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A Comparative Analysis on indoor positioning Techniques and Systems

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ABSTRACT
Positioning objects has been an important topic since it is needed to locate people, guide them to a certain place, and assist companies and organizations with their assets management. Several techniques and algorithms were proposed to solve the positioning problem and to enhance existing systems. In general, one of the several existing wireless standards such as Infrared, RFID, Bluetooth or Wi-Fi is chosen as the target standard for indoor positioning. This paper provides an overview of the existing wireless indoor positioning solutions and attempts to classify different techniques and systems. Comprehensive performance comparisons including accuracy, precision complexity, scalability, robustness, and cost are presented.

Keywords—Indoor Localization, Positioning techniques, Wireless Positioning Technologies.

I. INTRODUCTION
The problem of locating a user is a fundamental problem in many research areas. In outdoor environments, the Global Positioning System (GPS) can provide good location estimates. However, the GPS solution cannot be used in indoor environments. In this kind of environment (which is typically called GPS denied environment) the GPS signal is very poor because of the lack of line of sight between satellites and the receiver.

Due to the large number of applications that can benefit from a location service in indoor environments, indoor location systems have been an important research topic in recent years.

Because of the advances in wireless technologies and the consequent proliferation of wireless devices in indoor buildings,the use of radio frequency signals to perform localization has become an interesting and promising technique to build better location systems [1].

The primary progress in indoor location sensing systems has been made during the last ten years. Therefore, both the research and commercial products in this area are new, and many people in academia and industry are currently involved in the research and development of these systems**.**

This survey paper aims to provide the reader with a comprehensive review of the wireless location sensing systems for indoor applications. When possible, the paper compares the related techniques and systems.

The authors hope that this paper will act as a guide for researchers, users, and developers of these systems, and help them identify the potential research problems and future products in this emerging area.

Pedersen [2] proposed a micro positioning strategy that should be implemented within the indoor environment in order to position and track objects. He stated that this strategy would work as a replacement for the GPS positioning system. In addition, Fhelelboom [2] found that a wireless local area network (WLAN) can be used within any indoor environment to position objects.

In this paper, we review the different positioning environments, the different systems applied for each environment and the algorithms used within each system. We specify three scenarios for positioning people and objects within an indoor environment. Each of these scenarios has its own challenges, which researchers tried in the past to mitigate by proposing several solutions over the last ten years.

We have organized the paper as follows. In the next section, section II, we point out some preliminary technical information regarding indoor positioning techniques. In section III, we point out some problems and challenges of the systems. In the next section, section IV, there is number of technologies or systems for indoor localization. Finally in section V, there is conclusion and future scenario.

II. INDOOR POSITIONING TECHNIQUES
Here we present some preliminary information that researchers must be aware of indoor positioning systems and environments.

2.1 Choice of Scenario

In the previous section, three different kinds of scenarios have been presented:

• Path finding

- Requires calculation of path and determination of current position

• Tracking

- Requires determination of current position

• Location based services

- Requires determination of current position and maybe estimation of moving pattern.

2.2 Positioning Principle

There are mainly four principles used in building positioning systems. These principles are Trilateration, Triangulation, Scene Analysis and Proximity [3]. The principle used can provide a faster calculation of the position. It can also provide a better accuracy depending on the system architecture too.

2.2.1 Triangulation

The triangulation approach, illustrated in Fig. 2, consists in measuring the angle of incidence (or Angle of Arrival - AOA) of at least two reference points. The estimated position corresponds to the intersection of the lines defined by the angles.

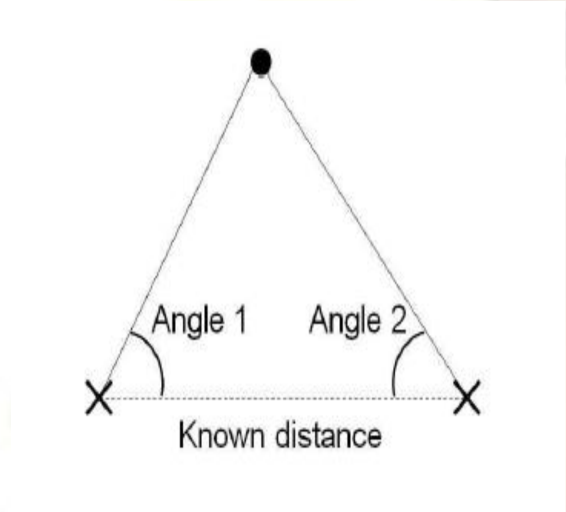

Fig. 2. Triangulation: the estimated location is calculated with the angles formed by two reference points and the target node

2.2.2 Trilateration

The lateration approach, illustrated in Fig. 3, estimates the position of the target by evaluating its distances from at least three reference points.

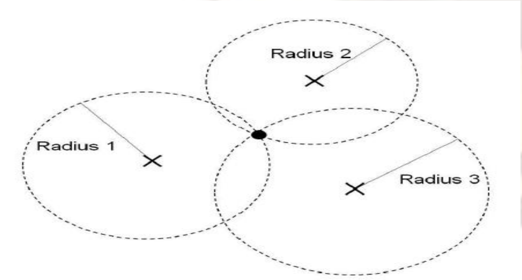

Fig.3. Trilateration: The estimated location corresponds to the intesection point of three circles.

2.2.3 Scene Analysis

Scene Analysis is another principle of positioning in which fingerprinting is used. A fingerprint is the signature that differentiates the scene from other ones. In other words, a fingerprint is the unique characteristic or collection of characteristics of the scene. It works by collecting some information from the scene and compare the collected information with the existing database match for each scene.

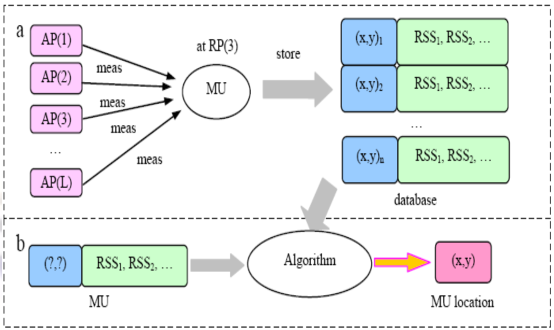

Figure 1. Two phases of fingerprinting (a) training phase and (b) tracking phase.

Fingerprinting Technique

This technique is composed of two phases: Training (Offline) phase and Tracking (Online) phase. During the training phase (Fig. 1.a), signal strengths from APs are collected at pre-identified locations, which are called reference points (RPs). The objective of this operation is building the fingerprint database which will be used in the tracking phase. Because mobile user's location is determined based on the surrounding RPs, they should be distributed in the target area evenly and homogenously.

In the tracking phase (Fig 1.b), MU's surrounding AP RSSs are compared with the RPs dataset collected in the training phase to identify the best matching RPs. The tracking phase could use deterministic and probabilistic algorithms to match real-time RSS readings with RPs signal data.

2.2.4 Proximity

The proximity principle [4] is mainly used in Radio Frequency based systems. In this principle, we use a grid of antennas with fixed locations within the building. When a person carrying the mobile station is detected, the closest antenna is the one considered when calculating the object's location. If the mobile is detected by more than one antenna, the antenna that receives the strongest signal is then considered when calculating the object's location.

2.2.5 Range Measurements Techniques

it use Received Signal Strength (RSS), Time Of Arrival (TOA), Time Difference Of Arrival (TDOA), or Received Signal has (RSP).

1) RSS: The attenuation of emitted signal strength is function of the distance between the emitter and the receiver. The target can thus be localized with at least three reference points and the corresponding signal path losses due to propagation. Several empirical and theoretical models have been proposed to translate the difference between the transmitted and the received signal strength into distance estimation. The RSS based systems usually need on-site adaptation in order to reduce the severe effects of multipath fading and shadowing in indoor environments.

2) TOA: The distance between a reference point and the target is also proportional to the propagation time of signal. TOA-based systems need at least three different measuring units to perform a lateration for 2-D positioning. However they also require that all transmitters and receivers are precisely synchronized and that the transmitting signals include timestamps in order to accurately evaluate the traveled distances. If more than three reference points are available, the least-squares algorithm or one of its variants can be used in order to minimize the localization error.

3) TDOA: The principle of TDOA lies on the idea of determining the relative location of a targeted transmitter by using the difference in time at which the signal emitted by a target arrives at multiple measuring units. Three fixed receivers give two TDOAs and thus provide an intersection point that is the estimated location of the target. This method requires a precise time reference between the measuring units. Like TOA, TDOA has other drawbacks. In indoor environments, a LOS channel is rarely available. Moreover, radio propagation often suffers from multipath effects thus affecting the time of flight of the signals.

4) RSP: The RSP method, also called Phase Of Arrival (POA), uses the delay, expressed as a fraction of the signal's wavelength, to estimate distance. It requires transmitters placed at particular locations and assumes that they emit pure sinusoidal signals. The localization can be performed using phase measurements and the same algorithm than TOA or phase difference measurements and the same algorithm than TDOA. The disadvantage of the RSP method when applied in indoor environments is that it strongly needs a LOS signal path to limit localization errors.

5) AOA: AOA consists in calculating the intersection of several direction lines, each originating from a beacon station or from the target. At least two angles, measured with directional antennae or with an array of antennae and converted in direction lines, are needed to find the 2D location of a target. Nevertheless, this technique requires complex and expensive equipments and notably suffers from shadowing and multipath reflections.

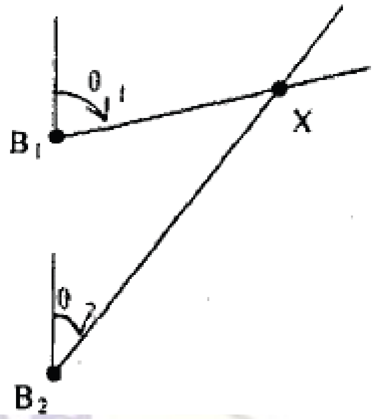

Figure 4. Angles of Arrival (AOA)

2.2.5 Type of location provided

There are three types of locations that can be provided by a positioning system. These types are (i) physical location, (ii) symbolic location, (iii) absolute location and (iv) relative location [5,6,7].

III. PROBLEMS AND CHALLENGES

In this section, we discuss the existing problems and challenges that are encountered when implementing indoor positioning systems and algorithms.

3.1.1 Accuracy

Accuracy of a positioning system is the closest calculated position that can be achieved to a target object. Different systems provide different accuracies. For example, RADAR systems provide an accuracy of 2-3 meters [8]. Where, a cricket system which uses ultrasonic signals has an accuracy of 2 cm [9]. However, the accuracy is still a very challenging area of research for many researchers in this field.

3.1.2 Range of Coverage

Each positioning system works in a different range. The most effective systems are the ones that cover the widest range. Ranges of existing systems go from 5 meters to 50 meters. Providing a system that has coverage of more than 60 meters is a challenge by itself.

3.1.3 Security

The security aspect of indoor positioning systems has not been a major concern in most of the undertaken research in this area. However, it is an important factor in positioning within Personal Network (PN) [10] which users use to position objects and people in their home. An example of a secure wireless indoor positioning system is the Beep system [11].

3.1.4 Complexity

Complexity of a positioning system can be attributed to hardware, software, and operation factors. In this paper, we emphasize on software complexity, i.e., computing complexity of the positioning algorithm. If the computation of the positioning algorithm is performed on a centralized server side, the positioning could be calculated quickly due to the powerful processing capability and the sufficient power supply. If it is carried out on the mobile unit side, the effects of complexity could be evident. Most of the mobile units lack strong processing power and long battery life; so, we would prefer positioning algorithms with low complexity. Usually, it is difficult to derive the analytic complexity formula of different positioning techniques; thus, the computing time is considered. Location rate is an important indicator for complexity. The dual of location rate is location lag, which is the delay between a mobile target moving to a new location and reporting the new location of that target by the system.

3.1.5 Precision

Accuracy only considers the value of mean distance errors. However, location precision considers how consistently the system works, i.e., it is a measure of the robustness of the positioning technique as it reveals the variation in its performance over many trials. We also notice that some literatures define the location precision as the standard deviation in the location error or the geometric dilution of precision (GDOP), but we prefer it as the distribution of distance error between the estimated location and the true location.

Usually, the cumulative probability functions (CDF) of the distance error is used for measuring the precision of a system. When two positioning techniques are compared, if their accuracies are the same, we prefer the system with the CDF graph, which reaches high probability values faster, because its distance error is concentrated in small values. In practice, CDF is described by the percentile format. For example, one system has a location precision of 90% within 2.3 m (the CDF of distance error of 2.3 m is 0.9), and 95% within 3.5 m; another one has a precision of 50% within 2.3 m and 95% within 3.3 m. We could choose the former system because of its higher precision.

3.1.6 Robustness

A positioning technique with high robustness could function normally even when some signals are not available, or when some of the RSS value or angle character are never seen before. Sometimes, the signal from a transmitter unit is totally blocked, so the signal cannot be obtained from some measuring units. The only information to estimate the location is the signal from other measuring units. Sometimes, some measuring units could be out of function or damaged in a harsh environment. The positioning techniques have to use this incomplete information to compute the location.

3.1.7 Scalability

The scalability character of a system ensures the normal positioning function when the positioning scope gets large. Usually, the positioning performance degrades when the distance between the transmitter and receiver increases. A location system may need to scale on two axes: geography and density. Geographic scale means that the area or volume is covered. Density means the number of units located per unit geographic area/space per time period. As more area/space is covered or units are crowded in an area/space, wireless signal channels may become congested, more calculation may be needed to perform location positioning, or more communication infrastructure may be required. Another measure of scalability is the dimensional space of the system. The current system can locate the objects in 2-D or 3-D space. Some systems can support both 2-D and 3-D spaces.

3.1.8 Cost

The cost of a positioning system may depend on many factors. Important factors include money, time, space, weight, and energy. The time factor is related to installation and maintenance. Mobile units may have tight space and weight constraints. Measuring unit density is considered to be a space cost. Sometimes, we have to consider some sunk costs. For example, a position positioning system layered over a wireless network may be considered to have no hardware cost if all the necessary units of that network have already been purchased for other purposes. Energy is an important cost factor of a system. Some mobile units (e.g., electronic article surveillance (EAS) tags and passive RFID tags, which are addressed later) are completely energy passive. These units only respond to external fields and, thus, could have an unlimited lifetime. Other mobile units (e.g., devices with rechargeable battery) have a lifetime of several hours without recharging.

IV. INDOOR POSITIONING SYSTEMS

Several types of wireless technologies are used for indoor location. Currently there are many indoor positioning techniques, such as infrared ray (IR) techniques, wireless Bluetooth techniques, radio frequency identification (RFID) techniques, ultrasound techniques, ultra-wideband (UWB) Techniques, WLAN , ultrasonic system and cellular based techniques. The following will be introduced one by one.

4.1.1 RFID

RFID is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit and is now being seen as a means of enhancing data handling processes [12]. An RFID system has several basic components, including a number of RFID readers, RFID tags, and the communication between them. The RFID reader is able to read the data emitted from RFID tags. RFID readers and tags use a defined RF and protocol to transmit and receive data. RFID tags are categorized as either passive or active.

Passive RFID tags operate without a battery. They are mainly used to replace the traditional barcode technology and are much lighter, smaller in volume, and less expensive than active tags. They reflect the RF signal transmitted to them from a reader and add information by modulating the reflected signal. However, their ranges are very limited. The typical reading range is 1–2 m, and the cost of the readers is relatively high.

Active RFID tags are small transceivers, which can actively transmit their ID (or other additional data) in reply to an interrogation. Frequency ranges used are similar to the passive RFID case except the low-frequency and high-frequency ranges. The advantages of active RFID are with the smaller antennae and in the much longer range (can be tens of meters). Active tags are ideally suited for the identification of high-unit-value products moving through a harsh assembly process.

4.1.2 Bluetooth (IEEE 802.15)

Bluetooth operates in the 2.4-GHz ISM band. Compared to WLAN, the gross bit rate is lower (1 Mbps), and the range is shorter (typically 10–15 m). On the other hand, Bluetooth is a "lighter" standard, highly ubiquitous (embedded in most phones, personal digital assistants (PDAs), etc.) and supports several other networking services in addition to IP. Bluetooth tags are small size transceivers. As any other Bluetooth device, each tag has a unique ID. This ID can be used for locating the Bluetooth tag. The Blue Tags tag is a typical Bluetooth tag.

Bluetooth technology is mainly used in small-scale positioning, such as single-room or warehouse. Bluetooth indoor positioning technology of the biggest advantages is the device small and easy to integrate the PDA, PC and mobile phones, so it is easy to popularize.

4.1.3 WLAN (IEEE 802.11)

This midrange wireless local area network (WLAN) standard, operating in the 2.4-GHz Industrial, Scientific and Medical (ISM) band, has become very popular in public hotspots and enterprise locations during the last few years. With a typical gross bit rate of 11, 54, or 108 Mbps and a range of 50–100 m, IEEE 802.11 is currently the dominant local wireless networking standard. It is, therefore, appealing to use an existing WLAN infrastructure for indoor location as well, by adding a location server. The accuracy of typical WLAN positioning systems using RSS is approximately 3 to 30 m, with an update rate in the range of few seconds.

4.1.4 UWB –Ultra Wide Band

UWB is a new communication technology and has great differences with traditional communication technologies. It does not require the use of traditional communication system in the carrier, but by sending and receiving a nanosecond or less of the extremely narrow nanosecond pulses to transmit data, which has the magnitude of the bandwidth. UWB can be used for precise indoor positioning, for example, found the location of the battlefield soldiers, robot motion tracking.

UWB systems compared with traditional narrowband systems has many advantages, such as the penetrating power, low power consumption, resistance to multi-path effects, high security, low complexity, and highly accurate positioning and so on. Therefore, UWB technology can be applied to indoor stationary or moving objects and people location tracking and navigation, and can provide very accurate positioning accuracy.

4.1.5 Cellular-Based

A number of systems have used global system of mobile/code division multiple access (GSM/CDMA) mobile cellular network to estimate the location of outdoor mobile clients. However, the accuracy of the method using cell-ID or enhanced observed time difference (E-OTD) is generally low (in the range of 50–200 m), depending on the cell size. Generally speaking, the accuracy is higher in densely covered areas (e.g., urban places) and much lower in rural environments [13].

Indoor positioning based on mobile cellular network is possible if the building is covered by several base stations or one base station with strong RSS received by indoor mobile clients. Otsasen et *al.* presented a GSM-based indoor localization system in [14]. Their key idea that makes accurate GSM-based indoor localization possible is the use of wide signal-strength fingerprints. The wide fingerprint includes the six strongest GSM cells and readings of up to 29 additional GSM channels, most of which are strong enough to be detected but too weak to be used
for efficient communication.

4.1.6 Ultrasonic System

Ultrasonic positioning technology has one-way law and reflective distance ranging method, which ultrasonic transmitter and receiver echoes generated by the measured object, according to echo the time difference with the launch wave under test to calculate the distance. Ultrasonic ranging mainly takes reflective distance method by triangulation

positioning algorithm to determine the location of objects. The higher the overall accuracy of ultrasonic positioning, simple structure, but the ultrasound by the multi-path effects and nonline - sowing great influence, and needs a lot of the underlying
Hardware infrastructure investment, the cost is too high.

4.1.7 IR System

The principle of infrared positioning is that infrared IR modulated infrared ray emission is identified by the optical sensor installed in the indoor positioning receiver. Although the infrared has a simple structure, low cost and relatively high accuracy indoor etc., because light cannot pass through obstacles, it makes the only line of sight infrared ray communication. The two main disadvantages of the indoor positioning are Short sight lines and Transmission distance.

Table 1.Comparison of Indoor Positioning Systems

Wireless Positioning Systems	Positioning Algorithms	Positioning Precisions
RFID	RSSI	Centimeters to tens of meters
Bluetooth	RSSI	Tens of centimeters to tens of meters
UWB	TDOA/TOA	A few centimeters to tens of centimeters
Ultrasonic	TDOA	tens of Centimeters
IR	AOA	A few meters

V. CONCLUSION AND FUTURE TRENDS

This paper surveys the current indoor positioning techniques and systems. Different performance measurement criteria are discussed and several tradeoffs among them are observed. For example, the one between complexity and accuracy/precision needs careful consideration when we choose positioning systems and techniques for different applications environments such as warehousing, robotics, or emergency. Usually, location fingerprinting scheme is better for open areas while Active RFID is suitable for dense environments. In terms of scalability and availability, these positioning techniques and systems have their own important characteristics when applied in real environments. The choice of technique and technology significantly affects the granularity and accuracy of the location information.

Future trends of wireless indoor positioning systems are as follows.

1) New or hybrid position algorithms are needed. A few of the works have already been started supporting such algorithms. For example, a calibration-free location algorithm based on triangulation, triangular interpolation and extrapolation (TIX), is introduced in [15]. A hybrid algorithm is presented in [16] for indoor positioning using WLAN that aims to combine the benefits of the RF propagation loss model and fingerprinting method. The same work has been done in [17]. The selective fusion location estimation (SELFLOC) algorithm infers the user location by selectively fusing location information from multiple wireless technologies and/or multiple classical location algorithms in a theoretically optimal manner.

2) Internetworking of different wireless positioning systems is a research and practical topic in order to extend the positioning range.

3) Wireless combined with other technologies Such as optical (e.g., IR), inertial, dc electromagnetic and ultrasonic for indoor location is another trend. How to combine these technologies into a practical system is a topic of sensor fusion.

4) How to deploy sensors to improve the positioning accuracy, how to finish deploying wireless positioning system in a short time, especially for emergency responder application is also worth considering [18].

5) Wireless indoor location using UWB (from 3.1 to 10.6 GHz) techniques and indoor positioning using mobile cellular network are other promising research topics [14].

6) How to integrate indoor and outdoor positioning system is another area of research. This integration may help in developing more efficient and robust detection systems for positioning of mobile computing nodes. In this case, a mobile node will be tracked indoor or outdoor using the same detection system.

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