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全球定位系統和無線區域網路整合定位系
統下的無接縫位置換手

A Seamless Location Handoff for Integrated GPS/WLAN
Geolocaiton Systems

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中 華 民 國 九 十 三 年 六 月

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研究生：徐國將　　　　指導教授：簡榮宏博士

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摘　　要

近年來行動裝置已逐漸成為我們生活的一部份，因此具有導覽和內容感知功能的應用程式也變得非常重要，有鑑於此，發展一套準確且全面的定位系統便成為重要的研究項目之一。本篇論文提出一個全球定位系統和無線區域網路整合定位系統下的無接縫位置換手架構，讓使用者在不同的環境下都能做到自我定位，並在轉換室內、室外環境的過程中定位系統也不會因此而中斷；此外，我們針對位置特徵演算法的定位方式做部份改進，並提出一個換手決策模式來判斷定位系統換手的時機。在根據實驗結果顯示，我們所改進的定位演算法可使定位結果更穩定且有效率；而在定位系統換手方面，發現產生延遲的主因是網路的切換所造成，而實驗結果也顯示我們的換手決策可以達到較高的正確率。

A Seamless Location Handoff for Integrated GPS/WLAN Geolocaiton Systems

Student：Kuo-Chiang Hsu Advisor：Dr. Rong-Hong Jan

DEPARTMENT OF COMPUTER AND INFORMATION SCIENCE

NATIONAL CHIAO TUNG UNIVERSITY

Abstract

In recent years, mobile devices have gradually emerged as a portion of our daily life. Therefore, navigation and context-aware applications become very important. According to this progress, it is necessary to create a geolocation system for all environments with high positioning accuracy. The thesis proposed a seamless location handoff for integrated GPS/WLAN geolocation systems. In our system, user's positioning information can be obtained by themselves in both indoor and outdoor environments and the positioning process will not be terminated. Besides the implementation of integrated geolocation system, we also improve the function of fingerprinting algorithm for indoor geolocation system and propose a handoff decision model for the location handoff. The experimental results show that our positioning algorithm can make the geolocation system more stable and efficient. It also shows that the bottleneck of handoff delay time is the network handoff and our handoff decision model can reach higher correctness.

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Chapter 1

Introduction

With the progress of wireless technology, mobile devices such as Notebook, Personal Digital Assistant (PDA), cell-phone, and personal communicator have gradually emerged as a portion of our daily life. People can easily communicate to each other anytime and anyplace. For this reason, there are some applications that include emergency rescue, tour guide [1], resource tracking and management, points of interest and so on to be created for mobile devices. It can be seen that the location-based application will play an important role among these applications. For creating location-based applications, we should develop the location-determination method that is the core technology of them. Many researches [2-9] are dedicated to location-determination methods. These methods can be divided into two major classes, outdoor geolocation method and indoor geolocation method.

The outdoor geolocation method had been developed in several ways. For example, the Dead Reckoning (DR) [3] technique gathers the information about user's velocity, time, and direction and then estimates user's location. The DR had been used for car navigation until the Global Positioning System (GPS) developed. In nineteen century, the GPS is invented by the U. S. Department of Defense for military usage. The GPS rely on the 24 satellites that orbit around the earth to transmit precise velocity, latitude, longitude and altitude to the GPS receiver and estimate its location. After the cold war, the GPS technique is released for commercial applications as in voyage, aviation and car navigation. Today, it becomes the most popular and useful technique for the outdoor geolocation. The accuracy of GPS can be up to 5 meter. However, the GPS is not always workable in anyplace. The GPS signal might be obstructed by climatic conditions or wall of building so it is not suitable for indoor environment.

For the duration of developing time between DR and GPS, there are also some outdoor geolocation methods that include Angle of Arrival (AOA) [5], Time of Arrival (TOA) [6], Time Difference of Arrival (TDOA) [5] and so on. All of them will be discussed in chapter 2.

The indoor geolocation method uses the specific network that is constructed in indoor environment to perform location estimation. The specific network might be a new network such as infrared (IR) network or an existing network such as wireless local area network (WLAN). The active badge [7] system utilizes a badge that emits an IR signal periodically (or on demand) and recognizes user's location. The IR network is built only for indoor geolocation method. In contract, the RADAR [9] system utilizes the WLAN that is already constructed in the indoor environment for users' communication to estimate user's location by received signal strength (RSS) of WLAN. The RADAR system uses the RSS that had been measured and stored in database in construction phase and performs location estimation via looking up the database. This kind of pre-measurement method is known as location fingerprinting method.

It is obvious that the former (Active badge) system is more expensive than the latter (RADAR) one because of the cost of network construction. Hence, it is more and more popular for indoor geolocation to use WLAN. However, the cost of network construction is higher than GPS and the accuracy is less than GPS. It is not suitable for large area environment such as outdoor environment to construct WLAN for location-determination because of cost and accuracy.

According to above two main classes of location-determination method, none of them is suitable for both outdoor and indoor environment. For solving the location-determination in different environment, we propose an integrated indoor and outdoor geolocation method. In this thesis, the GPS is used for outdoor environment and the location fingerprinting is used for indoor environment. In this integrated system, a handoff module should be performed for dealing with the handoff of indoor and outdoor geolocation method smoothly. Besides, the location accuracy should be improved and the location tracking via past location information should be presented in reasonable situation. In this thesis, we provided a total solution to supply a seamless location handoff for integrated GPS/WLAN geolocation system. The remainder of this thesis is organized as follows. In Chapter 2, we present some geolocation system, wireless geolocation system and the handoff decision module. The system architecture and performance analysis are shown in Chapter 3 and Chapter 4, respectively. Finally, the conclusion and future work are given in Chapter 5.

Chapter 2

Related Work

2.1 Previous Geolocation System

2.1.1 Global Positioning System (GPS)

The GPS [2] is a satellite-based navigation system that was developed by the U.S. Department of Defense (DoD) in the early 1970s. Initially, GPS was developed as a military system to fulfill U.S. military needs. As time goes on, it was available for both military and civilian users. The GPS consists of three segments: the space segment (satellites), the user segment (receivers), and the control segment (management and control). The GPS calculates absolute position of user that includes latitude, longitude and altitude by receiving more than three satellites' signal. If the distances from a point on the Earth (a GPS receiver) to three GPS satellites are known, then the location of the point can be determined by the concept of resection. From the practical point of view, however, the fourth satellite is needed to account for the receiver's clock offset. The horizontal positioning accuracy of GPS is currently about 10m and can be improved to about 5m under a differential mode. Although the GPS is very precise in personal position, its accuracy may be affected by many types of errors and biases such as multipath error, selective availability and satellite geometry measures. The position estimation will not be worked if the GPS signal is blocked.

2.1.2 Dead Reckoning (DR)

DR [3] is a very primitive positioning technique that had been used for ages to obtain a vehicle's position. DR estimates position based on velocity, time, and direction from a starting point. It is possible to calculate the vehicle's position at any instance provided that starting location and all previous displacements are known. In short, the basic idea is that we use sensors to measure the direction of the vehicle θ and the distance traveled d. After sampling, integrating and sensor fusion has been performed, the vehicle position (x_n, y_n) and orientation θ_n at time t_n can be calculated from the equations 2.1.

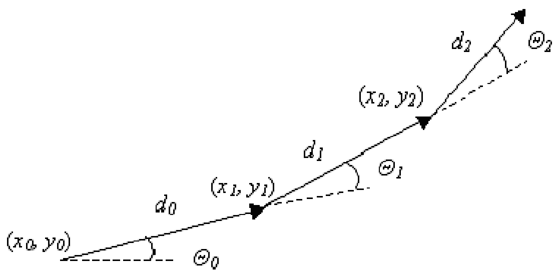

Figure 2.1: The Dead Reckoning algorithm.

$$
\begin{aligned}
x_n &= x_0 + \textstyle\sum_{i=0}^{n-1} d_i \cos\theta_i \\
y_n &= y_0 + \textstyle\sum_{i=0}^{n-1} d_i \sin\theta_i \\
\theta_n &= \textstyle\sum_{i=0}^{n-1} \omega_i
\end{aligned}
\qquad (2.1)
$$

where (x_0, y_0) is the initial position at time t_0, d_i is the distance traveled or the magnitude of the displacement between time t_{i-1} and time t_i, θ_i is the direction (heading) of the displacement vector, and ω_i is the angular velocity for the same time period. A drawing outlining this method is shown in Figure 2.1. Accuracy of the DR, however, is constantly degrading since errors in all measurements accumulatively affect the current position estimation. Besides, measuring distance directly with a pedometer is a practical means for pedestrian positioning. Taking the pace count to multiply the distance for each pace, the total distance traveled can be obtained.

2.1.3 GPS/DR

It can be seen that each of the GPS and DR systems suffers from limitations. For example, the GPS signal may not be available in obstructed areas, and the DR system drifts over time causing large positional error. Hence, a combinatorial positioning solution, GPS/DR [4], may be developed based on the two positioning systems. Kalman filtering technique is commonly used for system integration. With the integrated system, GPS helps in controlling the drift of the DR components through frequent calibration, while the DR becomes the main positioning system when the GPS fails. As such, the performance of the integrated system will be better than either system alone.

2.1.4 Infrared (IR) Positioning System

The Active Badge system [7] is one of the earliest indoor systems for location-determination, based on diffused infrared technology. A badge emits a unique IR signal periodically or on demand. IR sensors placed in the building pick up these periodic signals and transfer them to a master station for location processing. Although the Active Badge system provides accurate location information, it also subject to some restrictions such as line-of-sight limitations, poor performance with fluorescent lighting or direct sunlight. The Active Bat location system [8] developed by AT&T researchers uses a combination of RF and ultrasound time-of-flight to estimate the distance. When a controller connected to the personal computer (PC) broadcasts a radio request message, an Active Bat tag attached to the object reacts by emitting an ultrasonic pulse directed to a matrix of receiving elements mounted on the room ceiling. At the same time, the controlling PC sends a reset signal to the receivers over the serial network, so that they can measure the time interval and calculate the distances from the tag to the receivers. The use of ultrasound time-of-flight requires a large fixed-sensor infrastructure and the accuracy can reach about 9 cm. This approach yields a high reliability, but is expensive in terms of installation and maintenance.

2.1.5 RADAR

The RADAR system [9] which is developed by a Microsoft Research group is the first one that uses location fingerprinting approach to determine users' location. It is an RF-based geolocation system for users' tracking and locating in buildings. In this system, they placed three Pentium-based personal computers as access point (AP) in the building and treated a laptop computer as mobile station. The three APs measured the received signal strength (RSS) that is transmitted from mobile station. Then the server estimates the location of mobile station with location fingerprinting algorithm. The accuracy of RADAR is affected by the the number of data points, the number of samples, and user orientation. There are two advantages of RADAR approach:

1. It requires only a few base stations.

2. It uses the same infrastructure that is the building's general-purpose wireless network.

However the RADAR system has some drawbacks:

1. It requires more pre-measurement efforts.

2. Fingerprints of all locations only consists three AP's measurement in the same floor. This diminishes the accuracy of the positioning.

Nowadays, the fingerprints of some location are composed of the signals from several APs in multiple floors, not just in a single floor [10].

2.2 Wireless Geolocation System

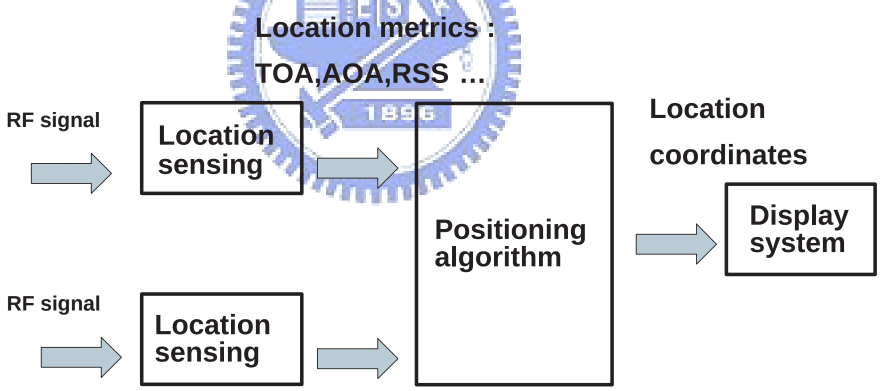

Figure 2.2: The wireless geolocation system.

The Figure 2.2 illustrates the functional block diagram of a wireless geolocation system [11]. The main elements of the system are a number of *location sensing devices* that measure metrics related to the relative position of a mobile terminal (MT) with respect to a known reference point (RP), a *positioning algorithm* that processes metrics reported by location sensing elements to estimate the location coordinates of MT, and a *display system* that illustrates the location of the MT to users.

2.2.1 Sensing Techniques

The signal metrics measured by sensor are determined by location-sensing techniques. These datum will affect the accuracy of location estimation by positioning algorithms. In the following, there are several sensing techniques in common use.

1. Angle of Arrival (AOA) [12]:

   Angle of arrival is the common metric used in direction-based systems. This approach requires the installation of complex antenna array at mobile terminal (MT). According to the arrival signal received by the two receiver stations can determine the angle between the MT and each of receiver stations. After getting these computed AOAs, we can find several lines projected from the receiver stations to where the signal originated at the angles as measured. The estimated position is the intersection point.

2. Time of Arrival (TOA) [6]:

   In the standard of IEEE 802.11b, the signal is coded by a known pseudo-noise (PN) and transmitted by a transmitter. Then a receiver cross-correlates received signal with locally generated PN sequence using a sliding correlator. The distance between the transmitter and receiver is determined from the arrival time of the first correlation peak. However, due to the complexity of multipath indoor radio propagation channels, the resolution of TOA estimation is roughly determined by the base width of the PN correlation function, or equivalently the signal bandwidth.

3. Received Signal Strength (RSS) [10]:

   This technique is based on the received signal energy of antenna of devices. The four units of measurement to represent RF signal strength are mW, dBm, RSSI (Receive Signal Strength Indicator), and percentage. The RSS metric can be used to determine the distance between a transmitter and a receiver with the radio propagation model because the signal decay with increment of distance square. Then we use triangulation approach to locate the receiver. The other approach using RSSs to perform the location-determination is location fingerprinting algorithm. It is based on that the received signals at different locations have different characteristic of the signal. The characteristic signal means that RSSs from different fixed transmitters, like access point (AP), is different. This is known as the location fingerprinting.

2.2.2 Positioning Algorithm

The measurement accuracy of location metrics in indoor areas depends on location sensing technologies and radio propagation conditions. Due to the imperfect sensing techniques and the multipath radio propagation problem, the measurements of location metrics always contains varying errors. To achieve high positional accuracy when the measurements of location metrics are unreliable, the errors have to be mitigated in the positioning process. Therefore, we discuss two types of positioning technique [11], the traditional techniques and pattern recognition techniques.

1. Traditional Techniques

In the indoor environment, it is difficult to measure AOA and RSS accurately, so most of the independent indoor positioning systems mainly use TOA based techniques. With reliable TOA-based distance measurements, simple geometrical triangulation method can be used to find the location of the MT. Due to the estimation errors of distances at receivers caused by inaccurate TOA measurement, the geometrical triangulation technique can only provide a region of uncertainty, instead of a single fixed position, for estimated location of the MT. The Figure 2.3 illustrates the geometrical triangulation technique and the gray region is the estimate location of MT.

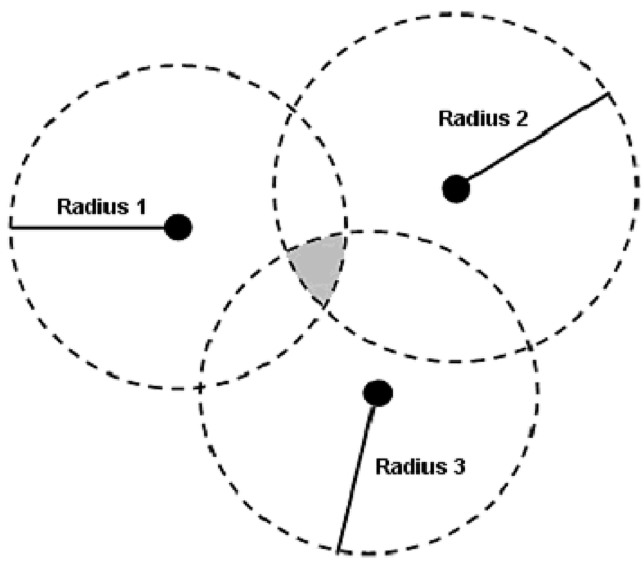

Figure 2.3: The geometrical triangulation technique.

2. Pattern Recognition Techniques

The small coverage of the system makes it possible to conduct extensive pre-measurement in the areas of interest. As a result, the pre-measurement based location pattern recognition (also called location fingerprinting) technique is practicable for indoor applications. The basic operation of pattern recognition positioning algorithms is simple. Due to the unique radio signal propagation characteristics in each indoors environment, each spot in a building would have a unique signature in terms of RSS, TOA, and/or AOA, observed from different sensors in the building. This unique signature also calls as "location fingerprint". A pattern recognition system determines the unique pattern features (i.e., the location fingerprint) of the area of interest in a training process, and then this knowledge is used for the rules of recognition. The challenge for such algorithms is to distinguish locations with similar signatures. To build the signature database, a terminal is used to gather signals through all location sensing elements in the interest area which is divided into nonoverlapping zones. Then we have to analyzes the gathered signal patterns and compiles a unique signature for each zone. The location estimation is determined to be the one associated with the minimum Euclidean distance [9]. Therefore, the measurement of Euclidean distance is computed for all the measured location fingerprint and all entries in the signature database. Usually we choose the physical location of the entry associated with the minimum Euclidean distance. Since general WLAN PC cards can more easily get RSS information than AOA and TOA, it is considerable to use the location fingerprinting approach based on RSS.

2.3 Handoff Decision Model

In our proposed architecture, the MT needs to perform handoff in different networks and applications and the handoff decision model is critical subject in our system. The handoff decision model will determine the timing to perform handoff. If the model is improper, it will affect the system performance and cause ping-pong effect, which means system changes the chosen network and application back and forth. Traditional handoff algorithms [13] employ thresholds to compare with received signal strength (RSS) or received power in different position and decide on mobile terminal. Some of the traditional algorithms are shown in the follows :

1. RSS:

   System chooses a base station whose signal is received with the largest strength.

2. RSS plus threshold:

   System chooses a new base station if the RSS of a new base station is greater than RSS of the current base station and the RSS of the current station is smaller than a threshold.

3. RSS plus Hysteresis:

   System chooses a new base station if the RSS of a new base station is greater than RSS of the current base station by a hysteresis margin.

4. RSS plus threshold and Hysteresis:

   System chooses a new base station if the RSS of a new base station is greater than RSS of the current base station by a hysteresis margin, and the RSS of the current station itself is smaller than the threshold.

5. Algorithm plus dwell time:

A dwell timer is used with above algorithms and started while the condition of above algorithm is true. After the dwell timer expired, the system will perform a handoff.

Chapter 3

System Architecture and Implementation

In this chapter, we propose an architecture which integrates outdoor and indoor geolocation method. The outdoor geolocation method is based on GPS and the indoor one is based on fingerprinting method. Our architecture can satisfy users that they can get the positioning service no matter where they are. We also provide a seamless location handoff so that the system can perform handoff both of network and display system when the user's environment changes. The location handoff could make user feel unaware and acceptable. Moreover, we hope the geolocation system is accurate in different positioning method and it is an effective positioning tool for users. Therefore, we propose some functions to improve the accuracy of our system. We will introduce each parts of the architecture and propose the improving functions of positioning algorithm and the seamless location handoff model in the following section.

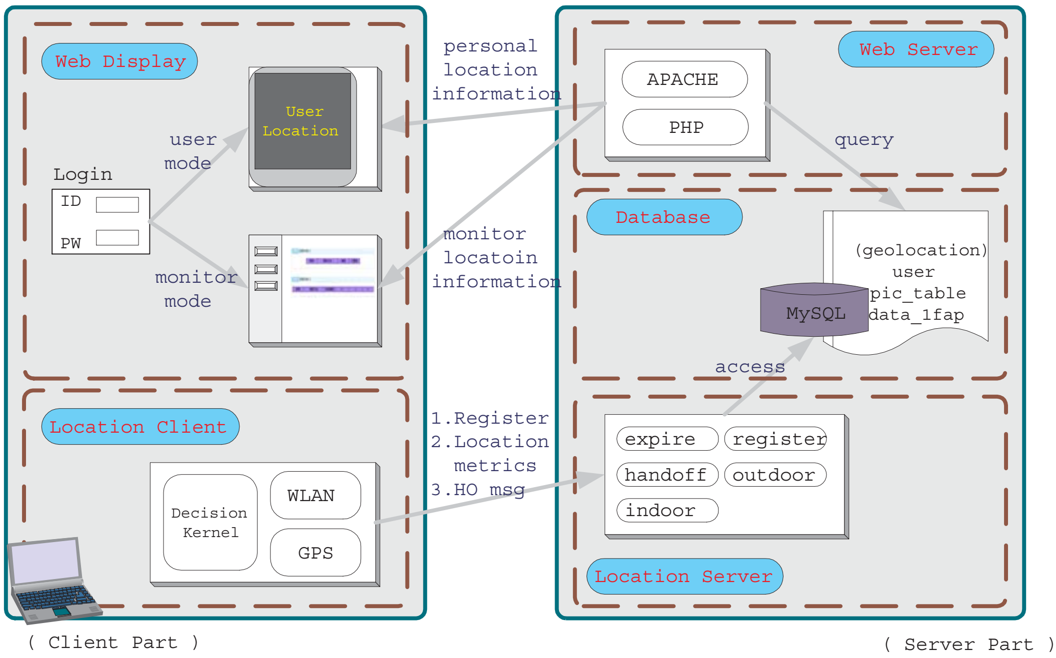

Figure 3.1: System architecture.

3.1 Architecture of Geolocation System

3.1.1 Overview

The architecture is shown in Figure 3.1. It is a client-server model and each part has several modules which have their own jobs. In client part, there is a location client program which runs in background. Besides, there is a display system in this part and users can access different display mode according to their priority. If the user has the highest priority, he can enter the monitor display mode that will show the location information of all users. Otherwise, he just can enter the user mode that only show his location information. In the server part, it consists of three parts:

1. a location server

2. a web server

3. a database

The location server has duty to listen the messages from the location client. The main jobs of location server are performing the positioning algorithm for the location client and storing the location information into the database. Here, we adopt MySQL for database in our system because it is freeware. The web server that uses APACHE comprises PHP and java servlets. We will show the detail of our system in the next subsection.

3.1.2 Operation Flow

The operation flow can be described with two subsections. One subsection is that how to initialize the location client, which will send the location metrics to the location server through 802.11b wireless network. And the other subsection is the display system.

- Start up the location client

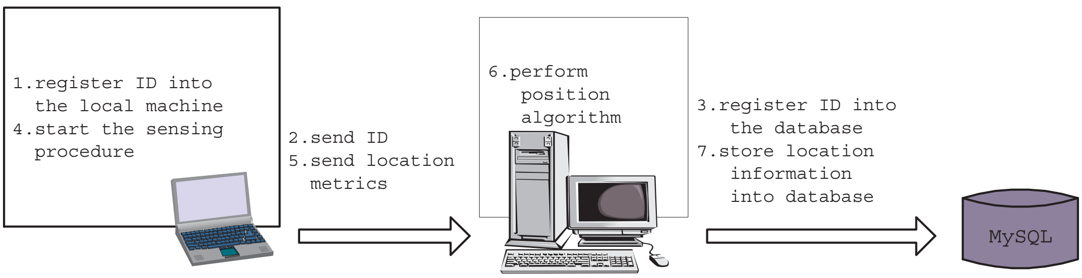

Figure 3.2: The operation flow of starting up the location client.

In Figure 3.2, it shows the initial steps of location client. The details of each steps are shown in the follows.

1. The user registers his ID into the local machine, and then the local machine stores the user's ID locally.
2. The local machine will send the user's ID to the location server.
3. The server will store the user's ID into the database.
4. The user can start the sensing procedure after he has registered successfully.
5. The procedure will produce the location metrics and send them to server. The procedure will collect the signals of several APs if the mobile terminal (MT) is in indoor environment. If the MT stays in outdoor environment, the procedure will read the geolocation information from the GPS receiver.
6. The location server will perform the positioning algorithm according to the received location metrics. And then it will determine the user's position.
7. The location server will store the user's location information into the database.

- Display system

  In Figure 3.3, it shows the steps of displaying the location information to user. The details of each steps are described in the follows.

  1. The user has to login his ID in the display system. Then the system will enter the user display mode or monitor display mode according to user's priority.

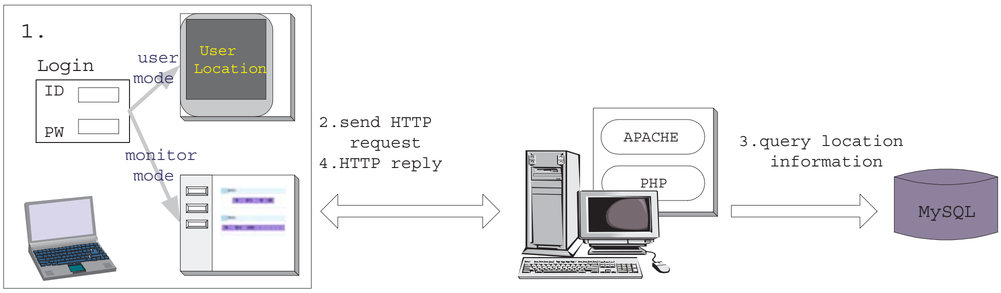

Figure 3.3: The operation flow of display system.

2. The local machine sends the HTTP request to the web server which is built with the location server.

3. The server queries the location information of the user from database.

4. The web server sends the HTTP reply back to the local machine.

3.1.3 Location Client

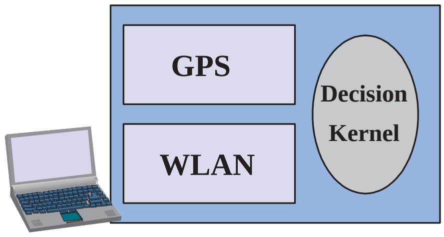

Figure 3.4: Location Client.

In Figure 3.4, the location client is built in the Window XP platform and constructed by C language with Windows DDK. The function of location client is to sense the environment characteristic and to produce the location metrics. The location metrics means that if the mobile terminal is in the building, the metrics will be a collection of the signals of APs and if it is in outdoor environment, the metrics will be the position information of GPS. Thus, there are GPS and WLAN modules in location client. In addition, the location client must have a decision kernel to judge that he is in outdoor or in indoor environment and send suitable location metrics, GPS or WLAN, to the location server. Furthermore, the location client has an important job to perform the handoff of network according to its handoff decision model.

3.1.4 Location Server

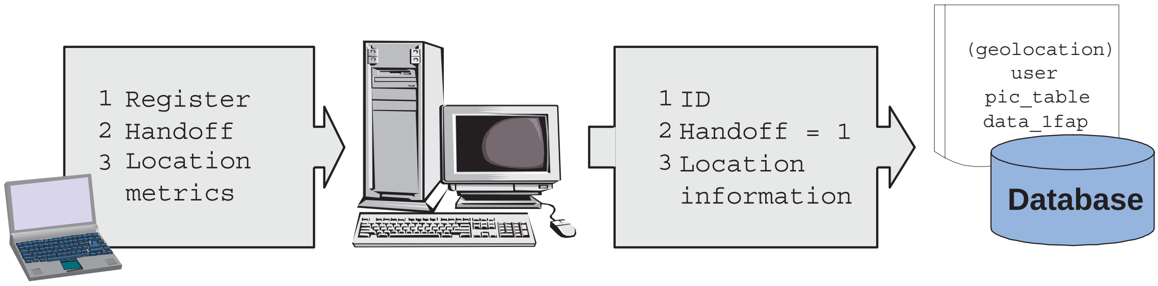

Figure 3.5: Location Server.

The platform of location server use the operating system of Red Hat 9.0 and it is constructed by Java language. The operation flow of location server is shown in Figure 3.5. It performs positioning algorithm with location metrics, determines the position of mobile terminal and stores the location information into the database. Besides, the location server has to deal with the register messages from user and record the user's ID into database. Finally, if the location server gets handoff messages from user, it has to update user's indoor or outdoor status in database. According to the received location metrics, the positioning algorithm will perform suitable steps. If the location metrics contains the APs' information, the server will execute positioning algorithm with fingerprinting method. If the location metrics contains the location information which is produced from GPS receiver, the server will simply pick up the position information from the metrics.

3.1.5 Display System

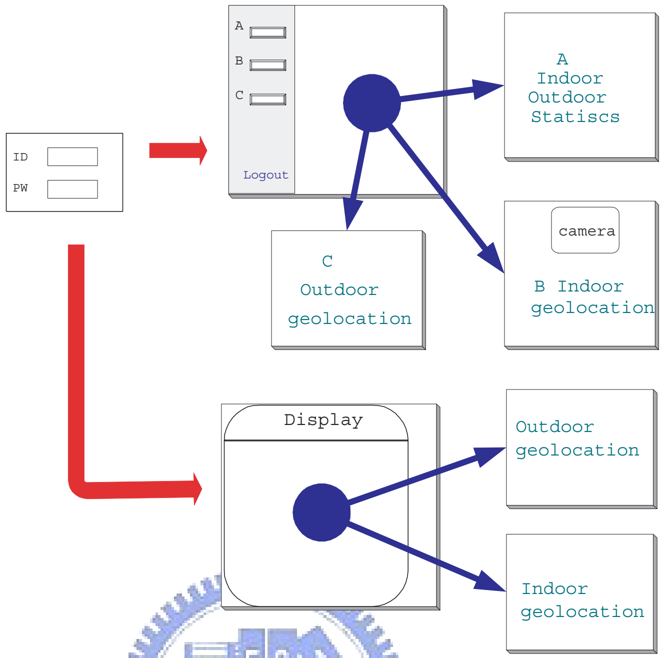

Figure 3.6: Display System.

The web display is shown in Figure 3.6. The system contains two modules, PHP and JavaScript modules. The PHP module works in the server and the JavaScript works in the client. Both of them cooperates to perform the display system which shows the user's estimated position on the browser in the client-server architecture. Users have different priority to use the system. If user's priority is low, he just can use the display in user mode which will track the user's actual position and show the appreciate location map. If user's priority is high, he can choose user mode or monitor mode. In the monitor mode, there is a statistic page which shows the information of all users in the system and the location map of indoor or outdoor environment.

3.2 Implementation

3.2.1 Positioning Algorithm

In indoor geolocation system, our positioning algorithm is based on the fingerprinting algorithm. About the experimental results, the estimated error of fingerprinting algorithm will increase while the signal patterns are similar.

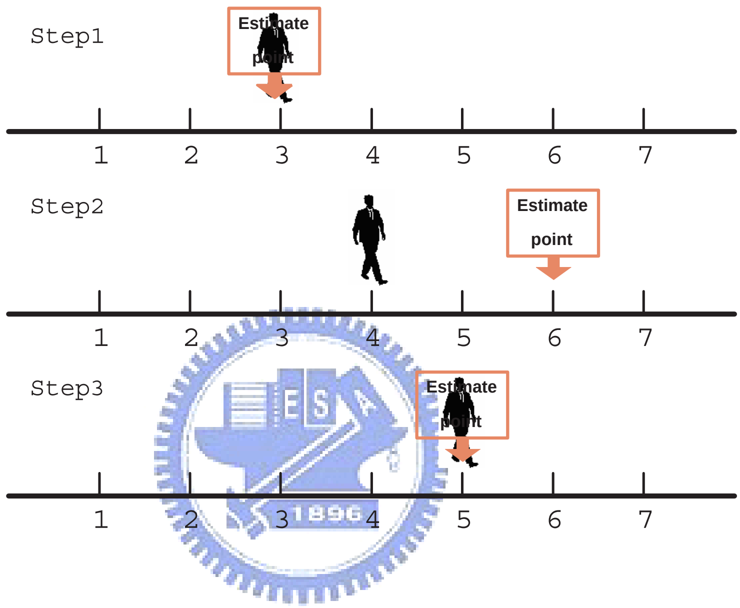

Figure 3.7: The estimation error.

Take the Figure 3.7 for example, the user walked along the path of point 3, 4 and 5 in turn. Because the signal characteristics of point 4 may be similar to point 6, the estimated point in step 2 will jump to point 6 from point 3. Then in step 3, the estimated point and the actual point are both in point 5. From step 1 to step 3, the estimated point will jump up and down. Such situation make the geolocation system unstable. Thus we propose two methods to avoid the unstable situation: fingerprinting with limited step and fingerprinting with tracking.

1. Fingerprinting with limited step (FWLS)

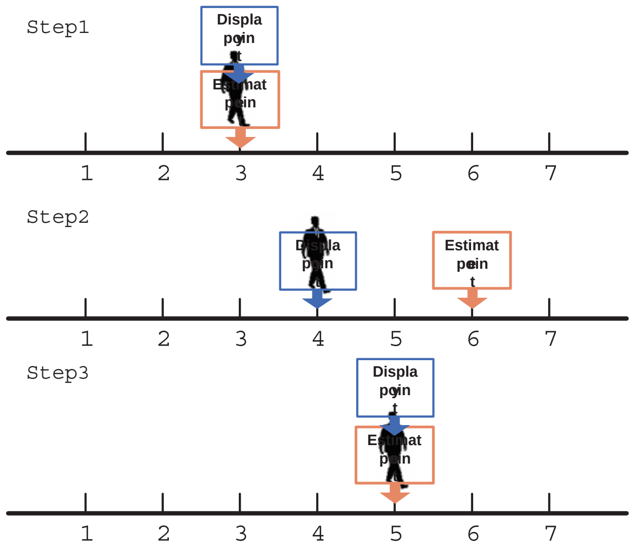

Figure 3.8: Fingerprinting with limited step.

In order to avoid the unstable situation, the difference of two adjacent steps is limited by k steps. In Figure 3.8, we let $k = 1$ and user's track is stable. If the estimated point in step 2 locates on point 6, the display point will be limited by one step (i.e. the display point is in point 4). Although FWLS can solve the unstable situation with smaller k, it cause another two problems. The first problem is that smaller k will cause the positioning delay when user moves quickly. The second problem is that the unstable situation can not be solved with larger k.

2. Fingerprinting with tracking (FWT)

According to the previous track of user, this method adjusts variety limited step. As shown in Figure 3.9, the step 1 and 2 are the same of FWLS but there is a background program to record the user's tracks. If the track is simple forwarding, the display range of estimated point will be two points

(i.e. $k = 2$). Thus the display point will locate on the point which the user will move on in next time. The FWT will keep the value of k to be 2 until user changes his forwarding trend. User's location tracking trend can be determine by his past estimated points. In simple forwarding, all of user's past estimated points are increase or all of them are decrease. Comparing the current and previous estimated points, user's location tracking trend can be determined. For example, when user walks forward in indoor environment for a period of time and then turns around to walk to the starting point, the order of user's estimated points will not be increase or decrease. According to this checking mechanism, we will reduce the value of k to be 1, 0, or -1. The minus means that user walks in reverse direction and the value of k to be zero means that the estimated point will be frozen. So this variety limited step that is controlled by k can solve the unstable situation and the positioning delay.

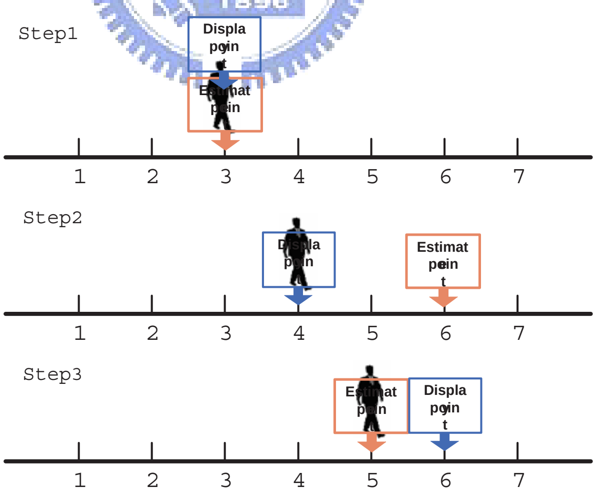

Figure 3.9: Fingerprinting with tracking.

3.2.2 Handoff Model

For providing a seamless location handoff, we propose a handoff model to perform the handoff of display system and the handoff of communication network for the geolocation system. The function of handoff model is that mobile terminal (MT) can transfer the geolocation system successfully as user's location changes from indoor to outdoor or vice versa. The MT has to cooperate with location client, server and web display.

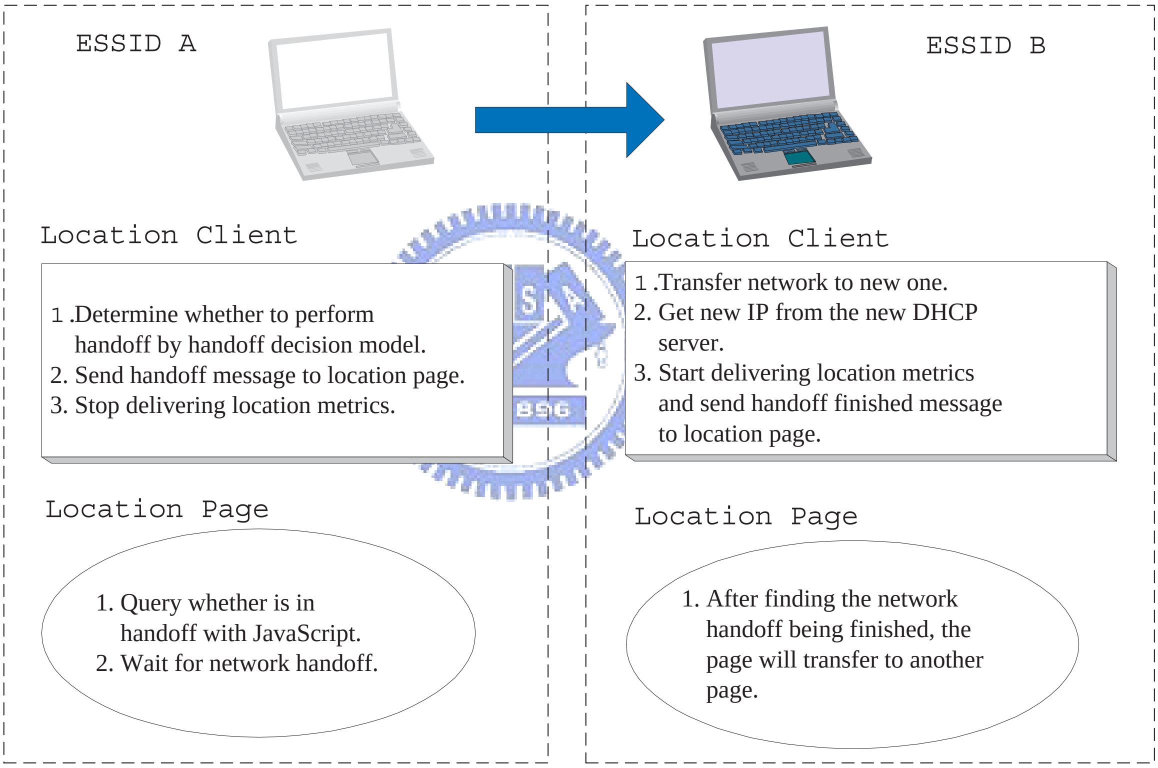

Figure 3.10: The steps for handoff model.

In Figure 3.10, it shows the handoff steps in MT. Before performing handoff, the location client (LC) and the location page (LP) should do the following tasks.

1. Location Client (LC):

The LC must determine whether it should perform handoff by the handoff decision model when it moves from indoor to outdoor or vice versa. If the LC active the handoff mechanism, it has to send handoff message to the LP and stop delivering location metrics. Then the LC just switches its network from one to another and request new IP address from the DHCP server. After the LC gets the new IP and connects to the new network, it begins to send location metrics. At the same time, the LC will send handoff finished message to LP. We know that the indoor location metrics and outdoor location metrics are different because the former contains the APs' signal strength and the latter contains the information of longitude and latitude.

2. Location Page (LP):

   When the LP gets the handoff message from the LC, it will stop to send HTTP request to server and wait for the notification of LC. After the LC finishes the network handoff, it will send the message of handoff finished to the LP. Then the LP will refresh the display page to show the user's new location.

During the handoff performance, the location server records the handoff status and modifies user's location information in database. When the LP queries to the location server about location information, it can get the correct location information responded from the location server.

Finally, we present the handoff decision model more detail. This model is very important for performing handoff. If the model execute incorrectly, it will cause our system to collect misleading location information. Hence, developing a suitable and correct handoff decision model should be carefully designed.

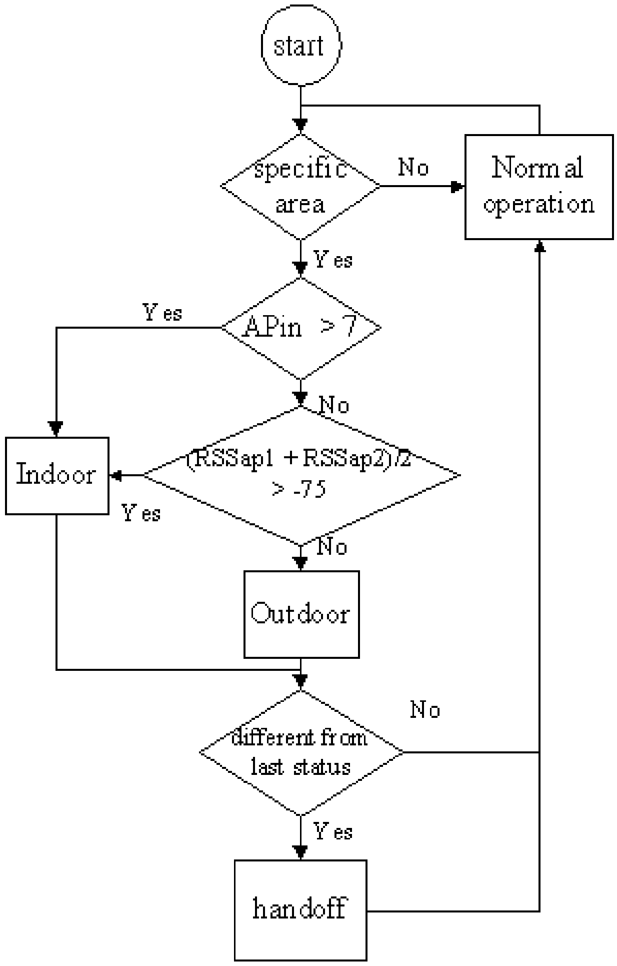

Figure 3.11: The handoff decision model.

The flow chat of handoff decision model is shown in Figure 3.11. When the MT enters a specific area, like around of building gates, the LC will start up the decision model to determine the status of the MT which is in indoor or outdoor. In the following, there are two possible requirements to determine that the MT is in indoor environment.

1. The number of APs are greater than seven.

   In the indoor environment that we simulated, the numbers of APs are usually larger than seven in the specific areas.

2. The mean of the greatest two APs' signal strengths is greater than 75 minus.

If one of the conditions is true, the handoff decision model enters the indoor module and triggers the fingerprinting algorithm for indoor geolocation. Otherwise, it enters the outdoor module and triggers the GPS for outdoor geolocation. After determining the status of MT, we will check the current status with the previous status. If they are different, the MT should perform location handoff.

Chapter 4

Performance Analysis

In this chapter, we will introduce our experimental testbed, environment and results. First, we list the software and hardware components of the system in Table 4.1 and show our measurement environment. Then, we will introduce what we want to measure about the system performance. Finally, the experimental results will be shown and analyzed.

4.1 Experiment Testbed

4.1.1 Client Part

The requirement of Client Part can be discussed in both hardware and software. In hardware, it needs a GPS receiver to estimate the absolute position (latitude, longitude and altitude) and a WLAN PC card to connect with the wireless network and to gather the APs' signals for producing the location metrics. Both of GPS receiver and WLAN PC card are connected to the MT (IBM T30 notebook) which can make data fusion, send the location metrics to server and display the results to users on the web. In software, it contains the operation system of Windows XP SP1 and the Windows DDK which is a device driver kits for Windows XP SP1. Windows DDK can help us to control the WLAN PC card. Besides we

	Software	Hardware
Client part	1.Windows XP SP1 2.windows DDK 3.Web browser 4.JavaScript	1.IBM T30 notebook 2.GARMIN eTrex Summit GPS receiver 3.BUFFALO WLI-PCM-L11GP WLAN card
Server part	1.Red Hat 9.0 2.APACHE 1.3.29 3.PHP 4.3.6 4.MySQL 5.0.0 5.Java	1.Pentium III 800MHz desktop computer

Table 4.1: The system specification.

need a web browser to display user's location information and a JavaScript that is built in the HTML to monitor the client whether it connects to the network.

4.1.2 Server Part

The location server is a Pentium III 800 MHz desktop computer. The software requirements of Server Part are Linux Red Hat 9.0 operation system, APACHE web server which includes PHP module and MySQL database, and a location server program which is constructed by java language . The web server will cooperate with PHP server page to reply the HTTP requests for the mobile terminal, and the PHP server page will query the MySQL database which keeps the location fingerprinting data and user's location information. The location server will perform the positioning algorithm and access the database.

4.2 Experimental Environment

Our experimental environment can be divided into two types, indoor and outdoor. The first floor of Engineering Building 3 in NCTU is our experimental indoor environment. The square between the library and Engineering Building 3 in NCTU is the outdoor environment. If the user is in outdoor environment, he can see his location with outdoor location map such as shown in Figure 4.1. If the user is in indoor environment, he can see his location with indoor location map such as shown in Figure 4.2.

According to this experimental environment, we want to measure the system performance in three ways. First, we want to analyze the accuracy of indoor positioning algorithm to show the feasibility of fingerprinting positioning algorithm. Second, we analyze the performance of our handoff architecture. Finally, we show the error ratio of our handoff decision model.

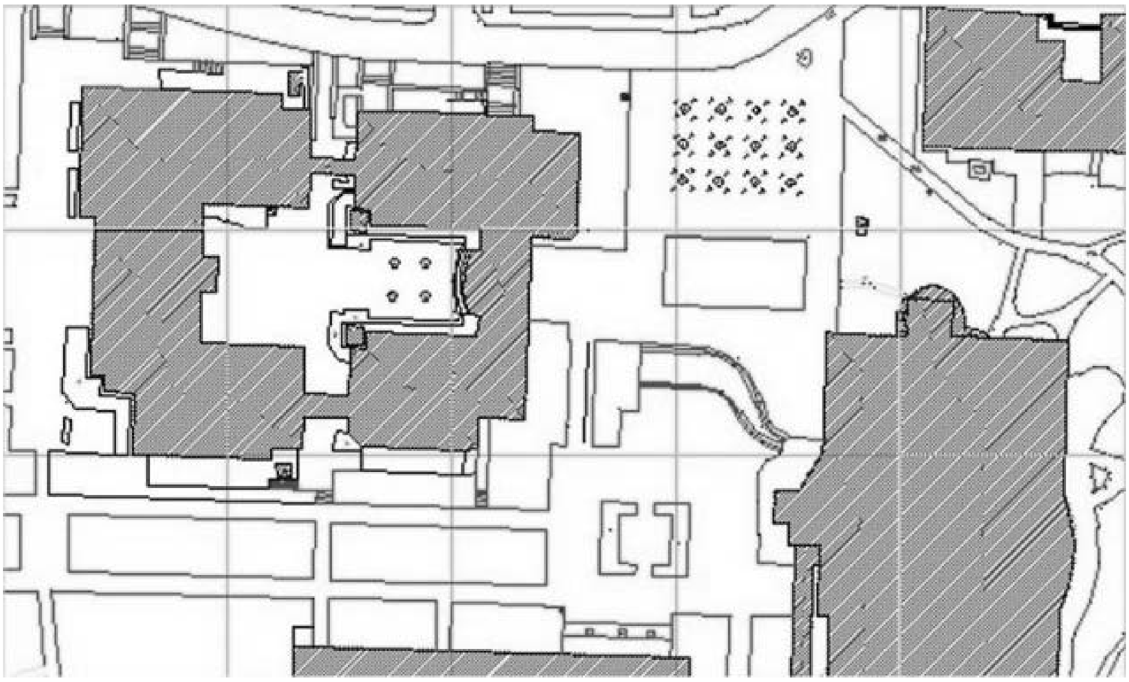

Figure 4.1: The map of square in NCTU.

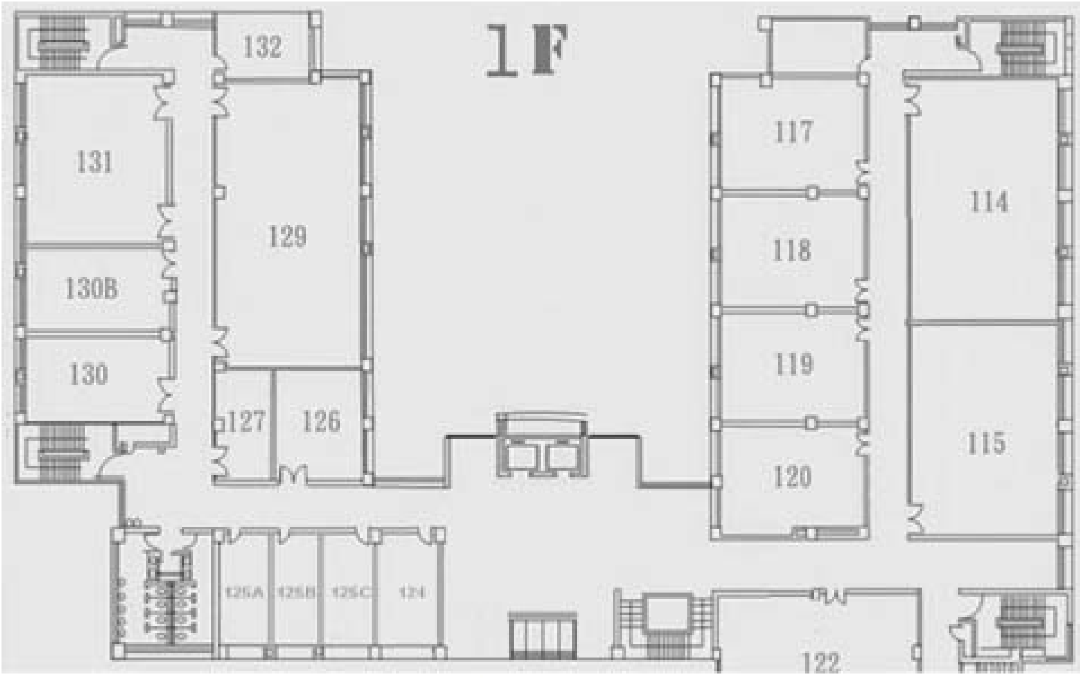

Figure 4.2: The 1F plan of Engineering Building 3 in NCTU.

4.2.1 Positioning Algorithm Analysis

In chapter 3, we propose two methods (FWLS and FWT) to improve the fingerprinting positioning algorithm in the areas with similar signal characteristics or unstable signal. As shown in Figure 4.3, we want to analyze the accuracy of FWLS and FWT. We assume that the MT is moving on the way in the first floor of Engineering Building 3. The error distance that is the absolute difference between the actual point and the estimated point will be compared with FWLS and FWT.

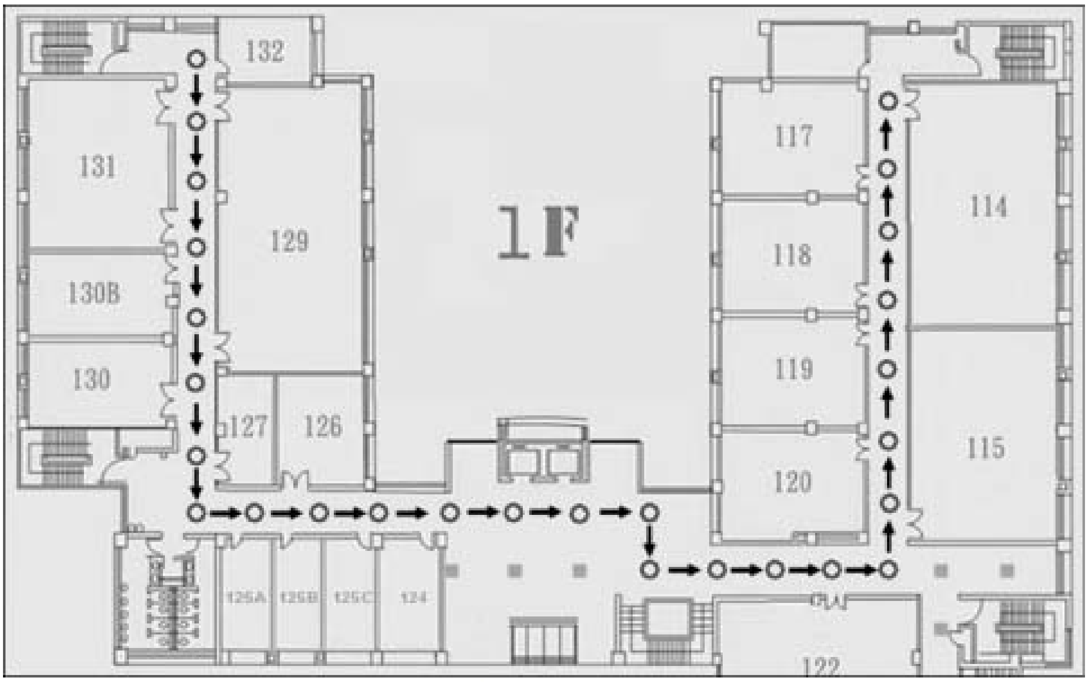

Figure 4.3: The experiment point in 1F plan.

4.2.2 Handoff Model Analysis

When the geolocation of MT changes, the handoff model should perform the handoff mechanism. So we want to know the correctness of handoff model from indoor to outdoor environment or from outdoor to indoor environment. We will also measure the handoff time to realize its bottleneck. The experiment of handoff model is that the MT get the gate of Engineering Building 3 in and out for fifty times. The handoff time will be estimated and the correctness of handoff will be counted.

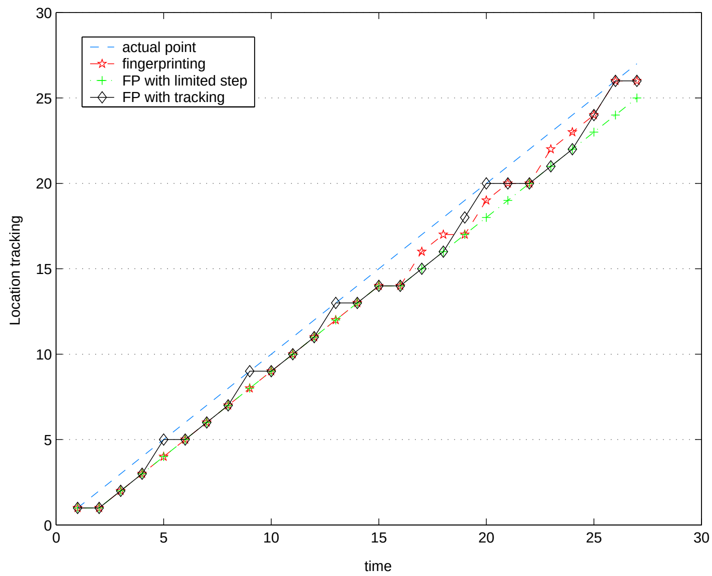

Figure 4.4: The location tracking of positioning algorithms with stable signal strength.

4.3 Experiment Results

4.3.1 Positioning Algorithm Analysis

In order to show the effect of RSS, we evaluate the positioning algorithm in stable and unstable signal strength. First, we consider the stable signal strength for positioning algorithm. In Figure 4.4, the actual point is the way which the MT moving on as time goes on. All actual points are numbered sequentially from point 1 to point 27. And the others are the estimated points of fingerprinting algorithm, FWLS and FWT. The Figure 4.5 shows the error of estimated point. We can see that the method of FWT is better than others.

Similarly, we show the estimated point with fingerprinting, FWLS and FWT method in unstable signal strength. As shown in Figure 4.6 and Figure 4.7, it is obviously that the error of FWT is also less than others. Because of the unstable signal strength, the error of fingerprinting method becomes worse. The method

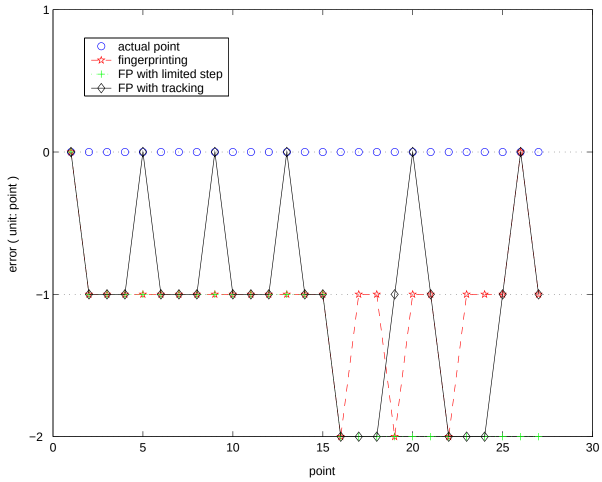

Figure 4.5: The error of estimated points from actual points with stable signal strength.

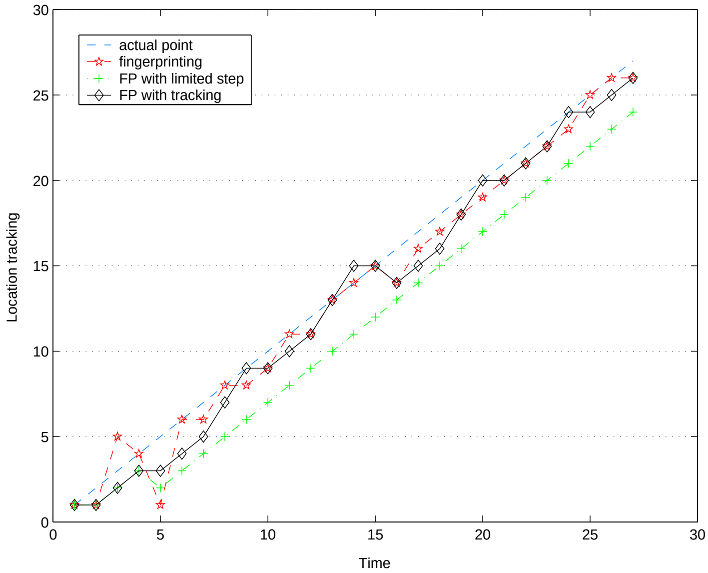

Figure 4.6: The location tracking of positioning algorithms with unstable signal strength.

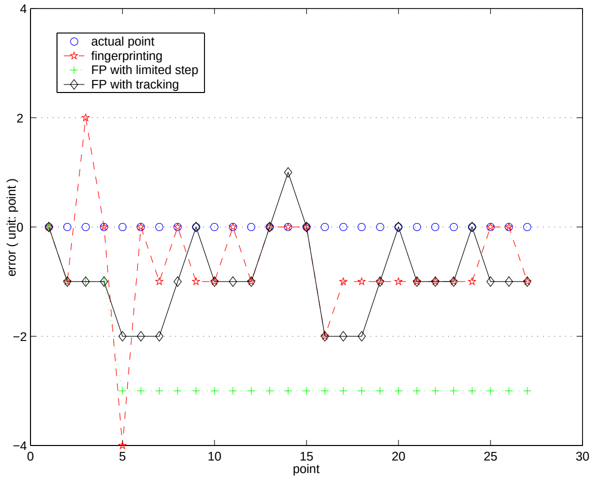

Figure 4.7: The error of estimated points from actual points with unstable signal strength.

of FWLS and FWT that we proposed are based on fingerprinting method and the error of them is less than it. Hence, the fingerprinting method can be improved by FWLS and FWT. According to these simulation results, the stability and correctness of FWT is better than fingerprinting method.

4.3.2 Handoff Delay Time

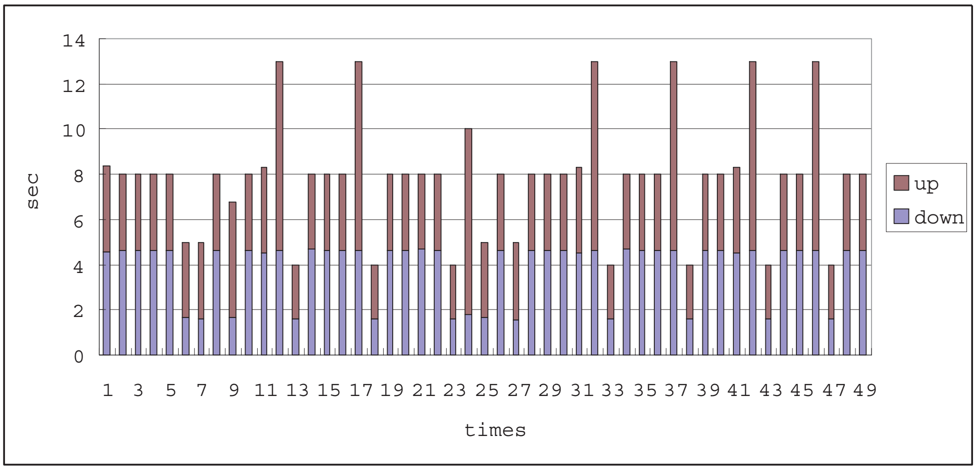

Figure 4.8: The handoff delay time from indoor to outdoor.

	Total	Down	Up
average	7.833	3.827	4.006
stdev	2.515	1.344	1.846
Max	12.999	4.697	8.362
Min	3.976	1.522	2.383

Table 4.2: The handoff delay time from indoor to outdoor. (unit:ms)

In Figure 4.8, it shows the handoff delay time when the mobile terminal moves from indoor to outdoor. The down part in histogram means the time of suspending the previous that MT connected network and the up one means the time of starting up the new network. As shown in Table 4.2, the mean of total handoff delay time is 7.833 seconds, the time of suspending the old network is 3.83 seconds and the time of starting up the new network is 4 seconds. We can see that the time of start-up is longer than shutdown, but the start-up will take a long time in some case. Besides, the range of delay time, from 12.999 seconds to 3.976 seconds, is large and the standard deviation is also large. This situation may be caused by the unstable signal outside the building. If the situation of signal is stable, we can perform the handoff quickly. Otherwise, the delay time will last up 8 seconds. The bottleneck of handoff delay time is the start-up time of the GPS receiver. Usually, the GPS start-up delay time is longer than the delay time of starting up the network.

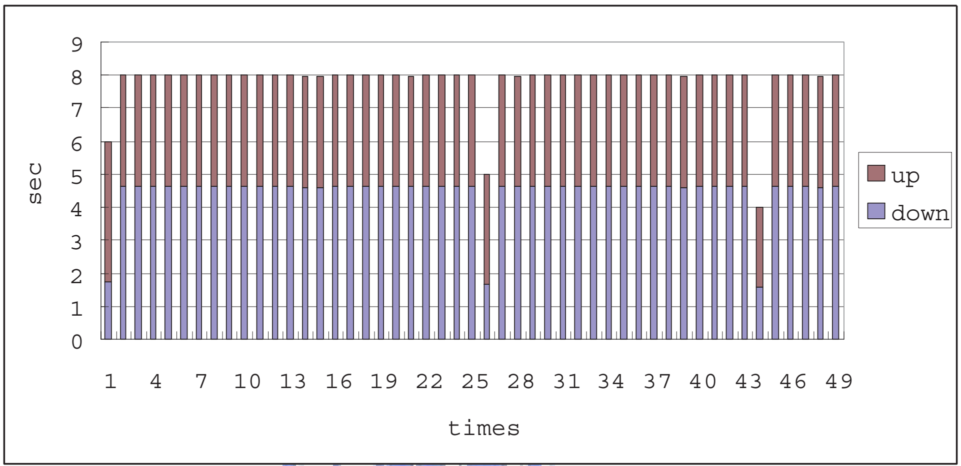

Figure 4.9: The handoff delay time from outdoor to indoor.

	Total	Down	Up
average	7.810	4.455	3.356
stdev	0.754	0.718	0.190
Max	8.002	4.657	4.256
Min	3.996	1.602	2.394

Table 4.3: The handoff delay time from outdoor to indoor. (unit:ms)

Similarly, we show the handoff delay time when MT moves from outdoor to indoor. As Shown in Figure 4.9 and Table 4.3, the handoff delay time is almost the same. Maybe the indoor signal is more stable because of less interfere.

4.3.3 Handoff Error Ratio

We present the handoff error ratio to show the correctness of handoff decision model. In Table 4.4, it shows that all of the handoff decision are correct when the MT goes in and out for fifty times. So we can conclude that the correct ratio in the application can reach 100 percent when the system performs handoff mechanism.

	Wrong	Correct
In-Out	0%	100%
Out-In	0%	100%

Table 4.4: The validity of handoff decision model.

Chapter 5

Conclusion and Future Work

In the thesis, we propose an architecture that integrates the indoor and outdoor geolocation systems. For implementation, the fingerprinting method based on WLAN is used in indoor geolocation and the GPS is used in outdoor geolocation. We proposed FWLS and FWT method to improve the fingerprinting method. The method of FWT is stable than fingerprinting method in stable and unstable signal strength. We also provide a seamless location handoff mechanism. Mobile users can switch their geolocation systems (indoor or outdoor geolocation) from one to other transparently. We present a display system to monitor users' location. If user's priority is high, then he can enter the monitor mode of display system to monitor all users in the system. If user's priority is low, then he can only enter the user mode of display system to watch his own location.

Our integrated system can switch geolocation system between indoor with fingerprinting method and outdoor with GPS. There are many geolocation systems to be invented in recent year. One geolocation system may suitable for a specific network environment but does not suitable for overall environment. One possible solution is to develop a geoloction system that can integrate all of them. In our future work, we will extend our system to combine all of the possible geoloation system to perform a universal geolocation system that can estimate user's location in any environment. Other possible future works are listing in the following:

1. reducing the delay time of location handoff,

2. improving the accuracy of geolocation system,

3. improving the robustness of geolocation system,

4. extending the function of location handoff decision model.

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