Merging Technologies Models for Indoor Mobile Device Positioning

Erick Alonso Salazar Molina[1], Jose Martin Molina Espinosa[1]

[1] Instituto Tecnológico y de Estudios Superiores de Monterrey
Campus Ciudad de México, Calle del Puente 222, Tlalpan, 14380, México City, México
{A00969900, jose.molina}@itesm.mx
(Paper received on November 28, 2010, accepted on January 28, 2011)

Abstract. In this work, we discuss the advantages and disadvantages of several indoor positioning systems (IPS) and compare them in terms of designing services for users. We propose a set of critical factors for IPS evaluation. The main contribution consists of the proposal of some merging techniques models using a wireless technologies hierarchy to estimate the position of mobile device in indoors environments. Finally we present a study case using the proposed models to locate objects in indoor areas.

Keywords: Indoor Positioning Systems, context aware location, mobile devices positioning.

1 Introduction

Since wireless access from mobile devices is now widely available, there is great demand for precise positioning in wireless networks, including indoor and outdoor environments. The process of determining a location with wireless technology is called location detection, geographic location, or position location. Different applications may require different types of location information. The main types discussed in this paper are physical location, symbolic location, absolute location, and relative location. Physical location is expressed in the form of coordinates, which identify a point on a map of two or three dimensions. Symbolic location defines a location using natural language, e.g. in the boardroom, in Building A, on the fifth floor of the tower, etc. The absolute location system uses a common reference for all located objects. A relative location depends on a custom frame of reference. The location information is usually based on proximity to known reference points or base stations. While cases of location in outdoors have been well treated by GPS, mobile device positioning inside buildings poses special problems. First, the GPS does not work under a roof, because it requires line of sight (LOS) between transmitter and receiver. Second, many interest problems related to indoor location tracking demand for better accuracy and precision.

The use of RF signals is not the only option for indoor location tracking. Programs based on infrared signals, acoustic signals, pressure sensors embedded in the ground, have been proposed and implemented. RF technology has the advantage of simplicity and low cost, especially with the proliferation of low cost wireless networks.

2 Location Technologies and Algorithms

It is difficult to model the propagation of radio signals in indoor environments, due to various RF signal multi-paths, low probability in the availability of line of sight (LOS), and site-specific parameters such as architecture and design materials, objects that change position, objects in motion, and reflective surfaces. To date, there is not a good model to address the characteristics of multipath indoor radio signals [2] [14]. Indoor Position Systems (IPS) use positioning techniques to locate objects and provide absolute, relative and proximity position information. There are three main techniques for estimating indoor position: 1) triangulation, 2) analysis of scenarios (fingerprint), and 3) proximity [3]. Triangulation, and fingerprints techniques can provide absolute, relative and proximity position information. The proximity positioning technique can only provide information with respect to reference points.

Several IPS use a combination of various techniques to compensate technical limitations due to the use of a unique positioning method [15]. Location algorithms have been specifically designed to define how to calculate the position of a target object. For example, in the technique of triangulation, when the distance between a target object and each reference point is obtained (at least using 3 references), the location algorithm calculates the location of the object.

2.1 Triangulation.

On the basis of the geometric properties of triangles, RSS, AOA and TOA can be used to calculate the position [1]. If the coordinates (xi, yi) of three reference points A, B, C, are known, the absolute position MS1 can be calculated using either the length or the directions R1, R2 and R3 [4]. Each triangulation method has its advantages and limitations. TOA is the most accurate technique, which can filter out multipath effects in indoor environments. However, it is complex to implement [4]. RSS and TOA need to know the position of at least three reference points to estimate the position of a target object. AOA requires only two reference points to determine a target object. However, when the target object is too far away, the AOA method may contain errors, which will result in less accuracy [11].

2.2 Scenario Analysis (fingerprints)

RF scenario analysis refers to the type of algorithms that first collect the identifying characteristics or mapping data (fingerprints) of a scene and then estimate the location of an object by matching the measurements with the fingerprint previously recorded. RSS is the preferred technique for when using a fingerprint location method. Positioning using scenario analysis refers to techniques that match the "fingerprint" of some signal property that depends on its physical location. There are two scenarios for fingerprint positioning: the offline scene and the online scene (runtime scenario).

Location coordinates (labels) and signal strengths (measurement units) for every base station are collected. During the online scene, a location positioning algorithm uses the signal strength observed during the time and the information collected above to calculate the estimated location. The main challenge for location-based techniques (fingerprints) is that the intensity of the received signal may be affected by diffraction, reflection and diffusion of RF signals during their propagation in indoor environments.

There are at least five localization algorithms based on pattern recognition techniques: probabilistic methods, k-nearest neighbors algorithm (k-NN), neural networks, Support Vector Machine (SVM), and the Smallest M-vertex polygon (SMP).

2.3 Proximity

The proximity location technique examines the target object location with respect to a reference point. Proximity location technique is based on a set of detectors of known positions. When a sensor detects a tracking object, the object´s position is considered to be within the area marked by the proximity detector. When more than one antenna detects the moving target, then it is considered in the area whose the antenna is receiving the strongest signal [14].

3 Critical Factors for IPS

To evaluate the indoor positioning systems, we had proposed a set of performance and implementation factors. Performance on IPS is mostly defined on accuracy and precision.

Accuracy. Accuracy or location error is the most important requirement in positioning systems. In general, the average distance error is taken as a measure of performance, which is the average Euclidean distance between the estimated location and true location. The greater the accuracy, the better the system, however, there is often a tradeoff between solution accuracy and other features. *Precision*. Precision is defined as the probability of success of position estimation with respect to the predefined accuracy. This factor is a measure of the strength of the technique of positioning, as it reveals the variation in performance on several tests. *Complexity*. The complexity of a positioning system can be attributed to hardware, software, and operating factors, as well as human intervention during its implementation and maintenance. *Robustness.* A robust IPS should be able to keep running even if some signals are not available, or when some of the RSS and AOA values are not presents, when the device is locked, or a mobile device run out of battery. The only information to estimate the signal direction is from other units of measurement. *Scalability.* Defined as the number of mobile devices that an IPS can locate using certain size and infrastructure within a period of time. Usually positioning performance degrades when the distance between the transmitter and receiver increases. A location system must scale along two axes, the geography and density. *Cost.* The cost of a positioning system may depend on many factors. Important factors include money, time, space, weight and energy [14].

4 Indoor Positioning Systems

Infrared (IR) positioning systems [1], [5] can provide absolute position but it needs a line of sight communication between transmitters and receivers [5]. The IR signal is affected by fluorescent light and sunlight. So, the range of coverage devices is limited to a room. *Ultrasound,* for indoor applications, the ultrasonic positioning systems have emerged using a combination of RF and ultrasound technologies [1], [6]. The mode of operation is setting a number of nodes installed on walls and ceiling, they transmit their location information via RF signals while emitting ultrasound pulses, which are synchronized with the RF signals [15]. *Radio Frequency Identification (RFID)* is a method for storing and retrieving data through electromagnetic transmission [7]. RFID positioning systems are commonly used in indoor complex environments. RFID as a wireless technology allows flexible and inexpensive identification of a mobile device or a person [8]. *Wireless local area networks (WLAN),* WLAN technology is very popular and has been implemented in WiFi access in public areas. Indoor positioning systems based on WLAN reuse existing infrastructures, which reduce its cost. The accuracy of WLAN IPS is estimated based on the received signal strength. RSS is affected by various elements in interior environments such as persons or object movement and orientation, overlapping Access Points (APs), etc. *Bluetooth,* The IEEE 802.15.1 standard is a specification for wireless person area networks (WPAN). The position of a Bluetooth mobile device is located through the efforts of other mobile terminals in the same group (cluster). Bluetooth IPS is a low cost technology that can use actual devices already equipped with Bluetooth technology [9]. *Sensor networks,* IPS based on sensors consists of a large number of sensors attached to predefined locations [10]. Sensor-based IPS provides a cost effective and convenient way for locating people and devices due to the decrease price and size of the sensors. *Ultra wideband (UWB),* RF positioning systems suffer from multipath distortion of radio signals reflected from the walls in indoor environments. The pulses of ultra wideband (UWB) [11], which have a short duration (less than 1 ns), allow filtering out reflected signals from the original signal, offering greater accuracy. UWB technology offers several advantages over other IPS technologies, it does not require line of sight, no multipath distortion, less interference, high penetration, etc [12]. *Magnetic,* the use of magnetic signals is an ancient and classical measurement of the positioning and tracking [13]. Magnetic positioning systems offer high accuracy and do not suffer from the problems of line of sight. However, magnetic systems have limited coverage range, which decreases location performance [15]. *Cell Identification (Cell-ID),* several systems have used GSM / CDMA technologies from cellular networks to estimate the location of mobile customers on the field. Mobile device location is based on cell identification implemented by the network, its main advantage is that it works for all phones and requires no modifications to the mobile phone. However, the accuracy cell identity

(Cell-ID) or Enhanced Observed Time Difference (E-OTD) methods is generally low (in the range of 50-200 m), depending on size cell. [14].

Table 1 shows a comparison among several indoor positioning technologies with some important features, including different algorithms that are used for location.

Classification	Accurrancy	Precision	Robustness	Complexity	Cost	Systems
WLAN (kNN)	3-5 m	50% on 2.5m	Medium	Medium	Lowo	RADAR
(SMP)	3 m	50% on 2.7m	Medium	Medium	Medium	MultiLoc
(PM)	2 m	90% on 2.1m	Medium	Medium	Low	Horus
(Bayesian)	1.5 m	50% on 1.5m	Medium	Medium	Medium	Robot-base
(PM)	1 m	50% on 2m	Medium	Medium	Lowo	Ekahau
RFID (kNN)	< 2 m	50% on 1m	Low	Medium	Low	Landmarc
UHF (LS)	2-3 m	50% on 3m	Medium	N/D	Low	WhereNet
UWB (LS)	< 0.3 m	50% on 0.3m	Low	N/D	High	Sappire Dart
(LS)	0.15 m	99% on 0.3m	Bajo	N/D	Alto	Ubisence
Celular (kNN)	5 m	80% on 10m	Medium	Medium	Medium	GSM Fingerprinting
BT / IR (PD)	2 m	95% on 2m	Low	N/D	Medium	Topaz

Table 1: Indoor Positioning Technologies Comparison

5 Merging Technologies Models

The availability of accurate information about the location of a particular mobile device enables mobile application development, value added in many vertical markets. For outdoor applications, GPS and positioning systems based on GSM offer performance and cost suitable for most applications. Unfortunately they do not work well indoors, for GSM location there could be arange error >100m. This has led to research other technologies that are becoming more and more available on ordinary mobile devices.

5.1 Mobile device location for contextual applications.

Contextual applications require knowledge about the position of an entity (user, mobile device, etc.) in order to offer operations, services, information. These applications do not need to interact with an estimate of position coordinates, but rather with a symbolic position, which understandably determine the location of the user [17]. Symbolic position is used because the final services are related to a certain level of information granularity, which means that although the position estimation is made for physical coordinates from the point of view of context applications these coordinates means areas, buildings, etc. An area can be estimated through simple infraestructure deployment, taking advantage of the capabilities of cell identification with many technologies (GPS, cellular, WiFi, Bluetooth, etc.). It is possible also to emply short-range technologies located at strategic crossing points (eg, RFID).

In the framework of context-aware applications, there are some features: there is not a need to obtain a very accurate location, most of the time it is sufficient to determine that a mobile device is within a specific area. Only for certain situations that require high accurate locations it is necessary to used another method, such as coordinates for example. This concept of cooperative and complementary use of different technologies to ensure a quality of context positioning, with a rational use of resources, is refered as "fusion of technologies".

5. 2 Fusion of technologies for location.

We have discussed some techniques of cellular and multicellular positioning, supported by different technologies, that can be used to estimate the position of mobile devices. The reason that these technologies have been described are: a) they are available, and increasingly, on mobile devices (Bluetooth, WiFi and RFID / NFC). b) They are now accessible through network infrastructure. However, deployments and normal use of these individual technologies in general do not ensure a minimal quality of service for location. Some limitations are: low postion accuracy, reduced scope coverage, roaming availability. These and other limitations of individual technologies can be solved by using a cooperative / complementary formed by several technologies.

The use of fusion or merging technologies can face major constraints on the use of individual technologies (Fig. 3) in relation to the four constraints mentioned previously we can observe the following: *The limitation on accuracy:* can be overcome by integrating the estimates provided by other technologies. *The limitation in coverage* can be improved by being able to substitute some other technologies to complete a successful deployment. For example, if the primary positioning system is WiFi, and at some point in space is losing coverage, the fusion system can try: 1. maintain the position of the user thanks to the inertial available on your mobile, 2. location on the base provided by a NFC / RFID sensor network, 3. seek close collaboration with peers ability to share his position, etc. *The limitation on the continuity and availability*, using redundant or alternative two or more technologies. *Calibration requirements* for a technology can be met by another.

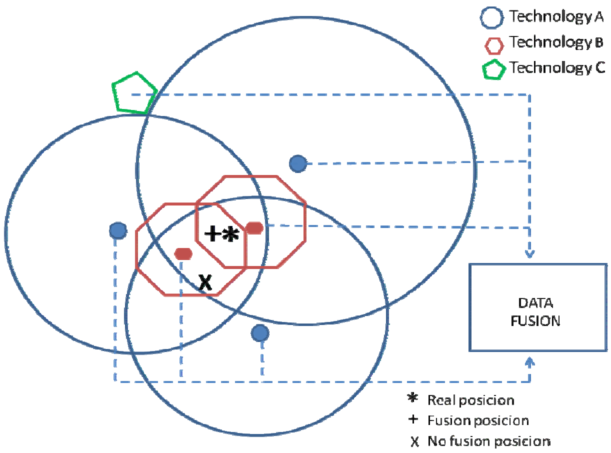

Fig. 3 Merging technologies

The possibilities are many and it is not to propose a redundant and costly deployment or use of complex algorithms as it is not necessary. A target to design a model for positioning, includes an abstraction of the technologies that are being handled, in this work we proposes two sets of hybridization / fusion, selected on the basis of application requirements. Model 1 combines two technologies WiFi multicellular and Bluetooth, wich may be combined in three different ways, cooperative, competitive or complementary. Model 2 combines a medium-range multi-cellular technology WiFi beacons in RFID checkpoints.

Model 1: WiFi and Bluetooth. Both WiFi and Bluetooth can be used as multi-cellular location technologies based on RSS. Different characteristics of coverage, functionality and deployment guide, make it possible to regard them as suitable to be merged technologies, especially to improve the accuracy and coverage issues [16] [17] (Fig. 3). The two technologies, infrastructure mode or terminal based, are able to measure the RSS of a series of beacons, access points/ devices collaborators. Depending on the coverage of technology, mobile devices, can be located in different ways.

According to the classification of fusion methods Durrant-White, one can infer three basic procedures that can improve the individual accuracy possible for separate technologies: *Fusion complementary, fusion competitive and fusion cooperative.*

Model 2, WiFi and Micro RFID cooperative Technology. The presence of geolocated microcells in which users enters or whom they interact may allow estimates to calibrate other technologies. In this perspective, a microcell is a small region in which the user is precisely located, at this point the concept of precision is relative. We can consider the RFID / NFC proximity zones where users can interact (like opening a door etc.) or markers placed at crossing points. This zones establish reference positions whichs relate to measurements taken with other technologies. But it could also be other microcells geometrically referenced on the map room.

The fundamental limitation of multicellular WiFi location model is the variations in the electromagnetic environment, decreasing their accuracy. Depending on the method used for positioning, it is possible to use a mapped database, describing electromagnetic situation depending on the state of the environment. Figure 5 gives a simple representation of the stage. The mobile is equipped with a NFC reader and the cards are deployed on well known locations of the environment that encourage user interaction (PCs, point-of-way or concrete objects). The cards are associated with a position. When the mobile device reads a card, it sent position data and signal strength measurements that capture WiFi access points.

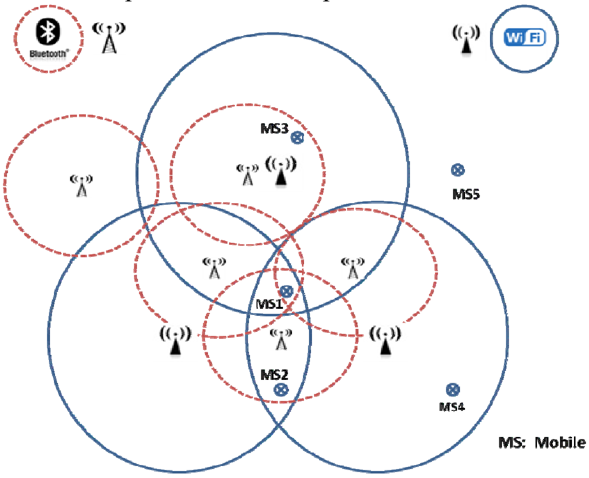

Fig. 4 Model 1, merging technologies WiFi – Bluetooth

6 Case of Study

We have tested our merging models in a scenario for mobile device location within a university campus. The scenario consists of locating a book withitin the library campus using a mobile device. The study case is proposed with hierarchy of areas, associated technologies and positioning methods.

The design of the positioning system must provide a solution which achieves the desired granularity, from the stated minimum aimed to find out if the user, via a mobile device, is or is not on campus, to the maximum, which is the detection if front of the shelf on which is located the desired book. For which we propose the following technical solution.

First Level, determine whether the user is or is not on campus. Solution, check device's connectivity WiFi and keep track of access doors in / out of campus in the door sensor. Second Level, determine the area of campus where the user is located. Solution, use the multicellular system of campus WiFi technology that allows us to determine on which floor of the library the user is located, with which there is at least three WiFi access points at each level. Third Level, determine specific areas of books by subject. Typically these areas will be associated with some shelf. Solution, the solutions to this level will be dependent on the shelves whose area of action aspires to be. The general solution of discovery will be the implementation of a microcellular technology such as ZigBee technology combined with proximity waypoints, or even only the latter. Fourth Level, association of presence with the use of an object. This level is specifically considered to detect the book (objective) in question, such as intelligent devices that emit a buzz. Solution, in general, the answer would be to use a proximity technology, which often come included in the same subject.

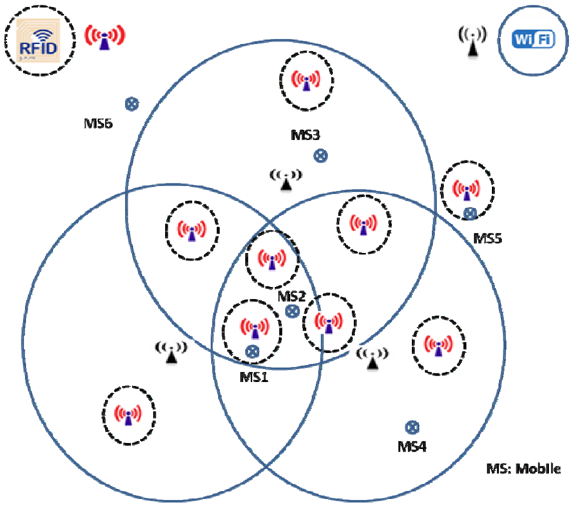

Fig. 5 Model 2, merging technologies WiFi – RFID

All these technological solutions require the user to carry a mobile device with location technologies or more mobile devices that allow the location. The system will keep track of hierarchical position, to anticipate potential communication with sensors in the active area. That is, if the user is in the area of electronic books, the system will activate the ZigBee motes for the various points of interest established to refine the position calculation. With additional background information, this activation can be made smarter, for example, the system can display the date of publication, thematic index, etc.

Conclusions

In this paper, we present an IPS indoor technology comparison made on the proposal and definition of five key factors on IPS performance: accuracy, precision, robustness, complexity, scalability and cost. IPS technologies employed as monolithic solutions present limitations on several key factors that limits their quality of service. We have defined two merging IPS technologies models to determine location of mobile device in indoor locations. Using a combination of several IPS technologies made and enhance in terms of accuracy, precision and robustness. The first model merges multi-cellular approaches based on WiFi and Bluetooth. The second model merges multi-cellular with micro-cellular approaches based on WiFi and RFID.

Finally, we have tested our models in a scenario where the objective is the localization of a book on a library university campus.

References

1. J. Figueiras and S. Frattasi, ”Mobile positioning and tracking, from conventional to cooperative techniques”, Wiley, 2010.
2. K. Pahlavan, X. Li, and J. Makela, “Indoor geolocation science and technology,” *IEEE Commun. Mag.*, vol. 40, no. 2, pp. 112–118, Feb. 2002.
3. J. Hightower and G. Borriello, ”Location sensing techniques”, Technical Report UW CSE 2001-07-30, Department of Computer Science and Engineering, University of Washington, 2001.
4. K. Pahlavan, X. Li, and J. Makela, “Indoor geolocation science and technology,” *IEEE Commun. Mag.*, vol. 40, no. 2, pp. 112–118, Feb. 2002.
5. R. Casas, D. Cuartielles, A. Marco, H. J. Gracia, and J. L. Falc, ”Hidden Issues in Deploying an Indoor Location System”, *IEEE Pervasive Computing*, vol. 6, no. 2, 2007, pp. 62-69.J.
6. H. Piontek, M. Seyffer, and J. Kaiser, ”Improving the Accuracy of Ultrasound-Based Localisation Systems”, *Proc. International Workshop on Location-and Context-Awareness*, Berlin, Germany, 2005.
7. L. M. Ni and Y. Liu, ”LANDMARC: Indoor Location Sensing Using Active RFID”, *Proc. IEEE International Conference on Pervasive Computing and Communications*, 2003, pp. 407-416.
8. H. D. Chon, S. Jun, H. Jung, and S. W. An, ”Using RFID for Accurate Positioning,” *Proc. International Symposium on GNSS*, Sydney, Australia, December, 2004.
9. M. Rodriguez, J. P. Pece, and C. J. Escudero, ”In-building location using Bluetooth”, *Proc. IWWAN*, 2005.
10. D. Niculescu and R. University, ”Positioning in Ad Hoc Sensor Networks”, *IEEE Network Magazine*, vol. 18, no. 4, July/August 2004.
11. J. Ingram, D. Harmer and M. Quinlan, ”UltraWideBand Indoor Positioning Systems and their Use in Emergencies,” *Proc. IEEE Conference on Position Location and Navigation Symposium*, April 2004, pp.706-715.
12. Y. Zhang, W. Liu, Y. Fang, and D. Wu, ”Secure localization and authentication in ultra-wideband sensor etworks”, *IEEE J. Select. Areas Commun.*, vol. 24, no. 4, 2006, pp. 829-835.
13. F. Raab, E. B. Blood, T. O. Steiner, and H. R. Jones, ”Magnetic Position and Orientation Tracking System”, *IEEE Trans. Aerospace and Electronic Systems*, vol. AES-15, no. 5, September 1979, pp. 709-718.
14. Hui Liu, Houshang Darabi, Pat Banerjee, Jing Liu, "Survey of Wireless Indoor Positioning Techniques and Systems", IEEE Journal 2007.
15. Yanying Gu, Anthony Lo, *Senior Member, IEEE,* and Ignas Niemegeers "A Survey of Indoor Positioning Systems for Wireless Personal Networks", IEEE Journal 2009.
16. Aparicio S., Casar J.R., Pérez J., Bernardos A.M.,. “A Fusión Method Based on Bluetooth and WLAN Technologies for Indoor Location”. Proceedings of the International Conference in Multisensor Fusion and Integration for Inteligent System. IEEE Computer Society (2008)
17. Bernardos Borbolla Ana. “Provision de servicios moviles basados en localizacion y contexto”. Universidad Politecnica de Madrid. 2008.