for Indoor Localization Using TDOA Algorithm. Applied Mathematical Modelling 34, 2893–2900 (2010)
28. Roshanei, M., Maleki, M.: Dynamic-KNN: A Novel Locating Method in WLAN Based on Angle of Arrival. In: IEEE Symposium on Industrial Electronics and Applications (ISIEA), Kuala Lumpur, Malaysia (2009)
29. Fengyan, X., Liangbin, L., Zongxin, W.: A new regional division based on the distance of a loss model indoor WLAN positioning system. Journal of Electronics & Information Technology, 1405–1408 (2008)
30. Anvar, N., Yongwan, P., Kookyeol, Y., Jaehwang, Y.: A Fast and Accurate Calibration Algorithm For Real-Time Locating Systems Based on the Received Signal Strength Indication. International Journal of Electronics and Communications 64(11), 999–1104 (2010)
31. Honkavirta, V., Perala, T., Ali-Loytty, S., Piche, R.: A Comparative Survey of WLAN Location Fingerprinting Methods. In: Proceeding of The 6th Workshop On Positioning, Navigation and Communication, Hannover, pp. 243–251 (2009)
32. Kuofong, K., IEn, L., Jiasiang, L.: An Indoor Location-Based Service Using Access Points as Signal Strength Data Collectors. In: International Conference on Indoor Positioning and Indoor Navigation (IPIN), Zurich, pp. 1–6 (2010)
33. Chan, E.C., Baciu, G., Mak, S.C.: Effect of Channel Interference on Indoor Wireless Local Area Network Positioning. In: Wireless and Mobile Computing, Networking and Communications (WiMob), Niagara, pp. 239–245 (2010)
34. Shihhau, F., Tsungnan, L.: A Dynamic System Approach for Radio Location Fingerprinting in Wireless Local Area Networks. IEEE Transaction on Communications 58(4), 1020–1026 (2010)