IPS - Indoor Positioning System with Wireless Sensors

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Abstract: - Recent developments in the area of ubiquitous and pervasive computing emphasize the interest in context-aware applications. Location is probably the most important context. Indoor location estimation and tracking remains challenging due to the lack of usable and cost-effective technologies. GPS has proved itself for outdoor usage, but it is not suitable for indoor applications due to poor coverage. Assuming that multiple wireless sensors will be attached to ubiquitous environments, they could also support location estimation and tracking. This paper presents an indoor positioning system using wireless sensors, called *LocSens*. LocSens works with a minimum number of sensor nodes in a real indoor scenario.

Key-Words: - Ubiquitous computing, pervasive computing, wireless sensor network, indoor positioning, indoor tracking

1 Introduction

Location is probably the most important context in ubiquitous and pervasive computing. Indoor location estimation and tracking remains challenging due to the lack of usable and cost-effective technologies. GPS has approved itself for outdoor usage. But it is not suitable for indoor applications due to poor coverage. To gather real world information from the environment, wireless sensors will be attached in everyday objects.

The main focus of this paper is to use wireless sensor networks for location estimation and tracking. Since the cost for sensors is low, the location tracking system is assumed to be cost-effective. Using wireless connections, it is possible to calculate the current location of a user or an object. For some applications it is even enough to estimate the room, in which the user remains at current time. Providing more precision opens opportunity for more specific services. The Smart Doorplate project [1] establishes a ubiquitous environment with intelligent doorplates, which present information about the office and employees to the visitors outside. Electronic touch-screen displays provide location of the office owner and some status information, e.g. on the phone, absent, or busy. For complete operation, the Smart Office system needs a service that provides the current positions of the users. This service should at least be able to determine the room a user is currently staying in.

This paper describes LocSens a location tracking system based on wireless sensors, that is used to get location information for Smart Doorplate services. LocSens works with fixed room sensors that communicate with mobile sensors carried by users.

Usually each sensor node in a wireless sensor network has its own processor, memory and application specific sensors. In previous versions, LocSens used the ESB430 sensor boards, which are now replaced by the more up-to-date model MSB430. [2] describes the LocSens system and provides evaluation results using ESB430. Both sensor boards are developed at the Freie University of Berlin [3]. The MSB430 board has a modular structure, where specific sensor modules can be easily attached. In the basic form, there exist two modules: a basis module (MSB-430T) and a kernel module (MSB-430). The kernel module uses a TI MSP430F1612 microcontroller and a Chipcon CC1020 radio transceiver, both enhancing the performance in comparison to the older board ESB430. Also three sensors are attached on the kernel module: an acceleration sensor, a temperature sensor, and a humidity sensor. Figure 1 shows a picture of the MSB430 basis and kernel module. It is a characteristic of sensor nodes that all resources are extremely limited. The energy supply is usually provided by a battery. LocSens uses cable operated sensor nodes for fixed positions in rooms as well as battery operated sensor boards carried by users. For current prototypes only a limited memory capacity is available. On the average sensor boards have less than 20 kilobytes of RAM and about 100 kilobytes of ash memory. In order to reduce the energy consumption, low performance processors are used on sensor boards.

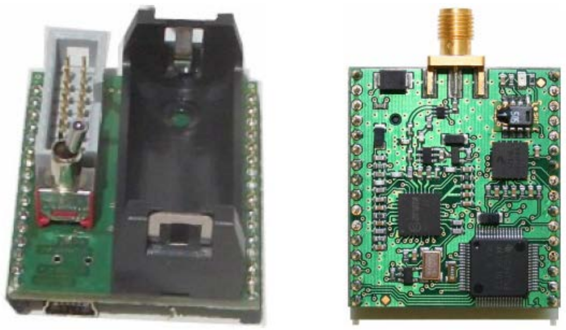

Figure 1. The MSB430 Sensor Board

In most cases it is an 8-bit microcontroller. Therefore, the performance and speed is very limited. Wireless communication has naturally a weak data throughput. Additionally problems with packet failures, packet loss, and collisions lead to increased time delays.

The next section describes related location estimation and tracking approaches. Section III introduces the LocSens system and the testing environment. LocSens is evaluated on the MSB430 sensor boards using different estimation algorithms and optimizations. We present also some evaluation results for location estimation and tracking. The paper ends with the conclusion.

2 Related Work

Pathbreaking work on positioning systems was done by Want et al. [4] with their Active Badges. This system was an inspiration for several following projects. The goal of the Active Badge project is to easily locate persons in public buildings like hospitals. The active badges are devices worn at the body and used to identify the person by sending an infrared signal every 100 milliseconds. The use of common IR technology holds the production costs low. The Active Badge system can locate persons or objects in a room-wide range. The granularity is very low and not sufficient for other applications. Another weak point is the high installation cost since the complete controlled area needs to be wired up. Extensions are hardly possible.

Wireless LAN technology was employed in the RADAR system by Bahl et al. [5]. This work discusses a wide range of methods for analyzing the measurements. RADAR is established in an area of 980m^2 with more than 50 rooms. Three base stations are used to cover the overall building. The range of the stations overlap partly. A laptop with a WLAN adaptor works as mobile device for locating and tracking. The laptop sends multiple UDP packets to the base stations that calculate signal strength and signal-to-noise ratio for each packet. Measurements comprise 70 points in the building with four directions (north, west, south, east). RADAR stores at least 20 values of signal strength for each combination of location and direction. Besides this it calculates for each position the means, the standard deviation, and the median. The accuracy of RADAR is similar to the Active Badge system. It is only possible to locate people in rooms. But the installation cost is lower since most buildings provide WLAN access infrastructures. The collection of reference data is the main disadvantage of RADAR. Each change in the room structure requires an update of the reference model.

Another project that uses WLAN for location tracking is described in [6]. This approach is similar to RADAR but uses a Bayesian interference algorithm for statical evaluation based on a specific model of state and observation spaces. The mean deviation could be improved compared to RADAR. Nevertheless this approach is also highly dependent to the room structure. Even small changes lead to huge re-calculations of the reference model.

Harter et al. [7] present another approach for location and identification of objects based on ultrasonic. Each person or object carries a device called bat that sends periodically an ultrasonic signal. Receivers of this signal are ultrasonic receiver units which are attached to fixed positions at the ceiling. These units are interconnected to a daisy-chain network. Using base stations, the ID of a corresponding bat, which needs to be localized, can be sent over wireless connection. The bat responds with the ultrasonic signal. Using the different arriving times at different receiver units, the location of the bat can be calculated. This project shows that ultrasonic provides high precision for location. On the other hand ultrasonic is interference-prone. Other signals can easily jam the ultrasonic signal. Since also in this project the installation cost is very high, it is difficult to extend the system infrastructure. Cricket [8] is another ultrasonic based location system. In this approach the device carried by the person determines the location itself. This ensures the privacy of the person. Beacons attached at the ceiling periodically send a radio and ultrasonic signal. Using multiple signals from different beacons the personal device calculates the current position. In further work, Cricket was extended to provide a tracking of moving objects. An outlier rejection component is used to eliminate measurement failures by deleting extremal values. Another component is the least square solver which has the task of minimizing squared mean failures. Current states are stored by an extended Kalman-filter that can even predict future states. The installation cost of Cricket is lower than other projects, but the interference problem of ultrasonic remains.

The technology of active RFID (Radio Frequency Identifier) tags is used in [9]. The aim of the LANDMARC project is to build an insensitive and cheap location system that does not need sight contact. LANDMARC uses RFID readers with a range of 150 feet. The range could be extended with specific antennas to 1000 feet. The readers have additionally an interface for wireless Ethernet that allows flexible positioning. Each reader has eight reading ranges which are changed incrementally. The reader can read out up to 500 tags in 7.5 seconds within one range. In a test scenario, four readers are attached in a large room. Since there is no possibility to get the signal strength, the readers have to scan all eight ranges sequentially. To determine a tag's distance LANDMARC sends detected tag IDs over wireless connection to a central computer. Using live reference measurements, it calculates the location of the tags. The results show that LANDMARC is insensitive for changes in the environment, like persons in the area. The main disadvantage of LANDMARC is the sequential scan of all reading ranges that takes nearly one minute for each turn. Also the readers are relatively expensive which affects the installation cost.

[10] presents ArrayTrack, an indoor location system that uses angle-of-arrival techniques to locate wireless clients indoors to a good level of accuracy. But the projects needs special hardware with multiple array of antennas. In [11] Smart ActionSLAM is presented, an Android smartphone application that performs location tracking in home and office environments that uses the integrated motion sensors of the smartphone and an optional foot-mounted inertial measurement unit to perform personal localization and tracking.

3 LocSens – Indoor Location Tracking Using Wireless Sensors

Due to the high inaccuracy or the high costs for existing systems, we decided to build our own location tracking system, called LocSens. The test bed in LocSens consist of three rooms of about 80 m^2 together, where we placed three sensor boards forming the basic infrastructure. A fourth board is worn by the user, who moves through the environment. Consciously, we use a passive infrastructure, i.e. the room nodes act only as receiver for signals sent by the mobile sensor board.

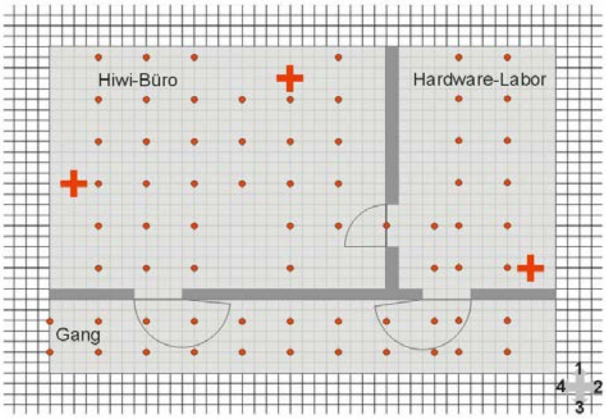

Figure 2. Testing environment

This has the advantage that chronological assignments of the signals onto actual positions become easier. With this configuration, we recorded a reference model consisting of more than 30.000 data sets. We defined 70 measurement points for all rooms. At each point we gathered data for four orientations (north, west, east, south). By recording several data sets at each point, we aimed to outweigh the jitter of the radio transceivers. Figure 2 shows a ground plan of the test environment, as well as room sensor nodes (red crosses) and points of measurements (red dots) for setting up the reference database.

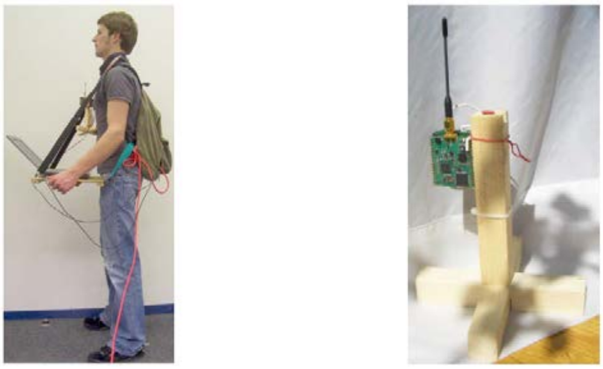
Figure 3. Mobile user with measurement equipment and room sensor boards

Besides the room sensor nodes, there is also a mobile user sensor board. Furthermore, signal strength of the user board is measured by room sensor nodes. As shown in Figure 2, points of measurement form a raster with a distance of about one meter between each point. Figure 3 shows the user carrying mobile sensor node and measurement equipment. The aim was to build up a reference model that should be used for location estimation performing different algorithms. For each point the coordinates, user's line of sight (N, E, S, W), and receiving level of all three room nodes were stored in a database. In order to have a reliable basis, 120 data points for each line of sight were gathered, achieving 33600 data points altogether.

The location estimation algorithms compare current received signal strength levels with data records in the database. In order to optimize the estimation, we implemented several algorithms. We chose *nearest neighbor in signal strength space* (NNSS) as first approach for location estimation. This algorithm searches the overall database for k points n_1, …, n_k, which have the lowest Euclidian distance to the current measured receiving level. After that, position P can be calculated by interpolation with weights of $\frac{1}{k}$. The following equation shows the NNSS algorithm:

$$P = \sum_{i=1}^{k} \frac{1}{k} n_i \qquad (1)$$

The main disadvantage of NNSS is that it needs a long time to calculate. Therefore, we modified the NNSS algorithm to achieve enhancements in time of calculation and accuracy. The first idea was to use an arithmetic mean of all relevant reference data points instead of regarding 100 reference data sets in NNSS for each position and line of sight. We call this modified algorithm M-NNSS. Following equation clarifies the modification:

$$R_{M-NNSS} = \{\begin{pmatrix} M(x) \\ M(y) \\ M(z) \end{pmatrix}\} \qquad (2)$$

where $M(a) = \frac{1}{100} \sum_{i=1}^{100} a_i$.

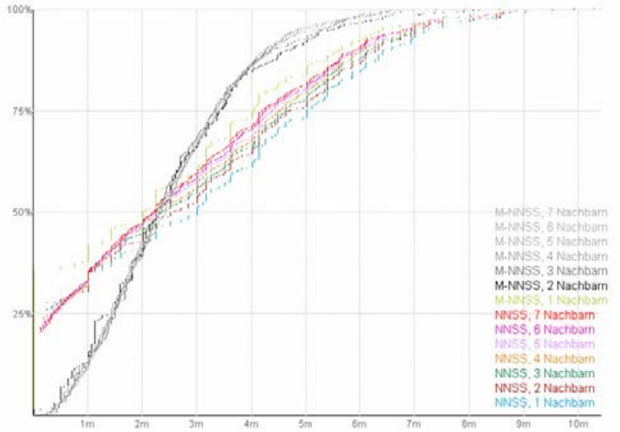

Figure 4. Percentile for M-NNSS and NNSS using MSB430 sensor board

Figure 4 visualizes the percentiles for both algorithms (NNSS and M-NNSS), i.e. the percentage of points where the difference between calculated and real position is at most x meters (e.g. %25 of the calculated positions have a deviation of 0-1.5 m from the real position). The algorithms were performed regarding 1-7 neighboring points. The results show that M-NNSS achieves higher accuracy in upper percentiles, i.e. there are more points with lower deviation.

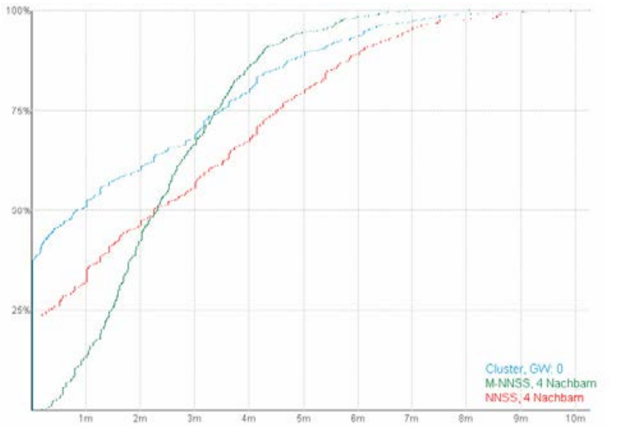

Figure 5. Percentile for M-NNSS, NNSS, and Cluster approach

3.1 Cluster Optimization

In some cases NNSS chooses neighbors which are too far away from the actual position. This leads to miscalculations that can be eliminated by filtering out neighbors with long distances. The cluster optimization approach chooses only the neighbors which have distances lower than a specific value. Figure 5 shows the results of the cluster approach compared to NNSS and M-NNSS using both four neighbors. It is clearly seen that cluster approach achieves much better results than NNSS and M-NNSS. In average the accuracy lies at 1.88m using cluster optimization.

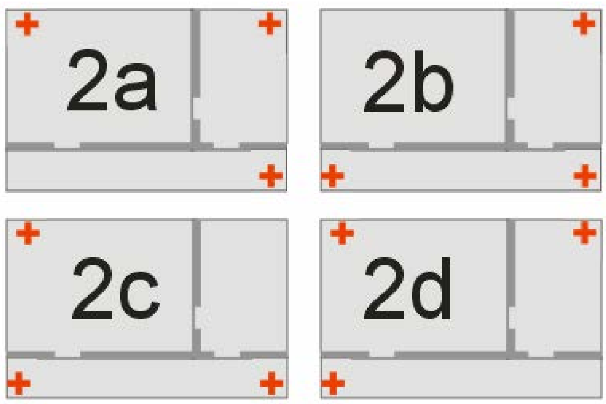

Figure 6. Different placements of room sensor nodes

3.2 Optimization of room sensor node positions

The position of room sensor nodes can also influence the location estimation. In order to examine different positions for the three room sensor nodes we established several placement constellations. Figure 6 shows four test configurations, where red crosses indicate room sensor nodes. For each constellation we performed the NNSS location estimation algorithm. The results are shown in Figure 7. The values for all four constellations are almost parallel, whereas constellation 2d achieves the best results. We also performed M-NNSS and cluster algorithms for all placements, but the differences between the constellations were unmentionable low.

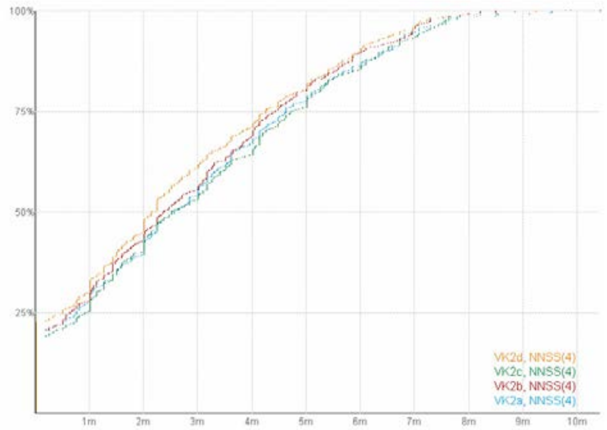

Figure 7. Percentile for NNSS in different room node placements

The next logical step would be to use four room sensor nodes instead of only three. This implies an increase of processing time due to additional calculations. But as you can see in Figure 8 all three algorithms achieve better results. The cluster approach gain 0:68m lower accuracy in average to 1:20m, which is obviously worth the additional calculations.

In all above test scenarios the user was carrying the mobile sensor node at his chest. Since the body blocks radio signals, the received signal level in some positions would be corrupted. In order to examine this fact we placed the mobile sensor node on top of user's head. Figure 9 shows a picture of the user. In this optimal scenario we could achieve the best result for all algorithms. Table I describes some chosen percentiles for NNSS, M-NNSS, and cluster algorithms. Unfortunately, carrying the sensor node on top of the head is inconvenient for a person. Therefore, this is not a realistic scenario. Nevertheless, this evaluation clarified the impact of interferences in wireless communication.

Table II gives an overview of several location estimation techniques compared with LocSens. As seen in this table LocSens achieves very good accuracy values with very low installation costs.

Table 1. Chosen Percentiles for NNSS, M-NNSS, and Cluster, where mobile node is on user's head

	25%	50%	75%	100%	average
NNSS	0.00	0.50	1.91	9.55	1.18
M-NNSS	1.12	1.68	2.26	5.34	1.82
Cluster	0.00	0.00	1.80	10.26	1.05

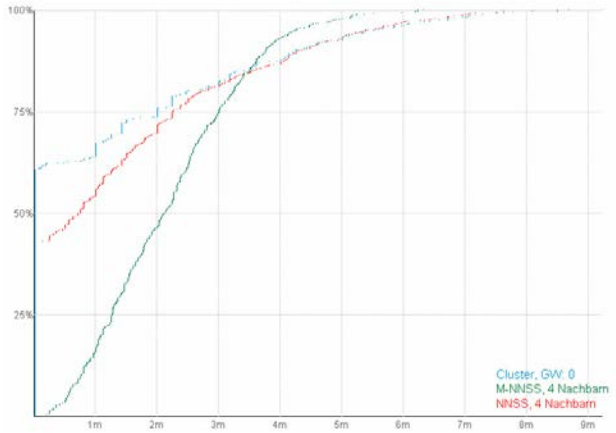

Figure 8. Percentile for NNSS, M-NNSS, and cluster using four room

Figure 9. Mobile sensor node on top of user's head

Table 2. Comparison of location estimation techniques

System	Technology	Range (indoors)	Accuracy	Size of test environment
Active Badge	Infrared	< 6m	exact room	unknown
RADAR	WLAN	25m - 50m	2.75m	44m x 23m
LANDMARC	active RFID	50m	1m	9m x 4m
LocSens (ESB430)	RF	< 20m	2.90m	10m x 8m
LocSens (MSB430)	RF	< 20m	1.05m	10m x 8m

3.3 Location Tracking

After examining possible optimizations of location estimation, we performed tests with LocSens where we tracked a moving user. Location tracking is performed by continually calculating timely related data sets. Since four room sensor nodes achieved best results in location estimation, we also used four room nodes for tracking.

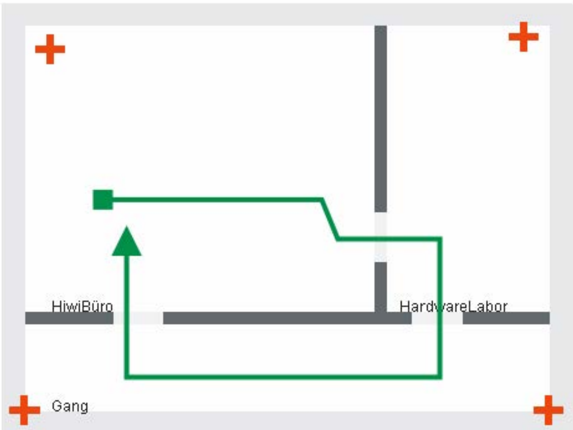

Figure 10. Tracking a moving user with LocSens

The user carries again a mobile sensor node on his chest. Room nodes request periodically location messages from the mobile node. Using signal strength level each node estimates the actual location of the user based on NNSS algorithm. Figure 10 shows the actual path of the user through three rooms. Red crosses at the corner of each room indicate the four room sensor nodes. Figure 11 illustrates calculated positions of the user by small red crosses and potential movement by blue lines. As you can see using NNSS algorithm without any optimizations result in bad tracking calculations.

It is impossible to assume the actual path the user took. The first optimization was to use sliding windows, i.e. we collected a specific number of signal measurements and calculated user's location over the means of collected data sets. Figure 12 shows enhancements of location tracking using sliding windows. *W(x)* indicates calculation based on *x* collected data sets. Increasing the number of data sets achieves better results, but the calculation needs more time. With this first optimization you can nearly see the path of the user, but still there are some miscalculated positions. In order to eliminate them we performed further optimization steps.

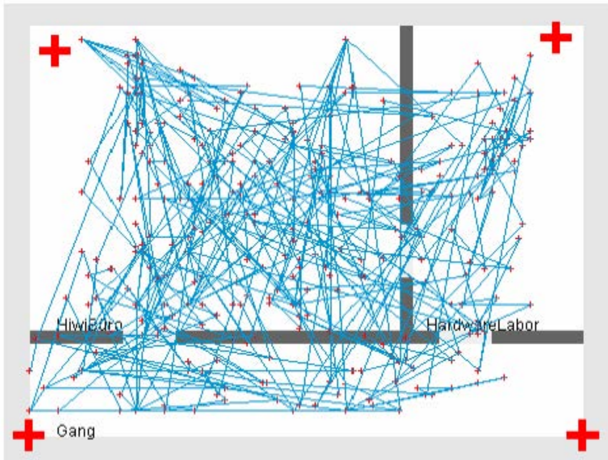

Figure 11. Calculated user locations without optimization

Using the acceleration sensor of the user sensor board, it is possible to detect the motion intensity. This information can be used to dynamically adapt the size of the sliding window. If the user walks faster, the range of considered points increases automatically. As you can see in Figure 12 there are several calculated location changes going through walls. This unlikely situations can be avoided by allowing room changes only near to doors.

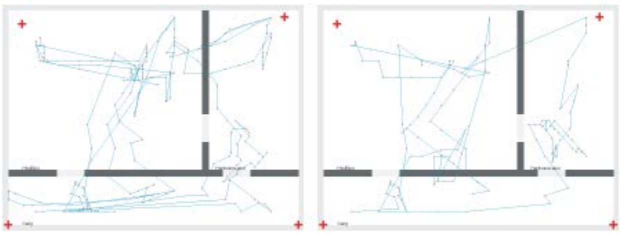

Figure 12. Location tracking using sliding windows: W(50) and W(100)

For this reason we adapted our algorithm to consider data sets from other rooms only if the preceding location was in vicinity of a door. Figure 13 illustrates the results after above mentioned optimizations. Still there are some miscalculated locations, but you can easily recognize path of the user across the rooms.

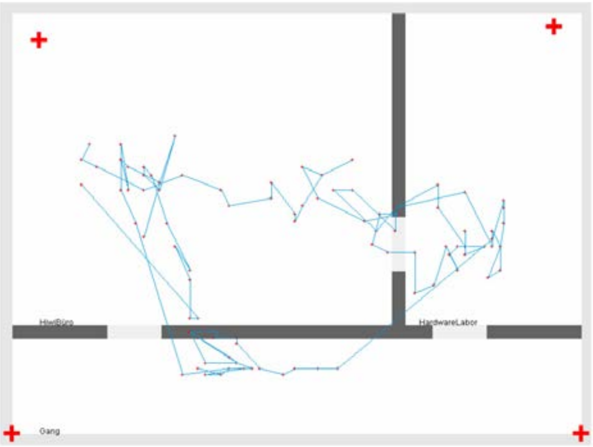

Figure 13. Calculated path of user with several optimizations

4 Conclusion

This paper presented LocSens, an indoor location tracking system based on wireless sensors. Since sensor boards are produced with low costs, the usage of wireless sensors minimizes installation cost of the overall system. LocSens was implemented with different location estimation algorithms, namely NNSS, M-NNSS, and cluster approach. We evaluated the impact of several modifications on the test environment and reference data, which resulted in enhancements of system performance. Also the usage of additional sensor information increased precision of calculation. Especially, location tracking can benefit from data about movement intensity of the user. Compared to other indoor location systems LocSens achieves acceptable results in location estimation and real-time location tracking with considerably low installation costs.

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