An Indoor Positioning System (IPS) using Grid Model

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Abstract: To date many positioning systems are available to determine or track a user's location; three main categories include Global Positioning System (GPS), wide area location system and indoor positioning system. GPS has its limitation (poor signals) in indoor or urban uses, while wide-area location systems are cellular networks dependent. For indoor positioning system many approaches like infrared sensing, radio frequency, ultrasonic etc. are proposed; each of these methods has their own advantages and disadvantages. Considering cost-effectiveness, speed and accuracy a recent interest is growing on using wireless technology. A Wireless Local-Area Network (WLAN) based positioning system has some distinct advantages like low-cost and wider area coverage. This researrch propose a system to determine the location of a mobile terminal or a handheld PDA in high speed, low-cost wireless networks by using the wireless communications infrastructure. The experimental set up used an indoor wireless facility of an auditorium, where signals from three Access Points (APs) were recorded to train a position determination model to calculate and map a position. Grid model was applied and compare the resulted position of a client. A handheld PDA equipped with application software was the client device. The accuracy assessment has been performed to identify the distance errors and the average distance error was found lowest for the grid model. The results of the experiments reveal that the accuracy of 0.05 m can be achieved.

Key words: Indoor positioning, wireless network, PDA, grid

INTRODUCTION

There are mainly three categories of geographic positioning systems to determine or track a user's location, which have been designed and proposed over the years. These systems are mainly three categories: Global Positioning System, Wide-area Location System and Indoor Positioning System. Global Positioning System (GPS) receives signals from multiple satellites to determine the physical location of a user. The limitation for this system is that it is inefficient for indoor use; alongside in urban areas it often possesses difficulties in receiving signals where high buildings shield the satellite signals[5]. Wide-area location systems are mainly based on cellular networks that involve measuring the signal strength, the angle of signal arrival and/or the time difference of signal arrival. The positioning information in wide-area location systems is highly limited by the cell size or cell coverage[11]. Several approaches have been proposed for indoor location sensing or indoor positioning system such as infrared sensing, radio frequency, ultrasonic and scene capture analysis[12]. There are also a few technologies to use within indoor areas, such as GPS psudolite, ultrasonic and cellular-based systems, which need considerable supporting devices and facilities. Each of these methods has their own advantages and disadvantages. Some are expensive to implement, while others are not very accurate. The Active Badge is the first location system[14]. Radar, well-known approach, is an RF system for locating and tracking users within large structures[1,2]. There are two approached are presented, one is an empirical method and a signal propagation model. This procedure determines user location by combining signal strength measurements with signal propagation models. RF signal strength within building is affected by multipath propagation effects and absorption, resulting in non-linear behavior. The results show that the empirical method is superior in terms of accuracy with median resolution in the range of about 3 m and the signal propagation model has 4.3 m accuracy (median), but it makes deployment easier.

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The applications of indoor positioning are many, for instance, location-finding, indoor robots, inventory tracking, security, etc. Various methods do exist for indoor positioning; however, the concern rises if the indoor positioning is addressing the issue of flexibility, cost and accuracy. While the demand for location-detection in indoor application is growing, so far there is no commonly agreed way to determine accurate position in indoors. In the recent past years, many researches have been conducted on indoor positioning system using mobile devices[10,7]. The earliest one, the Active Badge system, has used the infra-red network. A Radio Frequency or RF and an ultrasound are used in Cricket location-support system[9]. Most of these systems are based on an analysis of receiver signal-to-noise ratio and determine user location by combining signal strength measurements with signal propagation models[8,6]. For RF-based techniques, additional hardware is not required for user location determination, which uses only the possible existing wireless data network. Neural Network is one of the methods while the flexible modeling and learning capabilities are not required the detailed knowledge of the access point locations and of the building characteristics[3,4]. Using mobile computing devices and wireless LANs to determine the location of a device is becoming a popular application, particularly the WLAN that are based on the IEEE 802.11b standard. A wireless local-area network (WLAN) based positioning system has distinct advantages over all other systems. At first, it is an economic solution because in many areas usually the WLAN network already exists as part of the communication infrastructure. Secondly, the WLAN covers large area compared with other types of indoor positioning systems. With the availability of IEEE 802.11b standard and relatively low cost equipment, recently the use of WLAN positioning system for indoor applications has gained lot of attention[14]. It is becoming increasingly popular because it does not require additional hardware for user location determination. To estimate user location the system uses an underlying wireless data network, such as the IEEE 802.11b based wireless network. Therefore, using notebook computers, Personal Digital Assistants (PDA), or other mobile devices equipped with WLAN facilities the position system can be implemented on application software. To build location aware hand-held devices could be used in any mislead places or huge places such as museums, conference hall, airports and department stores. Guest or visitors, who walk to the room and hold the location device, will be able to locate their own information and guide depending on the existing generated data. The system will use the signal strength of WLAN infrastructure transmission from/to WLAN access points to determine the position of the user equipped with mobile computing devices such as PDA or notebook computer or so on[14].

This research introduces our proposed system to determine the location of a mobile terminal in high speed, low-cost wireless networks by using the wireless communications network infrastructure. It has described the experimental set up and system along with collection of data points and positioning models. Finally, an analysis has been made on accuracy and distance errors resulted from grid models. The grid model is a probabilistic model, based on the calibration of a grid with three interpolation methods, kriging, spline and inverse distance weighted interpolation.

SYSTEM DESCRIPTION AND EXPERIMENTAL SET UP

Generally, the WLAN-based positioning system relies on collection of WLAN signals to train the signal-distribution map, thus applying a position-determination model that can be used to determine the location of mobile devices[6]. In any WLAN-based indoor positioning technology, the signal distribution of access points is collected to train a position-determination model. The training phase is followed by the working phase, during which the mobile device observes the WLAN signals and applies the position-determination model to calculate a position. Many position determination models can be applied to locate user's position. In order to address the accuracy issue several.

The experimental site is the Conference Center (AITCC) in Asian Institute of Technology. The experiment is conducted in its auditorium room, which is situated at the ground floor of AITCC as shown in Fig. 1. The dimension of the room is 20×32 m, covering an area 640 m^2 in the auditorium. Three access points were installed in the auditorium, the locations are shown in the Fig. 1. The origin of the coordinate system (0, 0, 0) was placed at the left bottom corner of the map. The (x, y, z) coordinate of the access points are as follow: AC_1 = (12, 34, 2.5), AC_2 = (32, 34, 2.5) and AC_3 = (8, 40, 2.5).

The system was organized by client-server, access points and PDA as client devices. The schematic steps of this research is presented in Fig. 2. The data collection was done by BenQ PDA Smartphone, which was running on Windows CE. The PDA was equipped with wireless connectivity as client devices. Both the signal strength data and position were added into the database, which was later provided to the client for
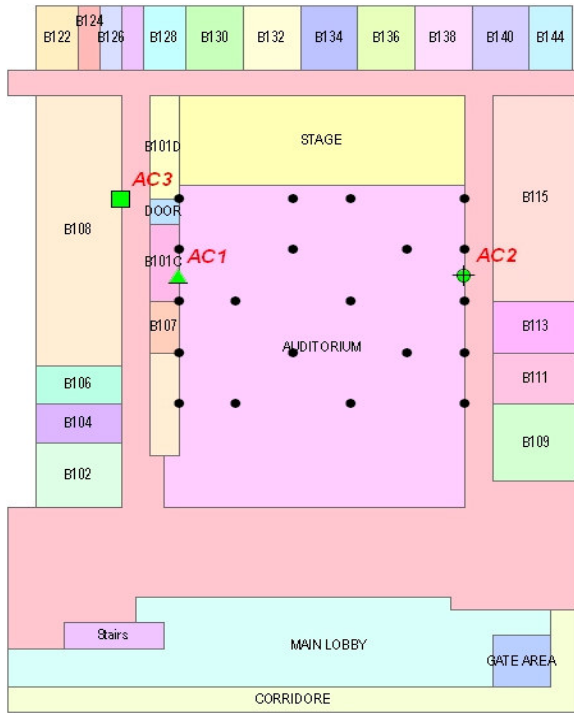
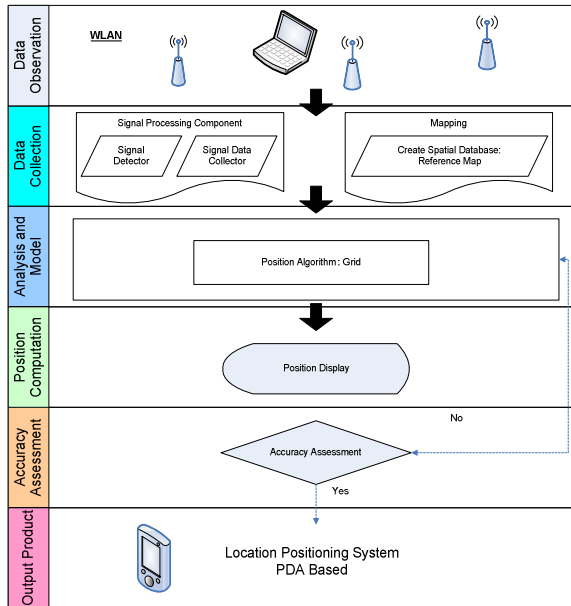Fig. 1: The distribution of the sample points and access points

Fig. 2: WLAN based Indoor Positioning System (IPS)

analysis. It was necessary to profile location determination data by access points and PDA to raise accuracy. The method utilizes the profile data as the

database for correcting the signal strength variation that is very large according to determination environments.

INFRASTRUCTURE NETWORK

In this research, they are three access points and a mobile device (i.e., PDA) in a WLAN environment, which is based on Wi-Fi. access points and PDA connect with the Wi-Fi (IEEE 802.11b standard). The PDA receives radio frequency signals from these three access points. The RSSI (Received Signal Strength Indication) value is used to determine the location. The collected signal strength is recorded in units of negative decibel-meters (-dBm). The cycle frequency was set to one second. Data collection was conducted for about 100 second at a particular spatial point and 30 such different sample points were collected.

APPLICATION SOFTWARE ARCHITECTURE

The OpenNav is client interface software, which is designed for the PDA used in this research. OpenNav has been developed using Microsoft Visual Basic.Net 2003. In this experiment, the PDA is used as the client. All the functions, required for the computation and visualization, are developed by Visual Basic.net language.

METHODOLGY: DATA CAPTURE

A mobile device, PDA in this case, captures location determination data (signal strength in -dBm) and sends it to a PDA. The PDA calculates the distance between access point (AP) and PDA and determines the location of PDA with the given methods. The mobile device gathers necessary data on the network structure of Windows CE. The location determination data includes signals strength, connected BSS ID, signal receivable BSSID list and MAC address. WLAN Native SDK can also be used, which is supplied by WLAN or mobile device manufacturers. If SDK is not available, data can be achieved by accessing network drivers directly using OID that is supported over NDIS 5.

GRID MODEL

The grid model is the probabilistic model, using an experimental approach only based on the calibration of a grid and is opposite of a method searching a functional relationship between signal strength and distance to the access point. A grid is a spatial data

structure that defines space as an array of cells of equal size arranged in rows and columns. In fact, experimental measures of signal strength do not show simple relationship between signal strength and distance to the access point and grid model seems to be the only way to ensure good results.

PRINCIPLE

The principle of this method is to create, for each access point W_i, a grid G_i of pixels covering the domain and giving, for each pixel, the mean value of the signal strength received from the W_i access point. For each pixel, we will also keep the standard deviation, while the signal strength varies in time and is not constant. The position of a point P is estimated selecting, in each grid G_i, the pixels that correspond to the value A_i measured at the point P and then selecting the intersection of these pixels. If the diminution of the signal strength is near a radial or harmonic function (theorical model without any external interference), three no aligned emitters are able to localize any point in the domain. But the real function giving the signal strength from the distance is unknown: more emitters can improve the precision.

The grid model is statistic: for example, for each access point i, the point P as 95% probability to be in the pixels j that correspond to the $C_j-2*e_j<A_i<C_j+2*e_j$ condition (A_i is the value measured at the point P, C_j is the mean signal strength value at the pixel j and e_j is the standard deviation at the pixel j). The values measured at the pixel j are supposed to follow a normal distribution. More generally, we consider the pixels given by the condition:

$$C_i - a \times e_i < A_i < c_i + a \times e_i \qquad (1)$$

where, a is a positive coefficient as small as possible. More small a, less pixels will follow the condition (1), smaller will be the probability for the point to be in the selected pixels and higher will be the precision of the result. If, for an access point i, no pixel correspond to the condition (1), it is necessary to increase the value of a. If the intersection of the pixels selected in the different grids is empty, it is also necessary to increase the value of a for each grid, but without to exceed two standard deviations (a = 2). If, for a = 2, the intersection is empty, the measure at point P must be repeated. Normally, proceed in reverse way, to find the smallest value of a giving a non empty intersection for the pixels corresponding to the condition (1). The final result will be the centroid of the selected pixels. Figure 3 shows the selected pixels from three access points.
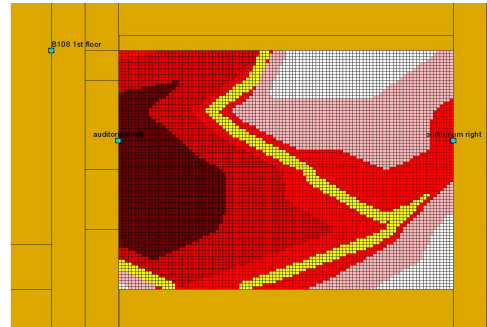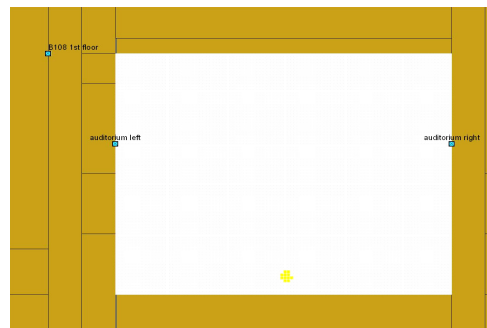

(a) SS from AC_1 = -45±0.5 SD
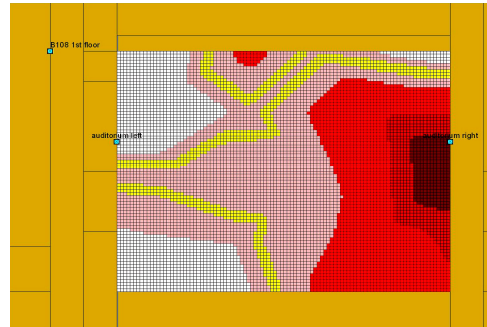
(b) SS from AC_2 = -46±0.5 SD
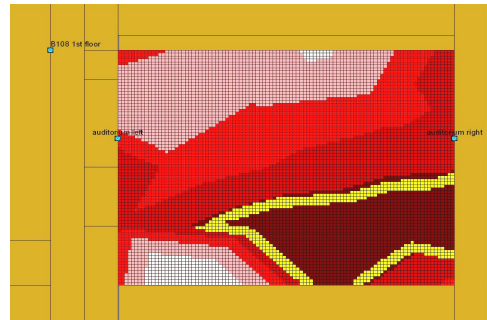
(c) SS from AC_3 = -70±0.5 SD

(d) The selected pixels are the pixels that SS from AC_1 = -45, SS from AC_2 = -46, and SS from AC_3 = -70

Fig. 3: The selected pixels from AC_1 (a), AC_2 (b), AC_3 (b) and the selected pixels from all of three access points (d)

GRID CALIBRATION

The grid pixel width depends of the expected precision for localization. This expected precision determined (from the purpose of the global study), pixel values must be estimated. In general, the number of pixels is very high and it is impossible to measure directly the value of each pixel: proceed by interpolation from measures in some points. For each access point, the signal strength is measured in some points of the domain, uniformly distributed to cover the domain and to allow a good spatial interpolation process. At each point, the number of measures must be enough to be considered as a statistical representative sample of the point value. In a second step, this data are spatially interpolated in order to establish the value of each pixel of the grid (signal strength, standard deviation). The interpolation process is able to give good results, while spatial variations of signal strength, from an access point, are spatially continuous. Several interpolation process can be applied, but a local approach is the most adapted to our case, while signal strength variations depend on local conditions (site and building geometry, walls, furniture, etc.). A barycentric interpolation on neighbors (inverse distance weight) is the most adapted and better than a global kriging method. The cell size or pixel cell is 0.05 m. Calibrating the grid must be done for every access point (minimum three no aligned), obtain as many grids as access points.

The steps of create grid are as the following:

- Obtain sampling values or signal strength values
- Compute an interpolation map using the sampling values with many interpolation methods
- Measure the accuracy of the interpolationed map

INTERPOLATION

Interpolation is a method of constructing new data points from a discrete set of known data points and estimate the values in unsampled locations. Surface interpolation functions create a continuous (or prediction) surface from sampled point values. The continuous surface representation of a raster dataset represents height, concentration, or magnitude-for example, elevation, pollution, or noise. Surface interpolation functions make predictions from sample measurements for all locations in a raster dataset whether or not a measurement has been taken at the location. There is a variety of ways to derive a prediction for each location; each method is referred to as a model. With each model, there are different assumptions made of the data and certain models are more applicable for specific data - for example, one model may account for local variation better than another. Each model produces predictions using different calculations. The mapping and spatial analysis often requires converting the field measurements into continuous space. Therefore the point data sets must be converted to a continuous form using an interpolation method. The errors, however, enter the spatial database long before any interpolation method is applied to the data set. The first type of error is associated with sampling design. The magnitude of a sample, as well as the procedure of obtaining it, depends on the objectives of the sampling process. Increasing the sample size also improves the accuracy of measurements up to a certain point. In spatial analysis the sampling is often performed on a regular grid or on an irregular set of points however, this might not depict the true variation of studied phenomena in the space. There are two categories of interpolation techniques: deterministic and geostatistical. Deterministic interpolation techniques creates surface based on measured points or mathematic formulas.

There are three interpolation methods used to be compare: Kriging, Spline and IDW.

- Kriging is a geostatistical interpolation technique that considers both the distance and the degree of variation between known data points when estimating values in unknown areas. A weighted linear combination of the known sample values around the point is to be estimated. It attempts to minimize the error variance and set the mean of the prediction errors to zero so that there are no over- or under-estimates. Kriging should be applied where best estimates are required, data quality is good and error estimates are essential
- Spline interpolation is a form of interpolation where the interpolant is a special type of piecewise polynomial called a spline. Spline interpolation is preferred over polynomial interpolation because the interpolation error can be made small even when using low degree polynomials for the spline. Spline estimates values using mathematical function that minimizes overall surface curvature. This results in a smooth surface that passes exactly through that input points
- The Inverse Distance Weighted (IDW) interpolation is a barycentric interpolation and one of the most commonly used techniques for interpolation of scatter points when the set of points is dense enough to capture the extent of local surface variation needed for analysis. The

interpolating surface is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases. Inverse Distance Weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The surface being interpolated should be that of a locationally dependent variable. The input can be limited by the number of sample points to be used or by radiuses within which there are points to be used in the calculation of the interpolated points

RESULTS AND ACCURACY ASSESSMENT

The signal strength data as received by PDA receiver at the sample point is not constant but varies for few dB. The variation is caused by several factors such as movement of people and other effects. The data distribution of 30 sample points shows a little difference, quite little overlap of each access point is observed. The grid map from three interpolation methods are given a different result and accuracy of each pixel is consist of signal strength value of the cell size of 0.05-2 m.

ERROR MEASURE

The accuracy of the indoor positioning system is compared with the location of the real position. The test results have been verified by measuring Distance Errors. The Distance Error (DE) is defined as the spatial distance between the original point to which the data belongs and the point which is reported by the program OpenNav. DE is used for measuring the precision. The test location is different from training location that has been recorded as Average Distance Error and accompanied with minimum distance error and maximum distance error are presented in Table 1.

$$DE = \frac{1}{P}\sum_{p=1}^{P}\sqrt{\left(tx_p - ox_p(w)\right)^2 + \left(ty_p - oy_p(w)\right)^2} \qquad (2)$$

where, $ox_p(w)$ and $oy_p(w)$ are the x and y coordinates obtained by the network tx_p and ty_p are the correct target values. P is the number of test or training patterns.

Table 1: The comparison of different interpolation method outputs

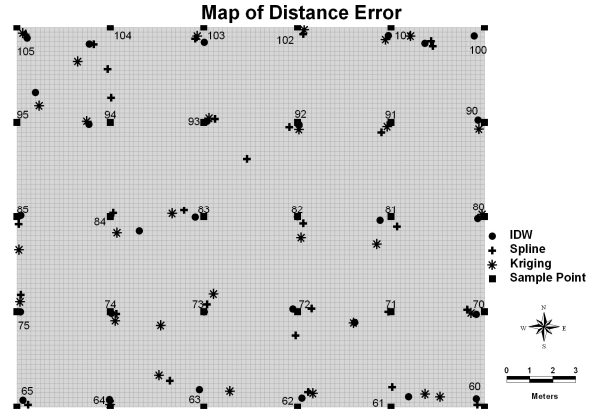| Interpolation Method	ADE (m)	Minimum distance error (m)	Maximum distance error (m)	DE<1 m
Kriging	1.3952	0.1100	9.1444	18
Spline	1.4379	0.1030	10.2652	22
Inverse Distance Weighted (IDW)	0.5723	0.0027	2.6242	25

Fig. 4: Accuracy assessment using signals obtained on three interpolation methods, sample points are plotted against output points obtained from IDW, Spline and Kriging interpolation method, in Asian Institute of Technology Conference Center

The Average Distance Error (ADE) is calculated using the Eq. (3), which is defined as the mean of all the summations of obtained/output distance errors.

$$ADE = \frac{1}{n}\sum_{i=1}^{n}DE_i \qquad (3)$$

The anticipated ADE (the lower is the better) has actually been obtained from IDW interpolation. The resulted ADE from other interpolations are found many fold higher if compared to the IDW. The range of distance errors are also found quite higher for other three interpolation methods and not necessarily have followed a trend of smaller ADE with smaller range. In Table 1, followed by the IDW interpolation output (0.5723 m), the ADE obtained has given a better value than from Kriging (1.3952 m) and Spline interpolation (1.4379 m). From 30 sample points, IDW interpolation method shown 25 points the error are smaller than 1 m., 22 points from Spline and 18 points from Kriging. The distribution of each interpolation methods is shown in Fig. 4.

DISCUSSION

Position determination technology on mobile devices such as PDA, notebook and cellular phones has been increasingly demanding for providing location-based services. While GPS is widely used and serving well in outdoor system, there have been few efficient techniques available for indoor positioning system. Recently there have been many trials on indoor

positioning system with the availability of Wireless Local Area Network (WLAN) which is based on IEEE 802.11b. Many approaches have been proposed by many researchers. In this research, the study was described designing and implementing a position determination system in indoor space. The study concluded that the geographical position of a client can be determined successfully using only three access points and with the small number of sample points. However, the positioning algorithm could give us different result and positing precision, which need to be considered for client devices. It was anticipated to use different methods in order to calculate and compare the position and finally to check the variability of geographical positioning precision. Using several position determination models, we have tested the location a client device (i.e., a PDA) in a WLAN infrastructure. Inverse distance weight, if the distance are small, the results maybe correct. Because the samples points is dense enough to capture the extent of local surface. And it is shown the better result that the other interpolation methods for this study.

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