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3D WLAN Indoor Positioning In Multi-Storey Buildings

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***Abstract* - Many scenarios for indoor positioning require position estimation not only in two dimensions but in the third dimension as well. This paper presents the expansion of two two-dimensional WLAN fingerprinting localization algorithms based on received signal strength indication (RSSI) to the third dimension. The third dimension is regarded discretely as the floor level. Both algorithms were evaluated in two different test beds. Evaluation results will be presented and discussed.**

***Keywords* – 3D-Positioning, Isolines, Euclidean Distance, WLAN, Indoor, Localization, RSSI**

I. INTRODUCTION

Positioning techniques are necessary for location based services in indoor environments, e.g. for autonomous robots or for digital museum guides. Different algorithms are used ([1], [4], [8]). By now positioning in wireless networks is mainly used in two-dimensional environments. Using positioning systems based on wireless local area networks (WLAN) in three-dimensional indoor environments needs a reliable estimation of the vertical position. This paper describes an expansion of two-dimensional algorithms by the third dimension for use of WLAN positioning systems in multi-storey buildings. These algorithms were evaluated in two different test beds, a museum building and a university building.

II. RELATED WORK

Ladd et al. ([5]) used a notebook for determining the two-dimensional position by measuring the received signal strength indication (RSSI) of several access points. The algorithm is based on fingerprints and Bayesian inference. Teuber et al. ([9]) again used fingerprinting and the method of minimal Euclidian distance together with fuzzy logic post processing. Their test bed was an empty airport hangar. Accuracy of two-dimensional positioning was 4.47 m using Euclidian distance alone. With Fuzzy logic post processing the accuracy improved to 3 m.

A two-dimensional positioning system for industrial automation with automatic calibration was developed by Ivanov ([4]). This system is able to perform automatic measurement and model calibration so as to no manual measurements are necessary. The Ekahau Positioning Engine (EPE) is a software commercially available using RSSI based WLAN indoor positioning. According to the manufacturer's instructions ([1]) the engine combines RSSI pattern recognition together with an attempt to include the user’s history (boundary conditions like allowed paths and speed). Determination of the current two-dimensional position is possible with an accuracy of 1-5 m depending on the environment. The system is able to determine the discrete third dimension (floor level) as well.

Positioning in three-dimensional environments is frequently investigated using other technologies than WLAN or combined technologies.

One approach to get a relatively good accuracy in positioning as well as accurate continuous information about the current position on the z-axis is shown in Woodman and Harle ([10]). They use a foot-mounted inertial sensor combined with WLAN based RSSI algorithms.

Mandal et al. ([6]) developed the system beep using audible sound signals emitted by batches. The client sensors receive these signals using microphones. The calculation of the actual three-dimensional position is carried out on a central location server which is connected to the clients by WLAN. The system reaches an accuracy below 3 feet in 95% of cases in a three-dimensional one-room environment. However one major concern are the audible signals which may be annoying to the users.

Hightower et al. ([3]) developed a three-dimensional localization system using radio frequency signals from long range RFID tags. The concept is based on the physical model of signal strength attenuation over distance. Using trilateration the mean estimation error amounts to 3m.

An Ultra Wide Band (UWB) approach for three-dimensional positioning is published by Schwarzer et al. ([7]). They calculated a mean estimation error of 45cm in a classroom environment.

III. ALGORITHMS AND TESTBED

A. Isolines Algorithm

One algorithm for WLAN positioning in two-dimensional environments is the Isolines Algorithm ([2]). The Isolines Algorithm is an approach based on fingerprinting. Tuples of RSSI values from Access Points (AP) are measured at calibration points within an initial calibration phase. A line of constant RSSI values is called isoline.

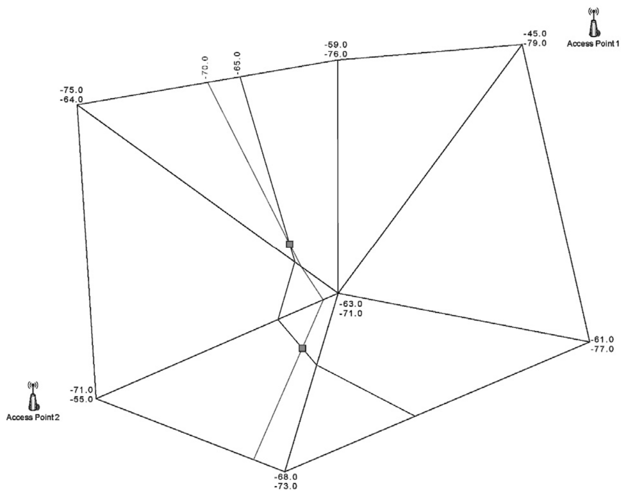
Below x and y refers to the two-dimensional coordinates of the position while z refers to the discrete vertical coordinate, e.g. the floor level number.

To use the Isolines Algorithm in multistory buildings a network of triangles with the calibration points as nodes using Delaunay-Triangulation is built for every floor.

During positioning phase a mobile device measures tuples of RSSI-values from all access points within reach. These RSSI-values are transferred to the location server where the position is calculated.

For every two-dimensional triangulation the RSSI-values are used to calculate isolines for every triangle using bilinear interpolation (see figure 1). Thereafter for every triangle the number of isolines contained is calculated. The triangles are ranked by this number in descending order (see table 1).

Figure 1: Interpolated isolines of two access points



For level estimation all triangles with maximum number of containing isolines are used. The vertical z-position is given by the number of the floor containing a maximum amount of triangles with maximum number of isolines.

Table 1: Level estimation with isolines algorithm

Triangle ID	Number of Isolines	Level (z-pos.)
20	7	2
22	7	2
25	7	3
10	6	2
15	6	2
33	5	2
6	5	1

Table 1 shows a ranking of triangles by number of containing isolines. In this case considering all triangles with seven isolines the algorithm would set z to two.

Knowing the z-value the x and y coordinates can be determined using the two-dimensional Isolines Algorithm ([2]). The x and y coordinates are given by the arithmetic mean of the mass centers of triangles from floor z with maximum number of isolines.

B. *Euclidean Distance Algorithm*

Another fingerprinting algorithm for localization is defined by using the Euclidean distance. An application of this algorithm is published in ([2]).

For comparison of received RSSI-tuples out of positioning phase and RSSI-tuples out of calibration phase the Euclidean distance is used as similarity measure. The estimated position is given by the calibration point with the smallest Euclidean distance between its RSSI-tuple and the current RSSI-tuple.

C. *Test bed*

For evaluation a series of measurements in two different environments were carried out. The first test bed was located in the exhibition area of a small museum, the second test bed inside a university building.

The museum has an exhibition space of approx. 2000m^2 spread over two floors. In total eight WLAN Access Points were installed within the museum, four in each floor. For calibration 44 calibration points were selected. The edge length of the resulting triangles generated by triangulation ranges between 5m and 13m.

Within the university building test bed four floors with 15 existing WLAN Access Points were used for evaluation. The measurements in calibration phase were carried out at 143 calibration points. The distance between adjoining nodes was approx. 2m. Only public areas were used for calibration (e.g. corridors, lecture rooms, library).

Both test beds had inhomogeneous grids leading to different triangle sizes.

For both test beds a Windows Mobile PDA was used for measurements carried out by a person. At all calibration points the RSSI-values were measured in four direction (0°, 90°, 180°, 270°) to allow for the influence of the human body.

After calibration phase measurements were carried out at randomly chosen positions with known coordinates, 26 positions in the museum test bed and 30 positions in the university test bed.

IV. RESULTS

In Table 2 the percentage of correct z-position estimations for both algorithms is shown.

Table 2: Percentage of correct vertical-position estimations

Test bed	University	Museum
Method of Isolines	86.67%	96.84%
Euclidean Distance	93.33%	100%

Within the university test bed the floor level (z-position) could be estimated correctly in 86.67% of cases for Isolines Algorithm and 93.33% of cases for Euclidean Distance Algorithm. The results in museum test bed reached 96.84% with Isolines Algorithm and 100% with Euclidean Distance Algorithm.

Figure 2: Estimation errors of two-dimensional positioning – university test bed

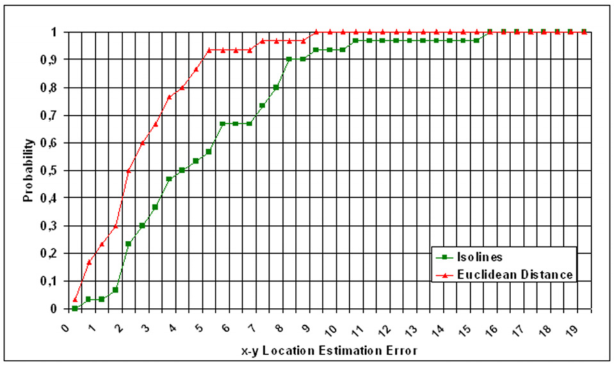
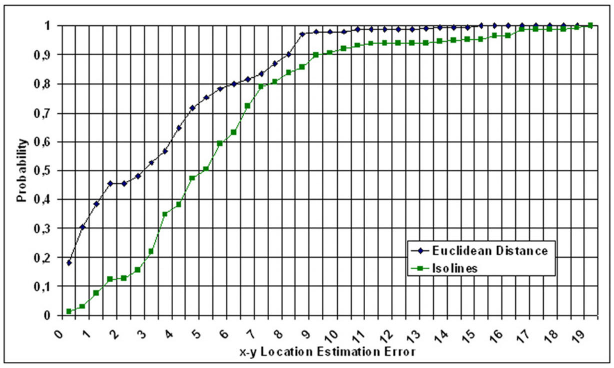


Figure 2 and figure 3 show the location estimation errors of two-dimensional positioning, figure 1 for the university test bed and figure 2 for the museum test bed. There are two graphs printed in each figure. The graphs show the cumulative distribution of estimation errors for Isolines Algorithm and Euclidean Distance Algorithm. The abscissa refers to the two-dimensional location estimation error while the ordinate refers to the cumulated probability.

For university test bed (figure 1) results show that about 90% of location estimation error values lie below 5m for Euclidean Distance Algorithm and 8.2m for Isolines Algorithm. 50% of location estimation errors show values below 2.2m for Euclidian Distance Algorithm and 4.2m for the Isolines Algorithm.

Figure 3: Estimation errors of two-dimensional positioning – museum test bed



Results for museum test bed (figure 2) show that 90% of estimation error values are less than 8.2m for Euclidean Distance Algorithm and less than 9.2m for Isolines Algorithm. 50% of estimation error values of Euclidian Distance Algorithm show values below 3m and below 5.2m for the Isolines Algorithm.

V. Discussion

From the results above it can be seen that Euclidean Distance Algorithm performs significantly better in both test scenarios. Earlier measurements in an empty seminar room have shown that Isolines Algorithm performs better than Euclidean Distance Algorithm ([2]). Furthermore, these measurements have shown significantly better results for two-dimensional estimation errors. The difference to the current results may be due to the more inhomogeneous grids with inhomogeneous triangle sizes and triangle shapes having larger edge lengths.

More detailed analysis of the results show that many of the incorrect level estimations happen at measurement points within peripheral areas. This effect may be due to the smaller amount of access points in reach within these areas.

To decrease the effect of incorrect estimation of z-coordinate (floor number) additional boundary conditions could be implemented, e.g. a denial of floor number change, if the previous two-dimensional position estimation is not located within a staircase.

VI. Conclusions

This paper shows that the discrete vertical position can be estimated with a reasonable reliability using WLAN localization algorithms. Exemplary boundary conditions could be to allow level changes only in areas where level changes are possible (e.g. staircases). By now the described algorithms are able to estimate z as a discrete variable which is appropriate for most scenarios. However there are some scenarios where a continuous z-estimation would be necessary (e.g. for positioning in staircases). This topic will be covered during future work.

VII. Acknowledgement

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