A Hybrid Indoor Positioning Approach for Supermarkets

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Abstract. A navigation service that can provide positioning functionalities is benefitial to both customers and supermarkets. Although there are quite a number of indoor positioning algorithms, the accuracy of the existing approaches is not very satisfying. In this paper, we propose a hybrid approach that combines Weighted Centroid Localizatioin Algorithm, Dynamic Position Tracking Model and Location Approximation Algorithm based on Received Signal Strength. The evaluations show that the proposed approach can achieve better accuracy than the existing approaches, with approximately 20% to 40% improvement.

1 Introduction

The majority of us had experiences of having difficulties to locate which aisle the needed goods are stored in a big supermarket. Therefore, a navigation system that shows how and where to reach your targets will be very helpful for customers to save time in a supermarket. On the other hand, such a navigation system will help to improve sales in supermarkets and to reduce man-power costs. Therefore, there arises the requirements for accurately navigate customers to a corresponding location where goods for customers are stored.

From comparisons of various wireless transmission technologies in [?], we can see that ZigBee precisely fill low-rate wireless communication technology vacancies. The complexity of ZigBee system is far less than that of the Bluetooth system, much lower-power comsumption (days versus years) and low-cost are the advantages of ZigBee technology. Although it has a lower data transmission rate, but the transmission rate is still able to meet positioning needs for supermarkets. Generally RFID(Radio Frequency IDentification) technology can be used in indoor positioning, but passive RFID technology is suitable only for close data reading and writing, for a long distance active RFID positioning system as in a medium scale supermarket, the flexibility of the RDFI positoining system is greatly restricted, and the cost of the entire system is no longer cheap compared to Zigbee based systems. Therefore in this paper we will use ZigBee technology to realize indoor positioning.

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Currently there are many researches that can provide the capabilities of indoor positioning which may faciliate the customer navigation for supermarkets. For example, using cellular infrastructure of GSM may help to realize indoor positoining [9] but it is found that this GSM based approach is not accurate [10] enough for navigation in a supermarket. Some researches are calculating the distance to the node basing on the time of arrival (TOA) of the signal transmission, where the time differences between transmission and reception are measured [1]. In this process, high accuracy of clocking between nodes should be synchronized in advance, which may not be realistic when there are a lot of nodes.

Received Signal Strength Indicators (RSSIs) are widely used for indoor positioning [13]. RSSI Fingerprinting, RSSI triangulation and trilateration are some of the representative approaches [8]. The RSSI Fingerprinting identifies specific positions with RSSI values [6], which needs a location fingerprint database to compute the current location. This requires a lot of time to build the fingerprint database before running such a navigation system. RSSI triangulation, and trilateration associate RSSI with distance or angular trajectory between a receiver and known transmitter positions [13][8].

Though there is quite some research using the RSSI triangulation and trilateration approaches [10], the accuracy of the existing work is not very satisfying. For example, in [10], using dynamic position tracking model combined with a probability density map, an average error of 1.21m can be achieved for localizing a person. For quite some small supermarkets as in China, the aisle is around 1m. This means that we need an approach that can have better accuracy. Henceforth, in this paper, we present a hybrid approach that helps to achieve this goal, where we combine the Weighted Centroid Localization Algorithm (WCLA) [12], Dynamic Position Tracking Model (DPTM) [10], and Location Approximation Algorithm (LAA) (details are in section 2) based on Received Signal Strength. The evaluations show that we can achieve better accuracy with less than 1m for the average error while positioning.

In the following, we will first present the proposed hybrid indoor positioning approach used for supermarkets navigation. Then we show the design of the navigation system. After that, we will show the evaluations of the proposed approach, where the average localization error, the maximum localization error are measured. Then we will compare our work with the related work. Finally, we discuss the conclusions gained in the project and point out some future work.

2 A Hybrid Positioning Approach

The RSSI (calculated using equation 1) dynamic tracking algorithm takes into account the fact that movement of objects within a certain range is not arbitrary, there is a relationship between the current location and previous location, and then this algorithm uses a speed constant to predict the next location [10]. Using DPTM, we can get the smoothed RSSI. The smoothed RSSI can then be used by the Weighted Centroid Algorithm to calculate an approximate location.

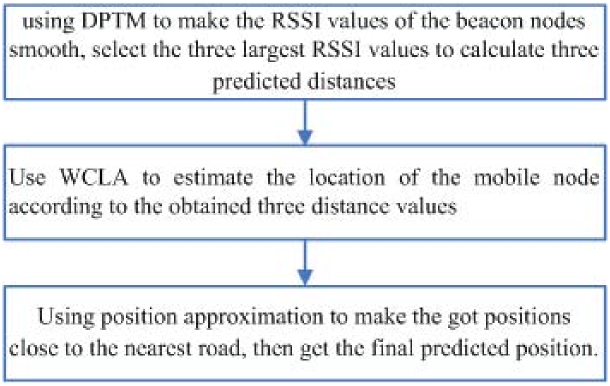

Fig. 1. A hybrid approach for indoor positioning

The Weighted Centroid Localization Algorithm is the improvement of the centroid algorithm by a weighting factor to reflect the beacon node to determine the centroid coordinates, to some extent, it can improve positioning accuracy [12]. Finally, considering the aisle characteristic of a supermarkets which is long and narrow, we make use of the location approximation algorithm to adjust the predicted positions to the nearest road midline to improve positioning accuracy. The whole process using the hybrid positioning approach is shown in Figure 1.

$$RSSI = -(10 \times n \times \lg[d] + A) \tag{1}$$

2.1 Dynamic Position Tracking Model

The dynamic tracking model [10] is based on the fact that the movement of mobile objects within a certain range is not arbitrary, the current location and previous location has relationships where speed between the two locations counts. The equations are as followed [10]:

$$\widehat{R}_{est(i)} = \widehat{R}_{pred(i)} + a(\widehat{R}_{prev(i)} - \widehat{R}_{pred(i)}) \tag{2}$$

$$\widehat{V}_{est(i)} = \widehat{V}_{pred(i)} + \frac{b}{T_S}(\widehat{R}_{prev(i)} - \widehat{R}_{pred(i)}) \tag{3}$$

$$\widehat{R}_{pred(i+1)} = \widehat{R}_{est(i)} + \widehat{V}_{est(i)} \cdot T_S \tag{4}$$

$$\widehat{V}_{pred(i)} = \widehat{V}_{est(i)} \tag{5}$$

where $\widehat{R}_{est(i)}$ is the estimated range, $\widehat{R}_{pred(i)}$ is the predicted range, $\widehat{R}_{prev(i)}$ is the measured range, $\widehat{V}_{est(i)}$ is the estimated velocity, $\widehat{V}_{pred(i)}$ is the predicted velocity, a and b are gain constants, and T_S is the time update period.

2.2 Weighted Centroid Localization Algorithm

The basic idea of the WCLA lies in the centroid algorithm. It uses weighting factors to reflect how a reference node (beacon node) determines right values of mass center coordinates, and these weighting factors reflect the degree of influences of the beacon nodes to the position of the mass center [2]. Weighted centroid localization algorithm to some extent, can improve positioning accuracy. But the problems of the WCLA are that the inconsistency of node positions and the random fluctuations of RSSI values, which make WCLA not suitable for accurate positioning [4]. In this paper, we use WCLA based on the smoothed RSSI values from Dynamic Position Tracking Model, to eliminate the randomness of the RSSI for WCLA.

2.3 Location Approximation Algorithm

Considering that usually the width of aisles in a supermarket is around 1m, and these aisles are straight, we can use the midlines of these aisles to represent these aisles. As shown in Figure 2, when an estimated location (say point A) is obtained through some other algorithms (say WCLA), it will be approximated to be on the midline of an aisle where the perpendicular distance is the shortest (A will be approximated to Ma on midline $M2$).

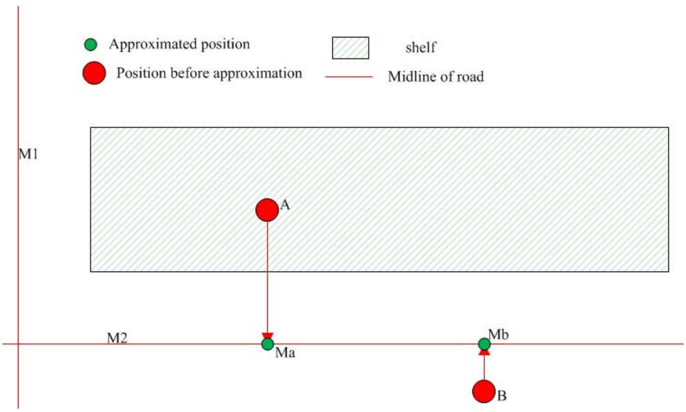

Fig. 2. Location approximation to the midline

The corresponding location approximation algorithm is shown in the following Figure 3:

```
n=the number of roads;
Pxy = location coordinates calculated with WCLA;
loop   i=1 to n
    Calculate vertical distance d between Pxy and the current road function road (i);
    Put d into an array named lenset;
endloop

Sort lenset from small to large;
Find the shortest distance ds, and the corresponding road function road (x);
Get P'xy which is the vertical projection from Pxy to road(x);
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Fig. 3. Algorithm for location approximation

3 Design and Implementation a Supermarket Navigation System

The network of the positioning system consists of a wireless ad-hoc network and a cable Ethernet network. The front-end uses the ZigBee network for data collection and transmission, the back-end uses the Ethernet network. In order to achieve the best positioning performance, we try to make each node deployed at the same height, and away from the floor, ceiling and walls. A few ZigBee wireless beacons (CC2430) are deployed below the ceiling, which are used as the reference node of the wireless location networks. Some of these wireless beacons are used as ZigBee routing nodes for the collection and transmission of ZigBee wireless signal. CC2431 module is embedded in the navigation system of the supermarket shopping cart and serves as mobile node. Each mobile node has a unique 16-bit segment address to be used to determine location information. Locator transmits 16-bit short address, node location information through a number of router nodes to the coordinator node which has the gateway role, and then the coordinator node transfer data through the wired Ethernet to a system server. Finally the location returned to the user by the system server. The architecture of the positioning system is shown in Figure 4.

Each mobile node (user terminal) has a unique identification address. Every 10 seconds the location information in the user terminal will be refreshed. After the reference node received the terminal information, it will send its signal information to the user terminal. The user terminal will calculate its current position accordingly using the approach introuced in Section 2, display the position on the terminal. The positioning process is shown in Figure 5.

4 Evaluations

To evaluate the effectiveness of the proposed approach, we simulate a running case of supermarket with the deployment of Zigbee devices as shown in Figure 6. Twelve reference nodes are deployed in an area of 40m*40m as shown in Figure 6. Different algorithms are experimentally simulated with Matlab, and the simulation results are shown in Figure 6. In the evaluations, we will compare our work with DPTM + TA (trilateration algorithm), and DPTM + WCLA, which are two popular approaches currently available.

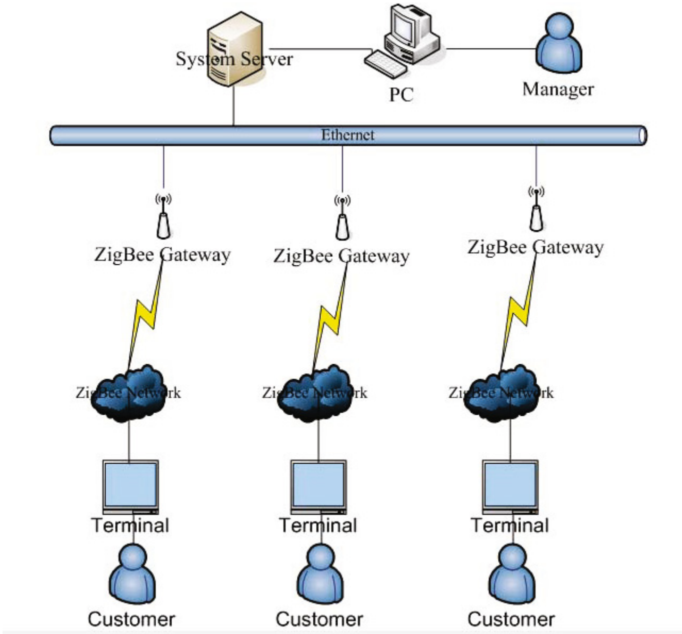

Fig. 4. Architecture of the positioning system

Before simulation using the Matlab, we need to have a clear understanding of aisles in a supermarket, and use linear functions to represent the aisles in order to use the location approximation algorithm. To simulate the RSSI signal, some Gaussian noises are added into the analog RSSI value according to a empirical formula using actual distances from the mobile node to the reference node. Then the dynamic position tracing model is use to smooth these RSSI values, followed by the usage trilateration algorithm or weighted centroid algorithm to estimate the coordinate of the mobile node. For the location approximation algorithm, the distance of a point to a straight line is calculated to make the estimated coordinates approach the nearest aisle.

Figure 7 shows the average error analysis of the three algorithms. It is obvious that the average error of the trilateration algorithm based on DPTM varies greatly, whereas the other two algorithms can get more stable results. However, the average error of our proposed approach is significantly less than that of the weighted centroid algorithm based on DPTM.

We show the detailed measurements in Table 1.

In our simulation, the reference nodes are configured in a reticular way, and at the same time, the nodes are configured to equilateral triangles. Such a configuration can avoid taking three RSSI values in a straight line, and the density of the number of nodes have little effect on the accuracy. This configuration will help to improve the accuracy of localization.

Through these measurements, we can see that the hybrid positioning approach proposed in this paper have a much better accuracy compared to the DPTM +

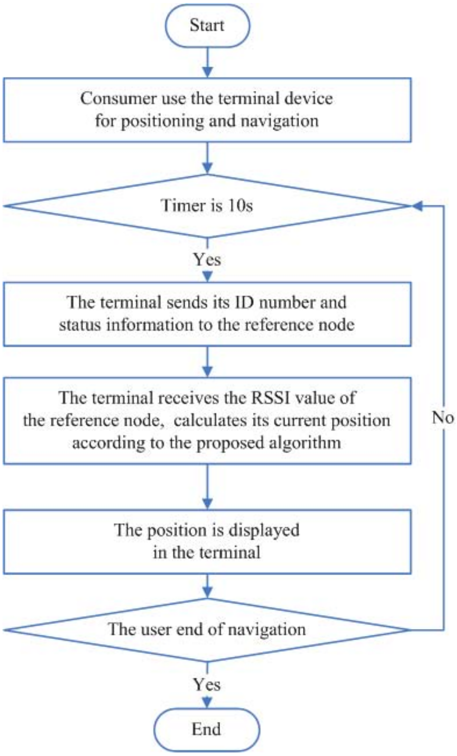

Fig. 5. Working flow the positioning system

TA and DPTM + WCLA approaches. Its accuracy improved 22% compared with DPTM + WCLA, and improved 40% when compared to DPTM + TA. In our approach, the randomly distibuted points are moved to the nearest straight line. This can avoid the possibility of somewhere that are not reachable at all, and makes the positioning more accurate. We may note that our approach has a limitation that it is not accurate for some very wide corridors when a user can move in a large area. But for supermarkets and normal apartments/villa/buildings, the aisle/corridors are usually long and narrow where our approach will work well.

5 Related Work

Reichenbach and Timmermann [3]proposed RSS based localization algorithm with weighted centroid method for indoor wireless senser networks, which offers low communication overhead and low computational complexity. The approach in this paper borrowed these ideas, and we also propose to use the location approximation to enhance the accuracy of positioning. The evaluations show that we achieved better accuracy.

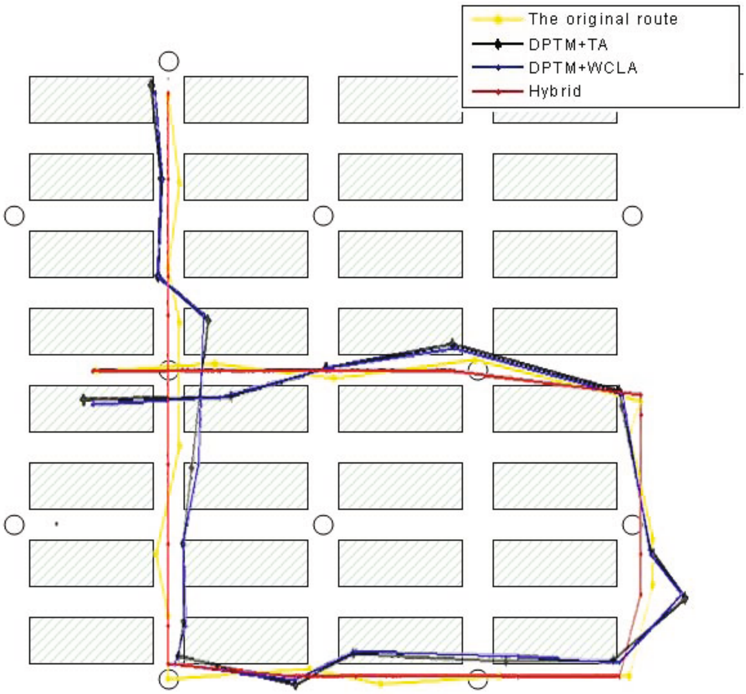

Fig. 6. Simulation result and comparisons of different localization algorithms

Swangmuang and Krishnamurthy [14] propose a new analytical model for estimating the probability distribution of fingerprint selection in an indoor positioning system using WLANs and location fingerprinting. This work needs a lot of efforts to build fingerprint database and we argue that it is more computation-heavy than our approach, as we do not need to compare any fingerpints and analyze these fingerprints, and may not suitable for real time localization, especially when we consider to make the localization work on small devices.

A context-aware tracking system is presented in [10], where power meter nodes are deployed throughout a building. A user carried a mobile node that tracked their current position. A smartphone is used to view the current position for a mobile node , via a cellular or wireless LAN connection. The context-aware tracking system localized a person's position by combining wireless trilateration, a dynamic position tracking model, and a probability density map. Our approach is less complex than that in [10] and we hope that our approach will consume less power. Through evaluations we can also see that our approach can achieve better location accuracy.

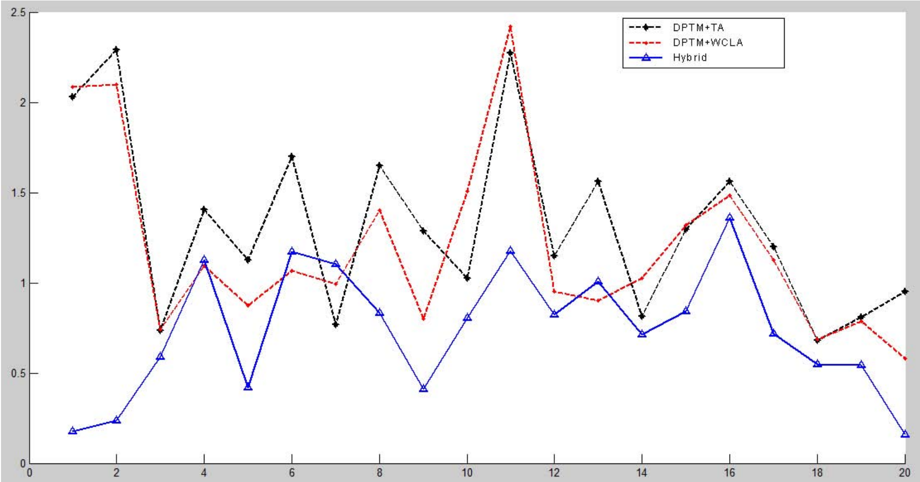

Fig. 7. Average error comparisons of different localization algorithms

Table 1. Detailed measurements for the three approaches

errorm	DPTM + TA	DPTM+ WCLA	Hybrid
Average	1.27	1.04	0.65
Maximum	3.11	1.57	1.28
Average	1.51	1.18	0.9
Maximum	2.9	2.72	2.7
Average	1.66	1.18	0.96
Maximum	4.4	4.02	3.92
Average	1.18	0.81	0.74
Maximum	4.91	2.07	2.29
Average	1.39	1.11	0.83
Maximum	2.7	2.38	2.56
Average	1.22	0.84	0.76
Maximum	2.03	2.24	2.21
Average	1.52	1.28	0.86
Maximum	4.57	3.2	2.6
Average	1.42	1.2	1.01
Maximum	3.05	2.62	3.88
Average	1.11	0.89	0.66

In [7], Kalman filter was applied to the fingerprint based indoor tracking. It was shown that the use of Kalman filter improved the accuracy of the indoor tracking. But for a complex trajectory, the Kalman filter didn't perform well in a corner and could not deal with the nonlinear factors in the tracking. Several filtering methods are compared in [11]. The accuracy of Analytic Moment Calculation (AMC) algorithm is the best among the filters that can achieve the accuracy of 2.5m of average error. Using filtering algorithms alone without considering human behaviors and characteristics of environments, it is hard to achieve high accuracy of positioning. In our work, the average error is in the range of 1m.

6 Conclusions and Future Work

Providing a navigation service in a supermarket is very useful for customers and sellers. Though there are a lot of indoor positioning research, but the problems of the existing approaches are the accuracies are not good enough to be used in a supermarket where the aisle may be long and narrow, and also most of the existing algorithms are too complex. In this paper, we proposed the location approximation algorithm to improve the accuracy of indoor positioning, which can be used together with other algorithms. We explored to use WCLA and DPTM together in this paper, as a hybrid approach to provide supermarket navigation. The evaluations show that our approach can achieve good accuracy compared to the existing approaches.

As the work reported are evaluated only through simulations, we will conduct real tests when we get our Internet of Things testbed which are currently on the way. In the real testing, we will evaluate again the accuracy of positioning and compare the results from simulation. Other important work is that we need to evaluate the power consumption of the mobile nodes and also the reference nodes. Together with the performance testing on how long it takes to obtain the position information. We will also work on viewing the location information on smartphones instead of a terminal screen.

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