A Survey of Mainstream Indoor Positioning Systems

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Abstract. Indoor positioning problems have been one of the most challenging research topics in recent years, which comprise smartphone-based indoor localization, tracking, and navigation. Many positioning systems have been designed to provide such reliable indoor location-based services (LBS). In this paper, we have compared different indoor positioning systems, and discussed its future improvements.

1. Introduction
In recent years, indoor localization has been one of the most popular problems in mobile community. In indoor environments, satellite positioning cannot perform well, since the satellite signal cannot penetrate the building, thus indoor localization technology is needed. Indoor localization technology can be applied in many areas, e.g., rescuing people in fire, tracking suspects, locating special targets in buildings. There are many indoor localization approaches, including infrared-based, ultrasonic-based, Bluetooth-based, RFID-based, UWB-based, and WLAN-based. These technologies use unique signal to replace the satellite signal. Among all these technologies, WLAN-based indoor localization approaches have been the center of attention, due to their low deployment cost, potential for reasonable accuracy and easiness to integrate into the mobile device. In this paper, advantages and disadvantages of different indoor localization approaches will be illustrated, and our focus is on the WLAN-based indoor localization approaches.

2. Motivation
Although so many technologies have been introduced, indoor localization is still facing many challenges, including environmental impact, channel attenuation. And higher accuracy with lower cost is still the center of attention. Since there are such a lot of indoor localization technologies and they all have advantages and disadvantages. It is necessary to distinguish them and to understand their principle, so that we can apply suitable technology to the right situation. In this paper, we will compare different methods in accuracy, cost, portability and anti-jamming capability, and our emphasis is the WLAN-based technology, including fingerprint method, propagation model method and technologies that combine the two methods. Our goal is to give a brief introduction to common indoor localization technologies, that readers can understand the status quo of the development of indoor localization.

The remainder parts of this paper is organized as follows, in Section 3 we will introduce several common indoor localization technologies, including infrared-based, ultrasonic-based, Bluetooth-based, RFID-based, UWB-based. In Section 4 we will focus on the WLAN-based technologies. We will present some future work in Section 5.
3. some common indoor location technology

3.1. Indoor Location Technology Based on Infrared
The infrared location system generally contains two parts, one is the CPE (customer premise equipment) which can transmit the modulated infrared ray (infrared IR mark) outwardly at a fixed frequency, the other is the receivers deployed in the room which can receive the signal from the CPE and locate it. A number of CPE and receivers will be used to form a signal detection network to cover the space to be measured.

The advantage of the system based on infrared is the high accuracy that the error is always below 10 cm. But infrared cannot pass through the obstacle, where the transmission distance is short, and vulnerable to indoor lighting or sunlight interference. And high accuracy needs many receivers, so the cost will be high.

3.2. Indoor Location Technology Based on Ultrasonic
The ultrasonic indoor location systems can be divided into two categories [6].

3.2.1 System based on reflective ranging method. A range finder carried by the user transmits the ultrasonic signal at a fixed frequency, and several (at least 3) receivers are deployed in the building to receive the ultrasonic signal and reflect the signal to the user. The range finder measures the distance to every receiver by the time at which the signal is received until the reflected signal is received, then the user’s coordinates can be obtained.

3.2.2 Ultrasound combined with radio frequency technology. The system contains several beacon nodes that transmit their own special mark of the RF signal and the ultrasonic signal without any information through the synchronizing channel. The CPE collects the radio frequency signal and the ultrasonic signal from each beacon node, and use the TDOA (time difference of arrival) to calculate the location of the user.

The system based on ultrasonic has a high accuracy and a simple system structure. But ultrasound is susceptible to multipath effects and obstructions, and for reflective ranging method, the cost is high due to the need of a large number of receivers.

3.3. Indoor Location Technology Based on Bluetooth
The key of Bluetooth positioning is the connection between user's Bluetooth device and the Bluetooth anchor nodes deployed in the building. When the connection established, the Bluetooth anchor nodes will collect the RSSI (Received Signal Strength Indicator) and LQ (Link Quality) of user’s device, and send the information to the server, then the server will calculate the user’s location.

The advantage of Bluetooth location technology is the low cost and low power consumption, Bluetooth module is easy to integrate, and now the mobile communication devices generally have Bluetooth. But the accuracy of Bluetooth system is low with an error more than 1 meter, which is also susceptible to noise signal interference, and the transmission distance is short [7].

3.4. Indoor Location Technology Based on RFID
The system usually consists of a RFID tag carried by user and several RFID readers deployed in the building plane which can receive the radio frequency signal transmitted by the RFID tag. Common RFID positioning system has two kinds.

3.4.1 LANDMARK System [8]. The system has several reference labels, the reference label which has the most similar signal strength with the target position is found by the NNSS (nearest neighbor(s) in signal space) algorithm, and the position of this label is the position of the target to be measured. The measurement accuracy depends on the number of reference labels.

3.4.2 SpotON system [9]. The system uses the relationship between the recognition distance and the signal strength and the triangulation method to find the coordinates of the label to be measured.
System based on RFID has high accuracy and low cost, yet susceptible to environment. The propagation distance is short and the system is not easy to integrate into the mobile device.

3.5. Indoor Location Technology Based on Computer Vision
There are two ways of use computer vision to locate.

By setting the geometric constraints between the feature points in the image and the feature points of the actual objects, a mathematical equation is established to obtain the closed solution of the object position in the camera coordinates, and the position of the object in the world coordinates is obtained by solving the equation [10].

Drawing the road signs on the ceiling of the building, and identifying the landmark information by the ceiling image taken by the camera set on the target to be measured, in order to obtain the location of the target [11].

The advantage of using computer vision positioning is high accuracy, and it is suitable for indoor robot routing. But image positioning is vulnerable to interference (debris in the images), and the need for a camera real-time shooting images makes it not easy to integrate the system into the mobile device.

3.6. Indoor Location Technology Based on UWB
Ultra-wideband (UWB) is a technique for transmitting data by sending and receiving very narrow pulses with nanoseconds.

Here are two common UWB system [5].

3.6.1 Sapphire system. The system consists of a plurality of robots and several (at least 4) receivers and a control center. The robots can transmit a pulse signal. The receiver measures the arrival time of the original signal and sends the result to the control center. Based on four or more data, the control center can calculate the three-dimensional position of the robot.

Unbise system

3.6.2 Unbise system combines RF (radio frequency) and UWB. The system consists of sensors and robots. Multiple sensors deployed in a fixed location using standard Ethernet, which can receive RF and UWB signals. The robot can send the UWB signal and the RF signal containing the identifier, the sensor uses the TDOA and AOA methods to calculate the position of the robot.

UWB signal is not sensitive to the channel weakness, which can go through the obstacles, and which is difficult to be intercepted with high precision, high security and low cost. UWB system almost meets all needs of indoor positioning. There are no obvious shortcomings, the main research direction is to further improve accuracy, reduce costs and improve compatibility.

| Technology       | Accuracy | Cost | Portability            | Anti-jamming capability               |
|------------------|----------|------|------------------------|---------------------------------------|
| Infrared         | High     | High | Integrated into mobile devices | Susceptible to indoor lighting or sunlight |
| Ultrasonic       | High     | High | Integrated into mobile devices | Susceptible to multipath effects and obstructions |
| Bluetooth        | Low      | Low  | Integrated into mobile devices | Susceptible to noise signal interference |
| RFID             | High     | Low  | Not integrated into mobile devices | Susceptible to environment |
| Computer Vision  | High     | Low  | Not integrated into mobile devices | Susceptible to interference(debris in the images) |
| UWB              | High     | Low  | Not integrated into mobile devices | Anti-interference |
All of the approaches in Section 2 need special devices to transmit signal to make it expensive to deploy the system. WLAN-based system uses wireless network signal that has almost covered everywhere in our world, this is an advantage of the WLAN-based system. In next section we will focus on the WLAN-based system.

4. WLAN-based Indoor Positioning System

4.1 Fingerprint-based WLAN Indoor Positioning System

In general, system based on the signal fingerprint positioning is divided into two stages. Take the RADAR system [4] as an example. First, in the offline phase, a client device that can transmit wireless signals is used to record the coordinates of multiple points in the building plane. The combination of the coordinates and the signal strength received by each access point is the fingerprint of a point. Use all fingerprint to plot a radio map. In the online phase, according to the signal strength information received by each access point, the nearest neighbor algorithm map can be used to find the most matching position in the radio, which is the estimated user location.

RADAR as the earliest WLAN signal positioning system is not accurate enough, because in the calculation of signal strength, in order to simplify the model, only consider the influence of user’s towards to the signal strength, ignoring some of the wireless channel changes. And then some positioning systems such as HOURS [3], improve accuracy by identifying and positioning wireless channel changes, and use location clustering technology to reduce the amount of calculation.

In practical applications, the accuracy of positioning system based on position fingerprint is depend on the density of position fingerprint in radio map. The higher the fingerprint density, the higher the positioning accuracy. In addition, multiple samples selected in the online phase can also improve accuracy, but the increase in the number of samples will also increase calculation delay, so the number of samples should be dynamically adjusted according to demand.

**Figure 1** The schematic of the RADAR system

The biggest advantage of fingerprint-based WLAN location system is the small computational complexity and the high accuracy, and now the penetration of WLAN network is high, so no additional wireless signal transmitter is needed. However, the cost of making a high-density radio map is high, and since the attenuation of the signal strength has a strong relationship with the layout of the plane to be measured, it is necessary to redraw the radio map if the layout of the plane changes. In the mall, cinemas and other place where people move around or obstacles move frequently, the measurement results will be a great impact.

4.2 Model-based WLAN Indoor Positioning System

The propagation model method uses the signal strength as the medium of the distance measurement, and converts the signal strength into a distance to determine the position of the point to be measured. The signal strength is inversely proportional to the square of the propagation distance, but in the indoor environment, due to the obstacles, the wireless signal will get multiple refraction, diffraction and
reflection, making the propagation model become complex. There are two kinds of propagation model method, which are statistical propagation model method and deterministic propagation model method.

In the statistical propagation model method, all environmental factors are implicitly included in it, so the polynomial regression model can be used as the signal propagation model. Another common model is the path loss model, which is based on the Floor Attenuation Factor propagation model. This model introduces a Wall Attenuation Factor, which mainly considers the affection of wall to the signal attenuation. The statistical propagation model does not need to draw a radio map, only a few samples are needed to calculate the parameters in the propagation model.

The deterministic propagation model is based on the physical nature of the propagation of radio signals and needs to be suitable for all environments. Therefore, the realization of the deterministic propagation model requires a huge database of environmental characteristics and is computationally intensive so it is difficult to implement in practical applications. Therefore, the deterministic propagation model is usually combined with the fingerprint, which is used to reduce the workload of fingerprint sampling.

The biggest advantage of the propagation model method is that it does not need to draw the radio map, nor does it need to arrange special receiving equipment, hence the cost is low, and the flow of personnel within the measured space has little effect on the measurement results, but the measurement accuracy is a bit lower than the fingerprint method and the calculation is also complex. At present the main research direction is still focused on how to build a more accurate wireless signal propagation model.

The following is a simplified propagation model in RADAR.

$$P(d)[dBm] = P(d_o)[dBm] - 10n\log\left(\frac{d}{d_o}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \geq C \end{cases}$$

**Figure 2** Propagation model in RADAR

In this model n represents the ratio of the path attenuation to the distance increase, P represents the signal strength, d represents the distance between the receiver and the transmitter, C represents the maximum number of obstacles, nW represents the number of obstacles between the receiver and the transmitter. WAF is the wall attenuation factor, which is related to the layout of the building and the wall material. Using the propagation model, the relationship between the signal strength and the distance can be obtained so that the user's position is determined by the actual received signal strength.

4.3 WLAN Indoor Positioning System Combine Propagation Model Method and Fingerprint Method

In the offline phase of the fingerprint method, the propagation model is used to reduce the workload of sampling. Taking the ARIADNE system [2] as an example, the system is divided into a map generation module and a search module. In the map generation module, a propagation model is constructed using ray tracing and simulated annealing algorithm. Combine the propagation model and a set of signal strength information received by the three sniffers arranged in the measured space, a location fingerprint can be found. In the search module, use clustering technology to reduce the amount of calculation and improve accuracy.

Although the propagation model reduces the cost of making radio maps, location fingerprint is still sensitive to environmental changes. And a radio map made by propagation model is accurate, even with five sniffers, the average error is still more than one meter. The accuracy can now be improved by optimizing the propagation model and sniffer distribution, or using historical location information. And a dynamic signal strength map can solve the problem that location fingerprint method sensitive to environmental changes.

For example, Modellet [12], an algorithmic approach that optimally approximates the actual radio map by unifying model-based and fingerprint-based approaches. Modellet represents the radio map using a fingerprint-cloud that incorporates both measured real fingerprints and virtual fingerprints,
which are computed from models with a local support based on the key concept of the supporting set. A supporting set is a set of real fingerprints from which a derived model can best approximate the local radio map. Using propagation model reduces the amount of measurement data needed to make a high quality radio map and to reduce costs.

5. Conclusion and Future Work
In this paper, we have compared different indoor localization approaches, and we believe WLAN-based technology is the most promising technology. Since WLAN network has a high penetration rate, we can integrate the positioning system into existing WLAN devices, so the cost is low, and the WLAN-based system has potential for reasonable accuracy. The fingerprint method will be the major approach, and the propagation model method can help to make high quality radio map.

The future work of indoor positioning system is to improve accuracy and reduce costs, make the system applicable to a variety of situations, and add more user-friendly features [13-17]. For WLAN-based systems [18, 19], finding a better way to combine the fingerprint method and the propagation model method may significantly increase the accuracy.

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