Analysis and Reduction of Systematic Errors in Wireless LAN Positioning

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Abstract - Regarding indoor location technologies Wireless LAN plays a vital part. This is due to relatively high accuracies, but rather low costs since WLAN infrastructure, particularly access points (AP), is often available in the indoor environment for communication purposes. This paper will describe some results investigated using a commercially available positioning system based on the 802.11b standard. After a brief introduction, it is divided into three parts. First, some basic performance results of the indoor tests are presented. As one of the outcomes of these tests systematic errors were detected. Part two investigates the time stability of these systematic errors and evaluates a simple correction approach. Proper analysis of these errors leads to the attempt of error removal by an interpolation method which is described in the third part.

1 Introduction

Recently, using Wireless LAN standards for indoor positioning has become an attractive technique. This is due to the fact that many office buildings are already equipped with WLAN hardware (AP) for communication purposes. Usually, WLAN systems rely on signal strength measurements which again are transformed into a range of integer values. This scale is called Receiver Signal Strength Indicator (RSSI). A typical distinction between WLAN indoor positioning systems is whether the RSSI values are used to determine distances by means of computing path loss or whether the RSSI values are initially used to establish a database in order to calibrate the system. The positioning then takes place by comparing a recorded RSSI sample with those in the database (fingerprinting). The first approach requires the coordinates of the AP. Following the second approach the location of the calibration points need to be known. Since WLAN radio signals are largely affected by multipath and signal attenuation dependent on the material to be penetrated, the first approach of computing path loss becomes complicated. For this reason the investigations in this paper have been carried out using on a system based on fingerprint technique. The system evaluated is the Ekahau Positioning Engine (EPE). It bases on a probabilistic framework comprising two main components [1]. The first one is the obligatory calibration on a sufficient number of sites in the indoor environment in order to establish the database of RSSI values. The second component is called rail tracking and integrates two assumptions. First, the history of the user is considered in a probabilistic way what mitigates too sudden movements. Second, the user is restricted to walk relatively close to the paths established during calibration to rule out user trajectories crossing walls. These paths are called rails.

2 Performance Evaluation and Preparatory Work

The first aspect of performance evaluation was to investigate the achievable positioning accuracy in relation to the density of AP. Tab. 1 shows the accuracies related to the number of AP used in the test as DRMS and 50% CERP. They were increased from three up to five. It can be recognized that the main improvement of accuracy occurs when deploying the fourth AP. This is due to the fact that a fraction of the sample points was not covered by the polygon of the 3 AP configuration, but by that of the 4 AP configuration. As a consequence, coverage is at least as important as AP density.

Number of AP	**3**	**4**	**5**
Absolute accuracy DRMS [m]	1.64	0.74	0.56
Absolute accuracy 50% CERP [m]	1.37	0.61	0.47
Relative accuracy DRMS [m]	0.72	0.41	0.36
Relative accuracy 50% CERP [m]	0.60	0.34	0.30

Tab. 1 Absolute and relative accuracy in relation to the number of deployed AP (sample points on rails).

In the next step of the performance evaluation of the EPE three different test environments were selected which are particularly relevant for potential applications. First, a very large undivided rectangular room of 30 x 7 m² (laboratory) was considered for the simulation of an open-plan office or a factory building. The second environment was a gallery representing a two-dimensional structure simulating long hallways. The third environment was a typical office environment with offices connected to a central foyer. In all three environments a mobile device was located on various marked points. An accuracy analysis was carried out. It comprised an absolute position accuracy with regard to the true position and, since multiple position solutions on the same location were generated, a sample standard deviation which is, for simplification, referred to as relative accuracy in the following. The performance evaluation in the three environments led to the result presented in Tab. 2. The accuracies are again given as DRMS and also as 50% CERP. In order to directly compare the results of the three environments the AP distance had to be equal since Tab. 2 showed that the accuracy is dependent on the AP distance. Actually, the average AP distance was about 14 m in each case.

Environment	**Gallery**	**Open**	**Office**
Absolute accuracy DRMS [m]	2.67	2.56	1.64
Absolute accuracy 50% CERP [m]	2.23	2.13	1.37
Relative accuracy DRMS [m]	1.69	0.75	0.72
Relative accuracy 50% CERP [m]	1.41	0.62	0.60

Tab. 2 Absolute and relative position accuracies in different environments.

Tab. 2 proves two main phenomena. First, the absolute accuracy in the office environment is significantly better than in the other two environments. In the open laboratory the probabilistic framework obviously suffers from the indifferent RSSI database due to the lack of walls separating the rails which are arranged in a strictly geometrical grid. Second, there are significant differences between absolute and relative accuracy (sample standard deviation), especially in the laboratory environment. The latter fact is an indication for a systematic error source which will be considered more detailed in the next chapter. Further results of the EPE performance evaluation can be found in [2] and [3].

3 Definition and Evaluation of Systematic Errors

Before correcting for systematic errors a precise definition of the term systematic error has to be found. A noticeable characteristic in the open environment is that there is a rather large offset between the true position and the computed position whereas the individual solutions of the computed positions do not differ much. In order to generally rule out blunders there is also an upper limit of the allowed absolute position error. Hence, the following four criteria were established and had to be met cumulatively in order to fulfil the definition of a systematic error:

a) The quotient absolute accuracy divided by relative accuracy exceeds a certain threshold.
b) The relative accuracy falls below a certain threshold.
c) The absolute accuracy falls below a certain threshold.
d) Additionally, the error must occur in succeeding sessions.

Systematic error investigation was then carried out in the laboratory environment. A total number of six AP were deployed. Fig. 1 shows the ground plan of the environment (red rectangle = laboratory) as well as the rails (blue lines), the calibration sites (yellow-green dots), and an isometric depiction of the signal strength.

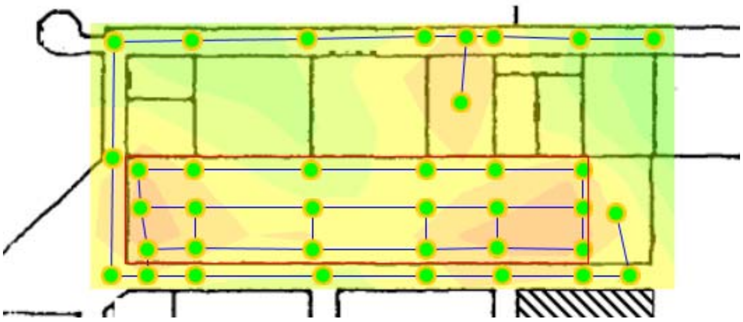

Fig. 1 Ground plan of test environment with rails, calibration sites and isometric RSSI depiction.

In order to assess the time stability of the systematic errors mentioned in d) a total number of five sessions were measured and compared. All 18 calibration sites inside the laboratory were used for the assessment. After careful consideration the following thresholds with regard to the first three systematic error criteria were selected: a) 2, b) 1.5 m, c) 6 m. The investigation was carried out separately for X- and Y-coordinate components. The number of sites affected by systematic errors with regard to the individual sessions and coordinate components can be found in Tab. 3. In the next step a very simple approach of correcting for the systematic errors was tested. If a systematic error was detected, the difference value μ_x,μ_y between the centre coordinate of the samples x_i, y_i and the true position x^, ŷ was computed (1) and applied to all future measurements on these points (2). The effectiveness of the approach is checked by investigating the achieved accuracies on these points during succeeding sessions comparing the data with and without application of the correction value.

$$\mu_x = \sum_{i=1}^{n} \hat{x} - x_i\,; \quad \mu_y = \sum_{i=1}^{n} \hat{y} - y_i \quad (1) \qquad x_{i,NEW} = x_{i,OLD} + \mu_x\,; \quad y_{i,NEW} = y_{i,OLD} + \mu_y \quad (2)$$

	X				Y			
Session	# of system. errors		RMS accuracy [m] a priori	RMS accuracy [m] corrected	# of system. errors		RMS accuracy [m] a priori	RMS accuracy [m] corrected
1	8	44 %	(3.42)	(0.00)	10	56 %	2.45	(0.00)
2	8	44 %	3.15	0.93	10	56 %	2.12	1.18
3	7	39 %	2.55	2.22	10	56 %	1.97	1.45
4	5	28 %	2.60	2.05	10	56 %	2.23	1.45
5	5	28 %	1.87	2.24	10	56 %	2.22	1.51
Mean			**2.54**	**1.86 = 73 %**			**2.14**	**1.40= 65 %**

Tab. 3 Application of 1st session correction values to succeeding sessions on points affected by syst. errors.

Tab. 3 shows that in three of the four succeeding sessions there was an improvement in accuracy in the X-component as well as in all four sessions in the Y-component. Thus, after averaging it was possible to suppress the errors on those calibration points detected as affected by systematic errors to 73% (X) respectively 65% (Y) of the original error. The first session is not considered here since its function was only to generate the correction values. Note that the accuracies slightly differ from those of the laboratory environment in Tab. 2 since it concerns a completely independent measurement carried out in the same environment, but at a different time using a different calibration.

4 Systematic Error Remedy by Interpolation

Since a considerable number of points in the investigated environment is affected by systematic errors an advanced method for their correction was applied. All of the 18 calibration sites acted as grid data points for an interpolation resulting in a correction value for every point within the grid. The calibration points are depicted as black dots in the principal scheme in Fig. 2. For interpolation the biharmonic splining method available in the MATLAB environment was applied. Details about the interpolation method can be found in [4]. It has to be pointed out that no modifications to the proprietary Ekahau algorithms had been carried out. The purpose of the interpolation was to provide correction data in the form of a post calibration to be applied to the data. For this reason 15 points acted as evaluation points located between the calibration points. They are depicted as green dots in Fig. 2. The interpolation was carried out separately for X- and Y-coordinate components. A total number of three sessions was measured. The overall a priori accuracy (RMS) with regard to the evaluation points was 2.88 m in X-direction and 2.29 m in Y-direction (Tab. 5).

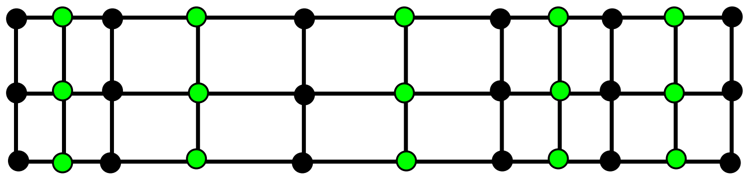

Fig. 2 Distribution of calibration points (black) and evaluation points (green) in the test environment.

Fig. 3 and 4 depict the spatial extension of the laboratory and the grid of calibration and evaluation points (black lines). The choice of a regular grid instead of randomly distributed points is only due to ease of reoccupying identical sites in different sessions without spending further efforts on marking the sites, e.g. The colours in Fig. 3 and 4 depict the result of the interpolation function for each session. It bases on the deviation of the calculated position with regard to the true position at the grid (calibration) points. The interpolation surface always goes exactly through the actual deviation values at the calibration points. Fig. 3 shows the results in the X-component for all three sessions. Fig. 4 does it in the same way for the Y-component. The colour gradient on the right shows the range of deviation from less than –4 m (deep blue) up to more than +5 m (dark red). Fig. 3 and 4 obtain two main outcomes. Firstly, the shape of the interpolation function is much smoother in Y direction than in X direction. The colour gradient is less sharp and to some extent there are areas of nearly equal (and low) deviation. Secondly, the individual results of the three sessions are in good accordance with each other.

After generating the interpolation function the measurements of the evaluation points were corrected by the actual values of the interpolation function. The resulting error is compared with the original one and the decrease of the positioning error is expressed as a percent value (Tab. 4). Since the individual solutions are rather well-suited the interpolation function of one session was also used to correct the evaluation points of the other sessions. Moreover, Tab. 5 compares the overall a priori accuracy with the overall post calibration accuracy in metres.

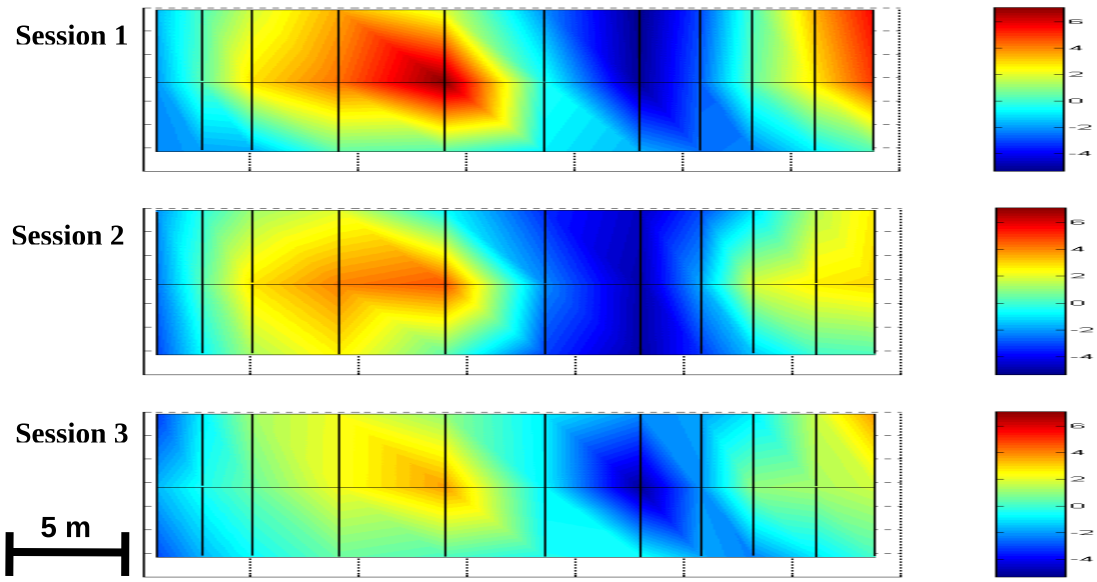

Fig. 3 Shape of the interpolation function (X-component) covering the test environment.

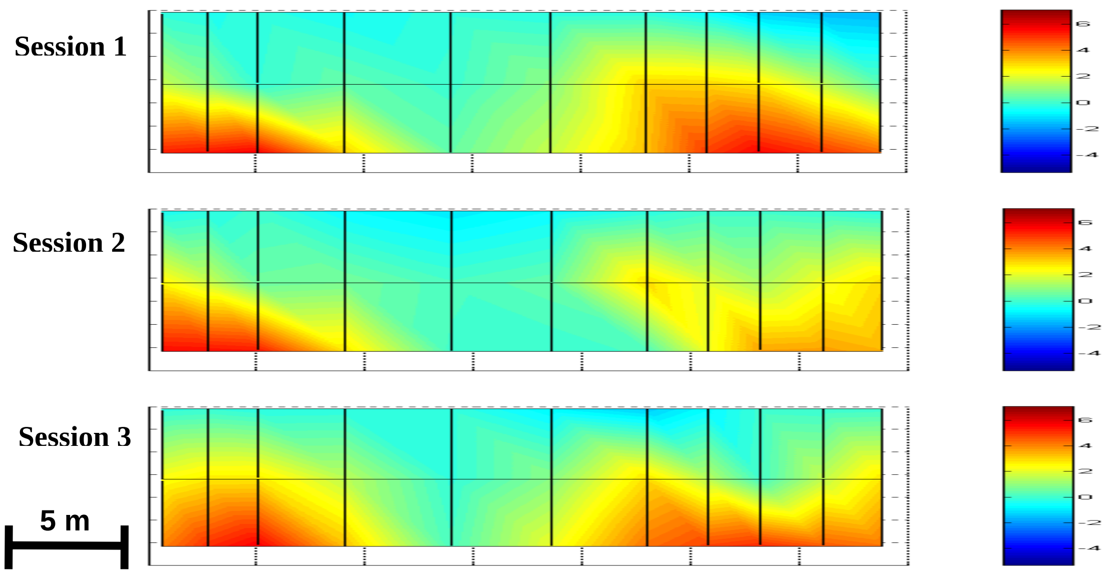

Fig. 4 Shape of the interpolation function (Y-component) covering the test environment.

The results show that the application of the interpolation leads to a significant improvement of accuracy in the Y-component. After applying the correction the average error was only 59% of the original one. Each of the nine individual combinations results in an improvement. For the X-component this improvement is less clear. Only the interpolation based on the interpolation using the second session leads to the same amount of improvement (59% of original error). However, the interpolations using the other two sessions even result in a tiny deterioration, Surprisingly, the measurements of the second session are most responsible for that. All in all, only a suppression of 89% of the original error is achieved.

There might be three reasons for the better performance in the Y-component compared to the X-component. First, the spatial expansion of the test environment was much larger in X-direction. This is of importance since (error affected) position solutions are principally possible throughout the whole area. In fact, the a priori accuracy was in Y-direction 20% better than in X-direction (Tab. 4). Second, the three individual interpolation functions match themselves better in the Y-component than in the X-component. Third, regarding the Y-axis all evaluation points are located on the grid of the calibration points, whereas in X-direction they are not. For this reason a repetition of the test using an irregular grid of calibration and evaluation points could be meaningful.

X					**Y**				
	Interpolation					Interpolation			
Session	1st	2nd	3rd	**Mean**	Session	1st	2nd	3rd	**Mean**
1st	87	51	84	**74**	1st	51	59	55	**55**
2nd	119	61	126	**102**	2nd	84	50	60	**65**
3rd	116	66	95	**92**	3rd	55	68	47	**57**
Mean	**107**	**59**	**102**	**89**	**Mean**	**63**	**59**	**54**	**59**

Tab. 4 Positioning improvement of correction by interpolation in percent of the original accuracy.

RMS Accuracy [m]	**X**	**Y**
A priori	2.88	2.29
Post calibration	2.61	1.35

Tab. 5 Comparison of the overall accuracies of all 15 evaluation points over all three sessions.

5 Conclusion

Especially in environments characterized by large undivided structures the evaluated EPE produced systematic errors which had to be defined in this work. In a first step the time stability of the errors was examined. After that a post calibration method without modifying the algorithms of the EPE based on interpolation between the calibration points was investigated. Applying the generated correction values to succeeding sessions led to a significant accuracy improvement especially in the Y-component. However, the actual user position is not known. Hence, the user will get the correction value for that (erroneous) location he supposes to be. Thus, when applying the interpolation method the error will be larger the larger the change rate of the outcome of the interpolation function is. The proposed post calibration technique can only be considered as an intermediate step to more sophisticated techniques like dynamic real-time databases substituting the conventional calibration approach.

6 References

[1] Ekahau, Ekahau Positioning Engine 2.0: 802.11-based Wireless LAN positioning system. *An Ekahau Technology Document*, November 2002.

[2] B. Eissfeller, D. Gänsch, S. Müller and A. Teuber, "Indoor Positioning Using Wireless LAN Radio Signals" in *Proceedings of ION-GNSS 2004*, Long Beach, California, 21-24 September 2004, pp. 1936-1947.

[3] D. Gänsch, "Indoor-Positionierungssysteme (Systemtest)", diploma thesis, unpublished.

[4] D. Sandwell, "Biharmonic Spline Interpolation of GEOS-3 and SEASAT Altimeter Data", *Geophysical Research Letters*, 2, 139-142, 1987.