Sensors & Transducers, Vol. 160, Issue 12, December 2013, pp. 125-129

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Sensors & Transducers

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A Novel Localization Solution Supported by ZigBee Wireless Sensor Network

[1, 2] Jianqi LIU, [1] Qinruo WANG, [2] CaiFeng ZOU, [2] YanLin ZHANG
[1] College of Automation, Guangdong University of Technology, Guangzhou, China
[2] College of Information Engineering, Guangdong Jidian Polytechnic, Guangzhou, China
E-mail: liujianqi@ieee.org, wangqr2006@gdut.edu.cn, ylzhxx@gmail.com

Received: 23 September 2013 /Accepted: 22 November 2013 /Published: 30 December 2013

Abstract: ZigBee network is popular ad hoc wireless sensor network (WSN) with low-power consumption, low cost, low complexity. But in fact as low localization accuracy, the ZigBee localization scheme is not large-scale use. In order to satisfy the demand for a large number of location-based applications, we add the interrupt module into the ZStack 2007 communication protocol, which improves the real-time processing capabilities, and reduce the power consumption of overall system. Meanwhile, this paper proposes reliability weighted TOA localization algorithm to mitigate the interference, and improve the positioning accuracy. Experiments and simulations show that this localization solution has a great advantage than the traditional solution. *Copyright © 2013 IFSA.*

Keywords: Localization, ZigBee, RSSI, Reliability weighted TOA.

1. Introduction

Traditional localization systems usually use optical localization technology (like laser scanning, image recognition) and sonic localization (ultrasonic). Since optical and sonic systems have backsides like highly-complex deployment, expensive cost, line of sight (LOS), these solutions are given up in indoor environment gradually [1-3]. With the rapid growth of WSN, WSN-based localization technology gradually appears in practical application in recent years as easier deployment, convenient maintenance, and low cost. Wireless localization is base-station localization (such as Chirp spread spectrum (CSS), Ultra wideband (UWB), WiFi, and RFID) [4, 8]. With the introduction of the ZigBee technology, people begin to research ZigBee–based positioning technology. 2006, Texas Instruments (TI) company pioneered a localization solution CC2431, which is system on a chip (SoC), equips a localization engine and is compatible with the ZigBee protocol. This family of chips can meet a variety of applications requirements, including asset and equipment tracking, patient monitoring, remote control, security monitoring network. But this chip has some defects, such low storage capability, and the short wireless transmission distance. Therefore, TI releases enhanced chip CC2530 in 2009, which have bigger storage capability (256k), and longer transmission distance. However, the type of chip have not localization engine. So we should achieve the localization function based on CC2530 [5, 6].

The remainder of this paper is organized as follows: We add the interrupt module into ZStack ZigBee protocol in Section 2. In Section 3, we emphasize the localization algorithm. We take reliability weighted TOA algorithm to reduce the error. Section 4 outlines the simulation results, and Section 5 makes a conclusion.

2. Related Works

CC2530 is widely used in localization filed with the features of low-power RF, small package, and powerful performance. Since the received signal strength indication (RSSI) decreases with increasing distance, CC2530 estimate the location of mobile node according to the received RSSI values. Mobile node sends the RSSI value to the server, the server calculates location based on the localization algorithm and network topological structure. Fig. 1 shows a typical network topological structure.

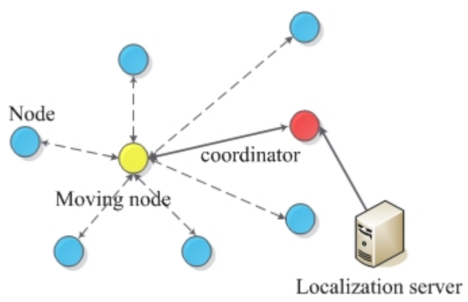

Fig. 1. Typical network topology.

In order to achieving more accurate than the existing indoor localization system, we have two work to do, first is to improve the existing localization algorithm, we will discussed in detail in Section 3; second is the expansion and improvement of existing ZigBee communication protocol, we will add interrupt module into existing protocol.

CC2530 use the ZStack2007 as communication protocol. ZStack2007 started by the main function, main functions were to do two things: First is initialization, the second is that beginning to poll whether there is a task needs to execute. During system initialization stage, the system initializes memory, stack and other hardware unit; then system begins execution of polling. Since the system is based on polling, operating system abstraction layer (OSAL) will execute the task according to the priority. If one task have not complete, the other task cannot be scheduled. The drawback of polling model is that poor real-time, and bring big burden to the router, coordinator and node, increasing the power consumption [7, 9, 10].

In this paper, we improve the protocol by introducing the interrupt into protocol. After using interrupt mode, whenever the state of the sensor node is changed, the node will send a message to the coordinator so that the coordinator can be collected status of the nodes in real time, and then sent to the server. Obviously, this interrupt way will achieve higher real-time with the node sending actively status information. Meanwhile, we can activate power control function in main task. If interrupt does not appear, the node enter sleep mode. So the whole system is in a low power state, thus greatly extend the sensor nodes battery life. The interrupt service flow is shown in Fig. 2.

3. Localization Algorithms

Time of arrival (TOA) localization algorithm is based on circle equation, by the intersection between the circle and the circle with different combinations of different positioning structure of the equations [7].

Analysis from the geometric model, if the signal arrival time from mobile node S to the base station i is get, the distance between S to i can be calculate. If there are 3 base station around the mobile node, location of mobile node will be calculate by the formula (1).

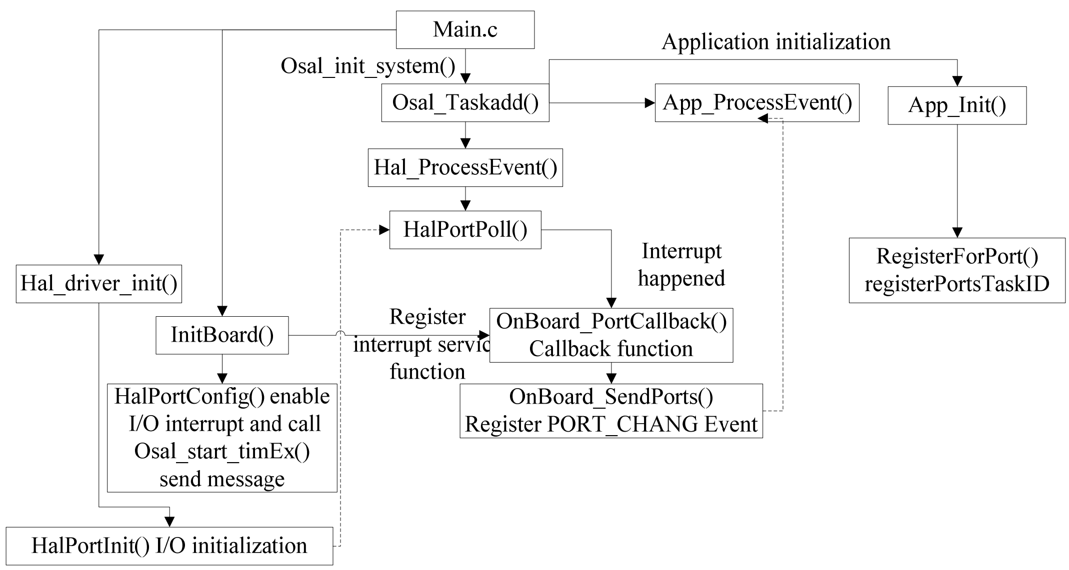

Fig. 2. Interrupt service process flow.

$$D_i = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2}, i = 1,2,3 \quad (1)$$

where (x_i, y_i) represents i^{th} base station coordinate, (x_s, y_s) is mobile node coordinate, its geometry is shown in Fig. 3.

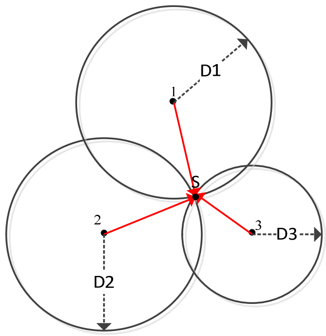

Fig. 3. TOA Geometry model in LOS.

Caffery proposed three intersecting line model is that, the first get the TOA measurement equation of three base stations, and then by measuring the intersecting lines equation, such as the base station 1 and station 2, using equation of base station 1 subtract equation of base station 2, the resulting equation of intersecting lines is shown in formula (2).

$$(x_2 - x_1)x_s + (y_2 - y_1)y_s = \frac{1}{2}[(x_2^2 + y_2^2) - (x_1^2 + y_1^2) + D_1^2 - D_2^2], \quad (2)$$

Similarly, over base station 2 and base station 3 the intersection of two circles intersecting line equation is shown in formula (3):

$$(x_3 - x_2)x_s + (y_3 - y_2)y_s = \frac{1}{2}[(x_3^2 + y_3^2) - (x_2^2 + y_2^2) + D_2^2 - D_3^2], \quad (3)$$

Intersection point coordinate (mobile node coordinate) can be to work out from simultaneous formula (2) and formula (3). (x_s, y_s) is solved from formula (4).

$$x_s = \frac{(y_2 - y_1)C_3 - (y_3 - y_2)C_1}{[(x_3 - x_2)(y_2 - y_1) - (x_2 - x_1)(y_3 - y_2)]}$$
$$y_s = \frac{(x_2 - x_1)C_3 - (x_3 - x_2)C_1}{[(y_3 - y_2)(x_2 - x_1) - (y_2 - y_1)(x_3 - x_2)]}, \quad (4)$$

where

$$C_1 = [(x_2^2 + y_2^2) - (x_1^2 + y_1^2) + D_1^2 - D_2^2]$$
$$C_3 = [(x_3^2 + y_3^2) - (x_2^2 + y_2^2) + D_2^2 - D_3^2],$$

In the actual environment, especially the urban, the signal propagation path between mobile node and base station will be blocked by the building, the signal propagate by reflection, refraction mode in non-line-of-sight (NLOS) environment. At this point, the calculated distance in NLOS environment is longer than in LOS environment. If still use Caffery measure method, the results don't necessarily accurate. Therefore, we should consider the influence of NLOS propagation to wireless localization. TOA Geometry model in NLOS is shown in Fig. 4.

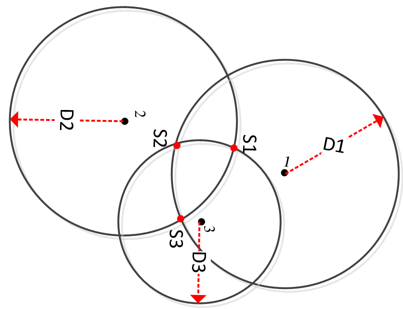

Fig. 4. TOA Geometry model in NLOS.

We propose using reliability weighting method to calculate the estimated position of the mobile node, to improve the localization accuracy. Generally, the stronger received signal strength of the mobile node is, the shorter the distance of signal propagation is. Relative to other node with weaker signals strength, this type nodes is more reliability, which is encountered less obstacles in the process of signal transmission, have high reliability. We will transform received signal strength (RSSI value) into the reliability values, then use reliability values as weight values for estimating the location of mobile node. Let the mobile node *S* RSSI value from three beacon nodes respectively: RSSI_A, RSSI_B, RSSI_C. After the mobile node weighted estimate is shown in formula (5).

$$X_S = \frac{\alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3}{3}$$
$$Y_S = \frac{\alpha_1 y_1 + \alpha_2 y_2 + \alpha_3 y_3}{3}, \quad (5)$$

where α_1, α_2, α_3 are the weighting coefficients:

$$\alpha_1 = \frac{RSSI\_A}{RSSI\_A + RSSI\_B + RSSI\_C}$$
$$\alpha_2 = \frac{RSSI\_B}{RSSI\_A + RSSI\_B + RSSI\_C}$$
$$\alpha_3 = \frac{RSSI\_C}{RSSI\_A + RSSI\_B + RSSI\_C},$$

The end, the coordinates of mobile node is got.

4. Experiments and Simulation

Since we selected experimental site is relatively small, build a small mesh network topological structure for test and simulation, the network topological structure is shown in Fig. 1. We use the CC2530 ZigBee chip as hardware platform, wherein, a mobile node, a coordinator, and some beacon nodes, the part hardware devices are shown in Fig. 5.

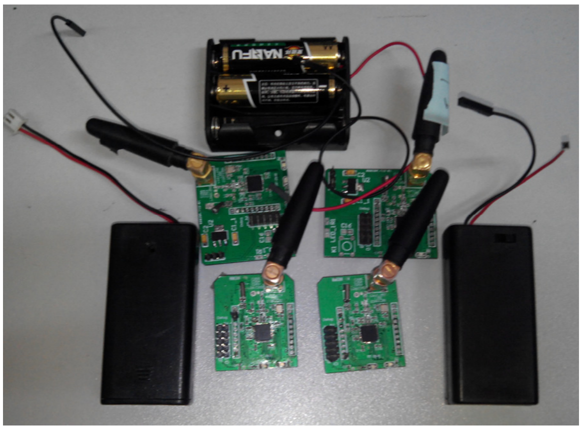

Fig. 5. Hardware platform.

We have improve the communication protocol by adding interrupt function based on TI's ZStack2007. Localization program is implemented on the server. When the mobile node needs to trace, the mobile node broadcasts request packet to the beacon nodes for positioning; the beacon nodes will send packet to the mobile node; the mobile node select the three strongest signal strength beacon nodes , and then send RSSI values to the server (personal computer) through the wireless transmission. The server will convert RSSI value into a corresponding distance and by the improved TOA algorithm to calculate the location of the corresponding mobile node.

The distance can be calculated by RSSI according the formula (6).

$$D_i = 10^{\frac{P_0 - P_i}{10n}}, i = 1,2,3 , \tag{6}$$

where P_0 represents the signal strength in beacon node, P_i represents the signal strength of received by mobile node, the signal is derived from i^{th} beacon node, n represents an obstacle attenuation factor between the transmitter to the receiver, this is related to the specific environment channel. Table 1 lists the measured RSSI value and corresponding distance; Table 2 lists the estimated coordinate value (*x, y*) mobile node under TOA algorithm and reliability weighted TOA algorithm.

Table 1. The RSSI and corresponding distance between Mobile node and beacon node.

	BS1				BS2				BS3			
	1	2	3	4	1	2	3	4	1	2	3	4
RSSI	-47	-48	-50	-45	-50	-55	-49	-52	-53	-57	-51	-54
D value	1.000	1.0798	1.2589	0.8577	1.2589	1.8478	1.1659	1.4678	1.5849	2.1544	1.3594	1.7113

Table 2. The estimated value (coordinate) of mobile node.

TOA estimate value	X	16.5	6.2	4.6	2.7	11.2
	Y	19.7	6.3	5.6	8.2	9.2
Reliability weighted TOA estimate value	X	15.5	4.2	3.9	3.9	12.9
	Y	20.5	5.0	6.4	7.6	9.3

Fig. 6 shows positioning error analysis of reliability weighted TOA.

Fig. 7 shows the accuracy comparison between TOA and reliability weighted TOA.

By Tables 1, 2, it can be seen that compared reliability weighted TOA with TOA positioning algorithm, the estimated location is closer to the actual location of mobile node. As can be seen from Fig. 6, 7, compared reliability weighted TOA with TOA, the positioning accuracy have significantly improvement. Simulation shows that the reliability weighted TOA algorithm is feasible and effective.

5. Conclusions

With the development of wireless sensor network, using WSN as localization technology is more and more popular. ZigBee is low cost, small, low power technology, which is no doubt that can become one of best choice for the indoor positioning, in spite of the disadvantage of poor real-time performance and low accuracy. This paper takes two methods to improve the performance of ZigBee localization system. The first is that realize interrupt function improve the real-time performance, the second is that use reliability weighted TOA algorithm to reduce the positioning error. The experimental results show that the solution is feasible. But there are some issues to solve in the future, such as MAC layer optimization, or energy-save issues.

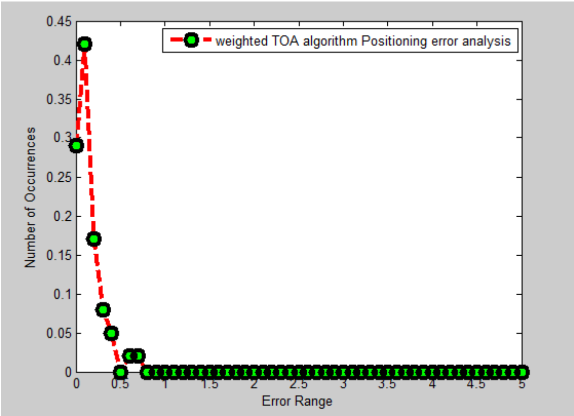

Fig. 6. Positioning error analysis of reliability weighted TOA.

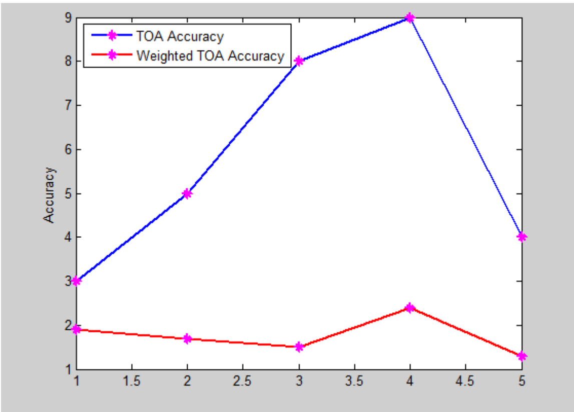

Fig. 7. The accuracy comparison.

Acknowledgements

The authors would like to thank the Natural Science Foundation of Guangdong Province, China (No.9151009001000021, S2011010001155), the Ministry of Education of Guangdong Province Special Fund Funded Projects through the Cooperative of China (No. 2009B090300 341), the National Natural Science Foundation of China (No. 61262013), the High-level Talent Project for Universities, Guangdong Province, China (No. 431, Yue Cai Jiao 2011), the Chinese Society of Vocational and Technical Education 2012-2013 scientific research and planning projects (No. 204921), and 2013 Higher vocational education teaching reform project of Guangdong province (No. 20130301011) for their support in this research.

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