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Review

A study of indoor positioning by using trigonometric and weight centroid localization techniques

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An indoor positioning system was developed to provide a fast and easy determination of unknown position coordinates. Wireless sensor nodes (WSN) are employed in a test area. Trigonometry techniques were employed to determine the position of the unknown objects by employing numerical analysis techniques on received signal link quality indicator (LQI) values. The distances between the unknown object position and the WSNs are calculated by using curve fitting techniques on received LQI values. Weight centroid localization (WCL) algorithm was introduced on the results of the trigonometry techniques to improve the position accuracy. An application program (AP) was developed to control and display all the results.

Key words: Wireless sensor nodes (WSN), weight centroid localization (WCL), transmitter, receiver, received signal strengths (RSS), received signal strength indicator (RSSI), link quality indicator (LQI), application program (AP).

INTRODUCTION

Wireless sensor nodes (WSN) technology is widely used to realize the positions of objects in different environments. It is employed for variety of indoor position detection (Lionel, 2004). There are many types of position identification systems using optical (Want et al., 1992, 1997), ultrasonic (Ward et al., 1997; Harter et al., 1999) and RF wireless technologies (Bahl and Padmanabhan, 2000; Hightower et al., 2000; http://www.aimglobal.org/technologies/rfid/; Konrad et al., 2005). Each has their own strengths as well as limitations.

WSN technology has several advantages such as having no contact and none line-of-sight nature. All transmitters can be read in extreme environmental conditions (http://www.aimglobal.org/technologies/, 2005; koyuncu and Yang, 2010).

To define the exact coordinates of the unknown sensor node, there is a need to measure the distances between the unknown node and the known transmitter nodes. These measurements require to measure the time of interval (TOA) or to measure the time difference of arrival (TDOA). Due to the difficulties of time measurements resulting from synchronization of WSNs and complicated electronics, these mea-surement techniques are not frequently employed. Received signal strengths (RSS) values are used to realize the unknown positions.

RSS values are represented in the form of LQI values by the Zigbee devices. In the study, WSNs are strategically placed in indoors and identified as transmitter nodes. An unknown sensor node which is also a WSN was identified as an unknown receiver mobile node. The receiver mobile node receives the transmitted signal packets in the form of LQI values from transmitter nodes, sends them to an attached PC. The topology is illustrated in Figure 1.

The wireless sensor node localization can be defined as finding the location of an unknown mobile node with respect to distances between the transmitter nodes and the unknown node. In this study, A well known weight centroid localization (WCL) method was employed. Unknown positions are calculated by dividing the test area into triangles and using numerical analysis technique to determine the locations of the unknown objects with respect to known WSNs.

RSSI and LQI

Received signal strength indicator (RSSI) is a parameter to identify the incoming radio signal. The transmitter

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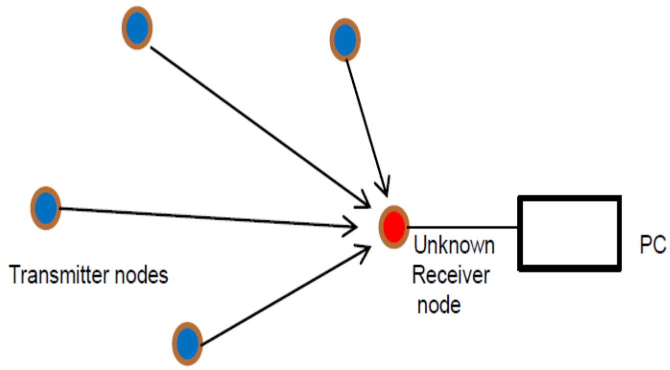

Figure 1. Topology of wireless sensor nodes.

power (P_T) at the transmitter node directly affects the received power (P_R) at the receiver device. The free space transmission equation (Rappaport, 1996), is given in Equation 1.

$$P_R = P_T.G_T.G_R.\left(\frac{\lambda}{4\pi d}\right)^2 \quad (1)$$

Where, P_T = transmit power. P_R = received power. G_T = gain of transmitter. G_R = gain of receiver. π = wave length. d = distance between transmitter and receiver. As it is seen in Equation 1, the received power decreases with the inverse square of the distance. In WSNs, the received signal strength is converted to RSSI. It is defined as the ratio of the received power to a reference power (P_{REF}) where P_{REF} = 1mW. Hence, RSSI can be expressed as:

$$RSSI = 10.\log\frac{P_R}{P_{REF}} \quad (2)$$

It can be concluded from here that RSSI value is also inversely proportional with d values. In practice propagating radio signal is effected and interfered by many environmental factors. Hence, in many applications, RSSI has a high variance and the localization of unknown node becomes very imprecise.

Another method of distance determination is carried out by LQI of transmission. According to IEEE 802.15.4 standards, LQI is identified as the strength of the received signal. It is proportional to RSSI and has a value between 0 to 255 (Ergen, 2004). Hence, RSSI can be directly mapped to LQI (Zigbeready, 2007). The transmitter nodes transmit the signal packets continuously. The receiver mobile node logs the LQI of the incoming signal packets and sends them to PC.

The position of the transmitter node varied between 0 and 40 m with respect to receiver mobile node. The recordings of LQI values received by the receiver mobile node are carried out in obstacle free outdoor space. The recording process is carried out with each transmitter. It was observed that their LQI versus distance plotting's were close to each other. An average plot of 4 transmitters is carried out and presented in Figure 2.

LQI of incoming radio signals decreases with increasing distance "d" between transmitter and the receiver in free space. Hence, LQI measurements versus distance curve also display a close correlation between LQI and the distance d (Ralf, 2007).

The free space model for recordings of LQI values versus d distances is used to calibrate the indoor values of d with respect to LQI for short distances. The test area in the study had no obstacles and it was approximated to a free space model for short distances. The reflections from the outside walls were considered negligible. A curve fitting technique (MATLAB v.9) is employed and a 5th polynomial curve is best fitted with 95% confidence boundaries on the recorded LQI values as seen in Figure 3. The curve fitted equation for the received LQI data between 0 and 40 m is generated by MATLAB and is shown in Equation 3.

$$LQI(d) = P_1.x^5 + P_2.x^4 + P_3.x^3 + P_4.x^2 + P_5.x^1 + P_6 \quad (3)$$

Where P_1 = -6.939exp (-005), P_2 = 0.007404 , P_3 = -0.2938, P_4 = 5.369 , P_5 = -46.14 , P_6 = 228.3.

A numerical analysis technique which is identified as bisectioning algorithm (http://en.wikipedia.org/wiki/Bisection_method), is used first time to determine the distance between the unknown node and each transmitter once its corresponding LQI value is known.

It is also called root finding method which repeatedly bisects the interval between the transmitter and the receiver and then selects a sub interval in which a root must lie for further processing. When an unknown LQI value is received from a transmitter and recorded in computer, its corresponding d value will be calculated by applying bisectioning algorithm with Equation 3.

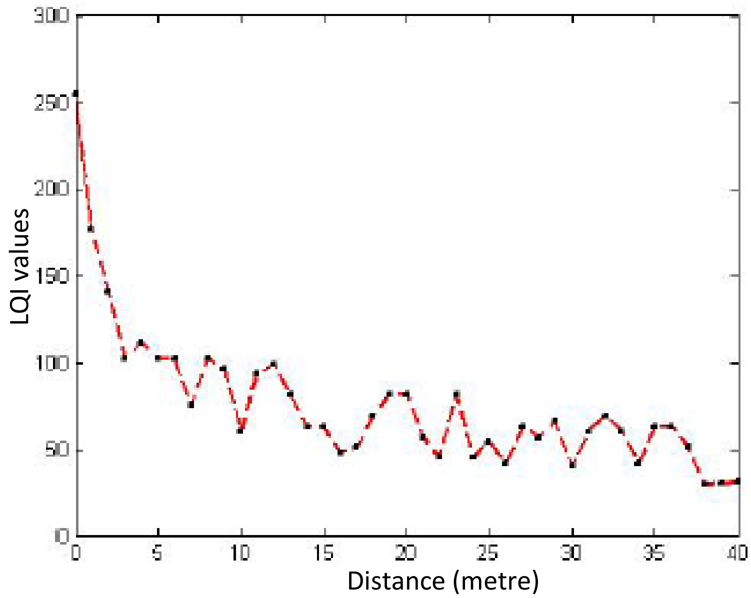

Figure 2. LQI values versus distance in m.

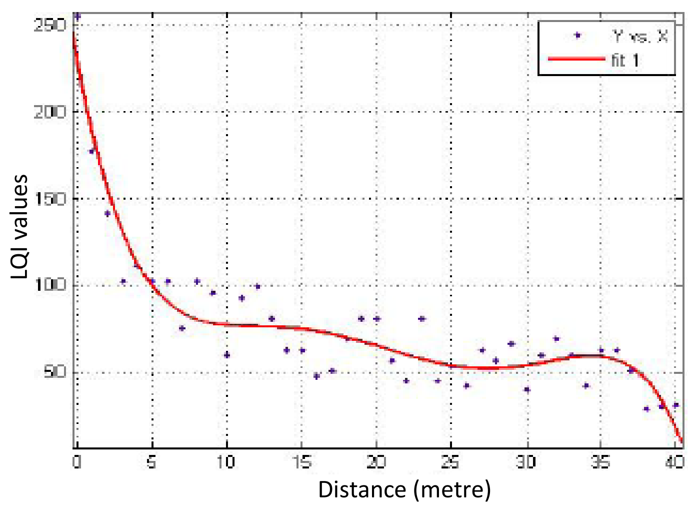

Figure 3. Curve fitted LQI values.

Trigonometric techniques will be employed with these d values to determine the positions of the unknown nodes. WCL technique will also be employed at a later stage to refine the previously calculated positions of the unknown nodes.

TRIGONOMETRY

Recordings of LQI values are carried out by the unknown mobile node in the test area. The corresponding d distance for each LQI is also calculated by using numerical methods. The block diagram of the rectangular test area is shown in Figure 4. The unknown mobile node P has four d values (d_A, d_B, d_C, d_D) at every location. Each of them corresponds to the distance between a transmitter and itself.

The unknown node P(x, y) could be in anywhere in the test area. The trigonometric equations corresponding to x and y coordinates of point P in $B_1B_2B_3B_4$ test area can be given by:

$$x^2 + y^2 = d_A^2 \tag{4}$$

$$y^2 + (5 - x)^2 = d_B^2 \tag{5}$$

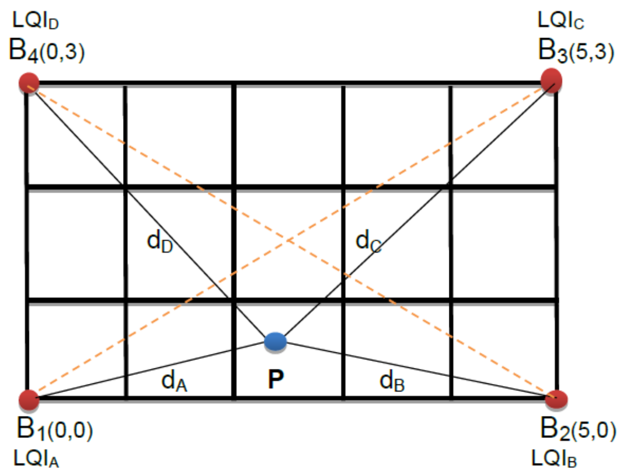

Figure 4. 5 × 3 m test area with B_i transmit- ters and P unknown mobile node.

$$(5-x)^2+(3-y)^2=d_C^2 \quad (6)$$

$$x^2+(3-y)^2=d_D^2 \quad (7)$$

Where B_1B_2 is the x axis and B_1B_4 is the y axis with B_1 is the (0, 0) coordinate center.

The test area is divided into sub sections in the shape of triangles and the coordinates of the unknown node are calculated with respect to these triangles. There are 4 triangles in test area which are $B_1B_2B_4$, $B_1B_2B_3$, $B_1B_4B_3$ and $B_4B_3B_2$. The unknown node could be in any one of these triangles. For example if P(x,y) is inside or outside the $B_1B_2B_4$ triangle, the x,y coordinates can be calculated as:

$$P_1(x,y)=\left(\frac{d_a^2-d_b^2+25}{10},\frac{d_a^2-d_d^2+9}{6}\right) \quad (8)$$

Similarly P_2(x, y) for $B_1B_2B_3$ triangle is:

$$P_2(x,y)=\left(\frac{d_a^2-d_b^2+25}{10},\frac{d_b^2-d_c^2+9}{6}\right) \quad (9)$$

P_3(x,y) for $B_1B_4B_3$ triangle is:

$$P_3(x,y)=\left(\frac{d_b^2-d_c^2+25}{10},\frac{d_a^2-d_d^2+9}{6}\right) \quad (10)$$

P_4(x, y) for $B_4B_3B_2$ triangle is:

$$P_4(x,y)=\left(\frac{d_d^2-d_c^2+25}{10},\frac{d_b^2-d_c^2+9}{6}\right) \quad (11)$$

By using these equations, unknown coordinates of the unknown node P(x, y) can be calculated by substituting (d_a, d_b, d_c, d_d) values in Equations 8 to 11 with respect to 4 triangles in the rectangular test area.

WCL

WCL introduces weights to improve the localization (Jan, 2007). Weight function is expressed by w_{ij} and the estimated position of the unknown node is defined by:

$$P_i(x,y)=\frac{\sum_{j=1}^{n}(w_{ij}.B_j(x,y))}{\sum_{j=1}^{n}w_{ij}} \quad (12)$$

Weight function w_{ij}, depends on the distance of the unknown receiver node to transmitter node. Shorter distances have more weight than longer distances. Therefore, w_{ij} and d_{ij} are inversely proportional and this relationship is expressed as:

$$w_{ij}=\left(\frac{1}{d_{ij}}\right)^k \quad (13)$$

d_{ij} is the distance between transmitter B_j and unknown receiver node P_i. k is the degree. The distance is raised to high powers of k in order to get longer distances to have lower weights. But if a very high degree k is used, estimated position moves to the closest transmitters and the position error e increases. Hence there is an optimal k value exists for minimum error e. This k value is determined as 1 in the literature.

Figure 5. Transmitter (Left), Receiver (Right).

Figure 6. Test bed area.

The position error e is represented by the distance between the actual position, (x_r, y_r) and the estimated position, (x_e, y_e) of the unknown node. It is expressed as:

$$e = \sqrt{(x_e - x_r)^2 + (y_e - y_r)^2} \qquad (14)$$

Positions of several unknown nodes will be determined and their error margins with respect to their actual positions will be calculated with Equation 14.

IMPLEMENTATION

JENNIC JN5139 wireless sensor nodes were deployed in the experiments (http://www.jennic.com/jennic_support/application). The Zigbee Home Sensor demo program was used to program JN5139 active devices to work as fixed transmitter nodes and mobile receiver node, respectively (http://www.jennic.com/files/support_documentation). The active transmitter/receiver pair used in this study is shown in Figure 5.

JN5139 receiver is interfaced to a PC through a USB port. ZigBee protocol which is based on the IEEE 802.15.4 protocol in the 2.4 GHz band is used during the data communication between the fixed and mobile nodes.

The test bed is on a single empty floor inside a building as seen Figure 6. A rectangular grid of 5 x 3 m is defined over the two-dimensional floor plane and all the unknown node positions are limited to grid points. Any position in the rectangular test area is implemented by P(x, y) coordinates. WSN trans-mitters are placed in the 4 corners of this test area.

The unknown mobile receiver node is positioned at any point in the test area interfaced to a computer. For the grid area of 5 x 3 m, there are 24 grid points. Receiver node is placed at each grid point and 4 LQI readings at each grid point are recorded by the receiver.

A total of 24 x 4 = 96 LQI entries are recorded in the data base. Each entry in the database includes a mapping of the grid coordinate (x, y) and d distances (d_A, d_B, d_C, d_D) of each grid point to 4 transmitters. Received LQI values exhibit a strong correlation with the receiver aerial orientation as well as its location. The LQI measurements at one location vary depending on the orientation. In the analytical model, the variations due to aerial orientation have been averaged out when the LQI is recorded for 4 compass directions by the receiver.

The outdoor free space recordings of LQI values at short ranges of less than 5 meters were approximately same with the obstacle free indoor test area recordings. Hence the radio wave reflections from the walls around the test area were considered negligible.

A visual C# based application program (AP), has been developed to control entire data manipulation and calculation process. As a result of communication between the mobile receiver and 4 transmitter nodes at every grid point, 4 LQI values and the grid coordinates are transferred to PC. Additionally, the distances (d_A, d_B, d_C, d_D), between each grid point and 4 transmitter nodes are also calculated. All the relevant data in the PC is further put in the form of a database by using Microsoft access.

CALCULATIONS

Trigonometry method

During measurements, AP measures four LQI values at an unknown location in the grid. These LQI values are recorded and the corresponding d values, (d_A, d_B, d_C, d_D) are calculated by using numerical methods on the fitted curve in Figure 3.

Once 4 d values are identified for each unknown location they are used to calculate the unknown coordinates P(x, y) of the unknown location by using previous four triangles defined as P_1(x, y), P_2(x, y), P_3(x, y) and P_4(x,y). These coordinates together with corresponding LQI and d values are tabulated in Table 1.

In conclusion, unknown location (x, y) coordinates are calculated for each triangle and there are 4 calculated P(x, y) values for each unknown location.

Table 1. P(x,y) unknown coordinates for each triangle test area.

Unknown (x,y) position coordinates	LQI values of mobile node at unknown positions				d values calculated with bisectioning algorithm for each LQI values				P_1, P_2, P_3, P_4 points calculated with trigonometric methods							
	LQI_A	LQI_B	LQI_C	LQI_D	d_A	d_B	d_C	d_D	P_1(x,y)		P_2(x,y)		P_3(x,y)		P_4(x,y)	
1, 1	110	120	125	150	3.43	2.96	2.96	2.03	2.80	2.78	2.80	1.50	2.03	2.78	2.03	1.50
1, 2	105	100	95	180	3.43	3.43	3.43	1.17	2.50	3.24	2.50	1.50	1.45	3.24	1.45	1.50
2, 1	95	145	95	137	3.43	2.34	3.43	2.65	3.13	2.29	3.13	0.44	2.02	2.29	2.02	0.44
3, 0	95	145	93	145	3.43	2.34	3.43	2.34	3.13	2.55	3.13	0.44	1.86	2.55	1.86	0.44
3, 2	97	151	108	132	3.43	2.03	3.43	2.65	3.26	2.29	3.26	0.21	2.02	2.29	2.02	0.21
4, 1	92	129	121	111	3.43	2.65	2.96	3.43	2.97	1.50	2.97	1.20	2.80	1.50	2.80	1.20

Table 2. Distances between P and respective triangle corners for each unknown location.

Unknown locations	Calculated P(x, y) points and their distances to respective triangle corners			
(1, 1)	P_1(2.8, 2.7)	P_2(2.8, 1.5)	P_3(2.0, 2.7)	P_4(2.0, 1.5)
	dA=3.94	dA=3.17	dA=3.44	dC=3.32
	dB=3.54	dB=2.66	dC=2.97	dB=3.32
	dD=2.8	dC=2.66	dD=2.04	dD=2.52
(1, 2)	P_1(2.5, 3.2)	P_2(2.5, 1.5)	P_3(1.4, 3.2)	P_4(1.4, 1.5)
	dA=4.09	dA=2.91	dA=3.55	dC=3.84
	dB=4.09	dB=2.91	dC=3.55	dB=3.84
	dD=2.51	dC=2.91	dD=1.47	dD=2.09
(2, 1)	P_1(3.13, 2.29)	P_2(3.13, 0.44)	P_3(2.02, 2.29)	P_4(2.02, 0.44)
	dA=3.88	dA=3.16	dA=3.05	dC=3.92
	dB=2.95	dB=1.92	dC=3.05	dB=3.00
	dD=3.21	dC=3.16	dD=2.14	dD=3.25
(3, 0)	P_1(3.13, 2.55)	P_2(3.13, 0.44)	P_3(1.86, 2.55)	P_4(1.86, 0.44)
	dA=4.04	dA=3.16	dA=3.16	dC=4.04
	dB=3.16	dB=1.92	dC=3.16	dB=3.16
	dD=3.16	dC=3.16	dD=1.92	dD=3.16
(3, 2)	P_1(3.26, 2.29)	P_2(3.26, 0.21)	P_3(2.02, 2.29)	P_4(2.02, 0.21)
	dA=3.99	dA=3.27	dA=3.05	dC=4.07
	dB=2.87	dB=1.74	dC=3.05	dB=2.98
	dD=3.34	dC=3.27	dD=2.14	dD=3.44
(4, 1)	P_1(2.97, 1.5)	P_2(2.97,1.20)	P_3(2.8,1.5)	P_4(2.8,1.2)
	dA=3.33	dA=3.21	dA=3.17	dC=2.83
	dB=2.51	dB=2.35	dC=2.66	dB=2.50
	dD=3.33	dC=2.70	dD=3.17	dD=3.32

WCL method

Weighted centroid localization will be introduced with the unknown P(x, y) points to improve their position accuracies. The distances between the P(x, y) and the corners of the corresponding triangle are calculated and used as weights in final recalculation of P(x, y) values. These distance values are tabulated in Table 2.

Recalculated P(x, y) values by using WCL are identified as Q(x, y). Calculation of Q_1(x, y) is shown in Equation 14

Table 3. Calculated unknown position coordinates with error margins.

Unknown locations	Q_1(x,y)	Q_2(x,y)	Q_3(x,y)	Q_4(x,y)	Ave= $(Q_1+Q_2+Q_3+Q_4)/4$	Error (m)
(1,1)	1.5, 1.1	3.5, 1.0	1.5, 2.2	3.0, 2.0	2.4, 1.6	1.5
(1,2)	1.3, 1.3	3.3, 1.0	1.1, 2.3	2.6, 2.2	2.1, 1.7	1.3
(2,1)	1.8, 1.0	3.6, 0.8	1.4, 2.1	3.2, 1.8	2.5, 1.4	0.6
(3,0)	1.7, 1.0	3.6, 0.8	1.3, 2.1	3.2, 1.9	2.5, 1.5	1.5
(3,2)	1.9, 0.9	3.7, 0.7	1.4, 2.1	3.3, 1.8	2.6, 1.4	0.7
(4,1)	1.9, 0.9	3.5, 1.0	1.8, 2.0	3.5, 1.8	2.7, 1.4	1.3
Total average error =(e_1+……..e_6)/6 =						1.1

as an example.

$$Q_1(x,y)=\frac{\frac{1}{d_A}(0,0)+\frac{1}{d_B}(5,0)+\frac{1}{d_D}(0,3)}{(\frac{1}{d_A}+\frac{1}{d_B}+\frac{1}{d_D})} \quad (14)$$

For each unknown location, 4 Q(x, y) values are obtained by using WCL techniques. The average of them represented the final position coordinates of the unknown location (Table 3).

Error calculations from all unknown positions revealed an average error distance of 1.1 m with the optimum weight function of w = 1/d. The average error distance calculations are later compared with the results in the literature.

CONCLUSIONS

In this study, determination of unknown positions by using trigonometric methods is investigated. Test area is divided into sub areas in triangle shapes and unknown position coordinates are calculated with respect to each triangle. Hence, each unknown (x, y) position coordinates had 4 calculated P(x, y) coordinates.

Numerical analysis techniques are introduced first time and the distance between transmitting and receiving WSNs are calculated with respect to LQI values. Received LQI values of WSN nodes are calibrated in free space with respect to distance between transmitter and receiver nodes and the calibration curve was used to calibrate the indoor LQI values for short ranges.

Free space calibration model for short ranges is used first time in obstacle free indoors. The modeling showed similar error distance results with the literature and justified its usage. WCL technique is employed to improve the calculated position accuracy. Distances between the calculated P(x, y) coordinates and the corners of respective triangles are used as weights. These weights are introduced with WCL techniques in each triangle and new unknown position coordinates Q(x, y) are calculated.

The average accuracy between the unknown position and the calculated position is found as 1.1 m. This was similar to the error values of calculated in the literature. For example in reference (Bal et al., 2010), average accuracy error was 1 to 2 m at indoors. In references (ni et al., 2004; Sugano et al., 2006), the average errors were 1 and 1.5 to 2 m, respectively.

Our application of numerical analysis technique to determine the d distances from LQIs introduced a new look into the randomness of the LQIs. An empirical formula is introduced to calculate d values from received LQI values. The error distance calculations revealed that the weight function w_i = 1/d produced the minimum error distances between the actual and the calculated coordinates. There were a few coordinates which did not follow this trend. This was due to the variance of LQI values in time. Finally, Trigonometric method together with WCL method produced a hybrid method of position calculation. This hybrid method generated an error margin of 1.1 m similar to literature. Hence, it can be an acceptable new technique for position detection in indoors.

REFERENCES

Bahl P, Padmanabhan VN (March 2000). RADAR: An in-building RF-based user location and tracking system,in: Proceedings of IEEE INFOCOM 2000, Tel-Aviv, Israel (March 2000), http://www.research.Microsoft.com/padmanab/papers/infocom2000.pdf.

Bal M, Xue H, Shen W, Ghenniwa H (2010). A 3D indoor location tracking and visualization system based on WSNs, IEEE, 978-1-4244-6587, pp. 1584-1590

Ergen SC (2004). "Zigbee/IEEE 802.15.4 Summary" http://pages.cs.wisc.edu/~suman/courses/838/papers/zigbee.pdf

Harter A, Hopper A, Steggles P, Ward A, Webster P (August 1999). The anatomy of a context aware application, In proceedings of the 5th annual ACM/IEEE International conference on Mobile Computing and Networking, pp. 59-68.

Hightower J, Wantand R, Borriello G (February 2000). SpotON: An indoor 3D location sensing technology based on RF signal strength, UW CSE00-02-02, February 2000, http://www.cs.washington.edu/homes/jeffro/pubs/hightower2000indoor/hightower2000indoor.pdf RadioFrequencyIdentification (RFID) homepage, http://www.aimglobal.org/technologies/rfid/ http://en.wikipedia.org/wiki/Bisection_method http://www.aimglobal.org/technologies/rfid/text-Awareness (LoCA 2005) at Pervasive 2005, May 2005 http://www.jennic.com/files/support_documentation/ JN-AN-1052-

ZigBee-Home-documentation/ Sensor-Demo-1v3.pdf http://www.jennic.com/jennic_support/application notes/jn-an 1052_home_sensor_demonstration_using_zigbee.
Jan BR (2007). Frank Gola- towski "weighted centroid localization in zigbee-based sensor networks", CELISCA centerfor life science automation, 2007.
Konrad L, Welsh M (2005). "MoteTrack: A Robust, Decentralized Approach to RF-Based Location Tracking," Proceedings of the International Workshop on Locationand Con13- RadioFrequencyIdentification (RFID) homepage.
Koyuncu H, Yang SH (2010). " A survey of indoor positioning and object locating systems", IJCSNS, 10(5): 121-128
Lionel M, Yunhao NI (2004). LiuYiuChoLauand Abhishek P. Patil ; LANDMARC: IndoorLocation Sensing Using Active RFID Wireless Networks, 10: 701-710.
Ni LM, liu Y, Lau YC, Patil A (2004). Landmarc,indoor location sensing using active RFID, wireless Networks 10, Kluwer academic Publishers, pp. 701-710
Ralf G (2007). "Localization in zigbee-based wireless sensor networks" Technical report University of Rostock, Institute MD.
Rappaport TS (1996). Wireless Communication: principles and practice, Prentice hall Inc, New Jersey.
Sugano M, Kawazone T, Ohta Y, Murata M (2006). Indoor localization system using RSSI measurement of WSN based on zigbee Standard, ın proceedings wireless and optical communi- cations, IASTED/ACTA press, pp. 1-6
Texas instruments" Zigbeready RF transceiver" http://focus.ti.com/lit/ds/swrs041b/swrs041b.pdf, 2007.
Want R, Hopper A, Falcao V, Gibbons J (January 1992). The active Badge location system,ACM Transactions on Information systems, 40(1): 91-102.
Want R, Schilit B, Adams N, Gold R, Gold- berg D, Petersen K, Ellis J, Weiser M (1997). TheParctabUbiquitous Computing Experiment", BookChapter: "Mobile Computing", Kluwer Publishing, Edited by Tomas z Imielinski, Chapter 2: 45-101, ISBN 0-7923-9697-9.
Ward A, Jones A, Hopper A (1997). A neq location technique for the active office , In IEEE personal Communication Magazine, 4(5): 42-47.