A Real-Time High-Precision Localization Algorithm for Wireless Sensor Networks

Wen Ouyang
Department of Computer Science and Information Engineering
Chung Hua University
Hsin-Chu, 300, Taiwan
ouyang@chu.edu.tw

Ying Tsao
Department of Computer Science and Information Engineering
Chung Hua University
Hsin-Chu, 300, Taiwan
M09602041@chu.edu.tw

Abstract—**Besides sensing the environment variables, the application of localization in wireless sensor networks has became an important research subject. Unlike the other range-free localization schemes which are not effective in real time performance, we propose a real time algorithm, which determines the location of the moving object based on dynamically changing signal strength. The simulation results demonstrated our algorithm is more effective and precise in the sense of real time localization scheme compared with previous method.**

Keywords-component; wireless sensor network, range-free, localization, tracking, real-time

I. INTRODUCTION

Due to the advancement of the microminiaturized technology and micro-electromechanical systems (MEMS) recently, the Wireless Sensor Network (WSN) [1] technology is being widely adopted in the military [6], homecare [5], and environment monitoring applications [2] [4].

A sensor network consists of a large number of sensor nodes. A sensor node is made up of four basic components, a sensing unit, a processing unit, a transceiver unit and a power unit. Most of them are powered by battery. They are also capable of self-organizing and cooperative processing. Generally speaking, the research subject areas addressed by WSNs are wireless communication, object-tracking [3] [8] [9] [11] [12] [13] [14] [15] [16] [17] and energy efficiency [7] [10].

The objective of localization in WSNs is to provide precise and real-time tracking ability on moving objects and the ability to predict the object's moving direction. Localization techniques can be classified into two categories: a range-based scheme [3] [8] [11] [12] [14] [15] [16] and a range-free scheme [9] [13] [17]. The two schemes differ from each other in the device hardware at the sensor node. The range-based scheme produces more precise localization. However, they rely on special expensive sensing devices installed at the nodes. The range-free scheme, although less precise does not require expensive devices, therefore incurs lower hardware cost. When precise localization is not critical, most applications will consider the range-free scheme.

Most of the range-free schemes are unable to detect position change in real-time. Our proposal improves the precision of the localization by frequently observing the changing signal strength. Under this scheme, we introduce some anchors that have the knowledge of their own position. These anchors observe the signal strength of moving objects frequently. Based on the changing signal strength, an anchor determines if the object is closing in or moving away from it. Together with information such as the rate of moving and the sampling frequency, we can forecast the moving object's new position. This is how real-time localization can be achieved with precision.

The rest of the paper is organized as follows. We first present a background on WSN localization problems in Section 2. We then provide a detailed description of our algorithm in Section 3. In Section 4 we will show our simulation results and performance evaluations. Finally, we have a brief conclusion in Section 5.

II. RELATED WORK

There are many object tracking methods proposed in WSN. Fundamentally, we can divide these methods into two types: range-based and range-free. The primary difference between them is the gathering method of the distance data. The former utilizes the distance or angle measurements of radio signals and needs more expensive measurement hardware. The latter uses special protocols to estimate position but these methods are with high accuracy only when the density of anchors is high and the distribution of anchors is even.

For range-based schemes, the common step is to measure distances or angles to calculate coordinates. Time of Arrival (ToA) [8] [11] measurements are commonly used to obtain range information between two communication anchors, for example GPS [12] and RADAR[16]. This type of positioning methods is based on the theory of radio propagation.

978-1-4244-5113-5/09/$25.00 (c) 2009 IEEE

On the other hand, range-free schemes can be classified into static anchor approaches, such as [13][17][18], and mobile anchor approaches, such as [19] [20]. Our work focuses on static anchor deployment.

Centroid [17] is a simple approach where anchors beacon their positions to all one hop neighboring anchors. These neighbors then record the beacons received. Utilizing this information, a node's position is evaluated as the average of its neighboring anchors' positions. However, if the density of anchors is low or the distribution of anchors is irregular, the estimated location may be inaccurate. This method exhibits a problem that unless the set of anchors covering an object is different, the estimated location is not changed and thus may not be accurate enough to reflect the real time location of the object.

APTI [18] was another range-free localization protocol which divides the sensing range into triangular regions with the tips of triangles being anchor nodes. An object may inside or outside these regions. The location of the node is narrowed down by evaluating the number of triangles covering each area. This method portrays the same issue with Centroid

Szymanski [13] proposed another approach similar to the Centroid method, but instead of finding the centroid it estimates the location on the arcs. The basic idea is when an object enters an area covered by anchors or leaves that area, the location evaluated. According to the model, each anchor will generate a bit. These bits correspond to the times at which the target enters or exits the sensing range of the node. The estimated location of the node is at the middle point of the arc, which is part of the border circle of the anchor's sensor region. These arcs are chosen based on the bit information collected. Because of this, the method only finds the location when the nodes moves into or leaves an area which makes the update of locations not accurate enough when the anchor density is low.

In this paper, we aim to provide high accuracy real-time location estimation at low anchor densities. It uses the signal strength difference to determine the directions of the moving object moving. Although this method takes the radio signal strength into account, it is only used to decide whether the object is closer to an anchor or not. Along with the known speed of the object and the sampling frequency of the anchor, we can estimate the new position of the moving object. Simulation shows that our approach not only achieves estimations in real-time but also acquires closer estimative locations.

III. Our Proposal

Our approach deploys three anchors at the three corners of an equilateral triangle. All anchors communicate through symmetric RF channels and have a fixed sensing range equal to the length of the triangle's vertices. Anchors detect a moving object at a constant sampling frequency and compute the variation of signal strength between samples. The assumption is that there is no fixed mathematical relationship between the signal strength and the distance between the anchor and moving object. However, the signal strength is stronger when an object is nearer the anchor than when it's farther. In this section, a detailed description of our algorithm is provided.

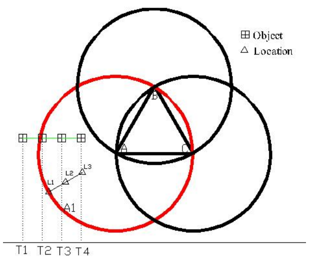

Fig. 1 Moving into one node sensing range

A. Into one anchor sensing range

In Figure 1, each node initializes the status at the network deployment stage. At T1 there is nothing in any of the anchors' sensing ranges. At T2, anchor A discovers the object's presence within its sensing range and it identifies the arc of the sensing range border circle the object is crossing as A1. It then estimates the location of the object as the middle point of arc A1, and broadcasts this message to its neighboring anchors B and C. At T3, we are able to estimate the location at L2 due to a stronger signal. This process is repeated until the object leaves A's one node sensing range and enters a two or three node sensing range or it leaves the entire sensing range.

B. Entering two anchors sensing range

There are two scenarios two anchors will detect an object within their sensing range. As shown in Figure 2, the first scenario is when the object moving from a one anchor sensing range into a two anchor sensing range. The second scenario is when the object moving directly from outside of the entire sensing range into a two anchor sensing range.

Scenario#1: The object passes through the sensing range of anchor A into the overlapping sensing range of anchors A and B. Since this is the first time node B discovers a change in the object's presence within its sensing range, the object's location is considered to be on either arc B3 or B4. However, node C does not discover the change in the object's presence within its sensing range therefore B3 is eliminated and the final estimated location is B4.

Scenario#2: As shown in Figure 2, the object enters the overlapping sensing range of anchor A and B directly crossing point X. Consequently, the estimated location is point X.

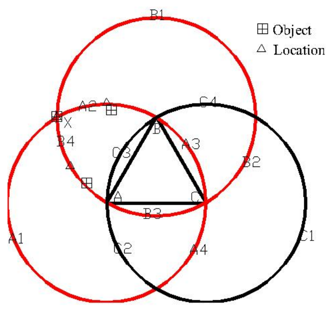

Fig. 2 Two nodes sensing range

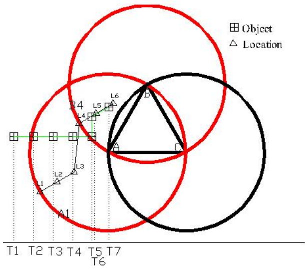

Fig. 3 Moving into two nodes sensing range

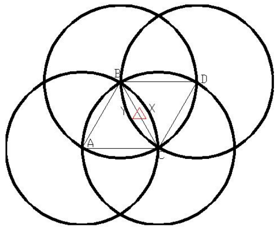

Fig. 4 Multiple node sensing area

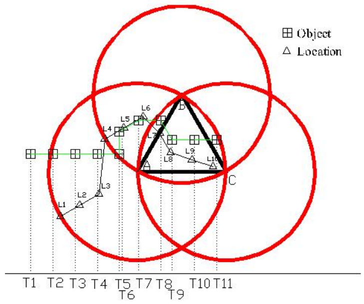

Fig. 5 Object into three nodes sensing range

The two anchors will detect the object's signal strength simultaneously. There are two possible directions of motion relative to the change in signal strength:

A) The object is moving toward one anchor – the signal strength will show increase in one node and decrease in the other. As shown in Figure 3, from T5 to T6, the strength of anchor B increases, as the strength of anchor A decreases. The object is moving towards node B, and the location is at L5.

B) The object is moving toward both anchors along a line tangential to both range borders - show signal strength increase on both nodes.

C. Entering the three-anchor sensing range

When an object enters the overlapping area of three nodes, we can determine the initial location to be on the middle point of $\overline{AB}$ 、 $\overline{AC}$ or $\overline{BC}$.

As shown in Figure 4, it is imprecise to estimate the location to be on arc X or Y. As was previously stated, anchor A, B, and C will detect the signal of an object and the change in signal strength to determine the direction of the object relative to the anchors. Table 1 shows all possible scenarios of the signal strength change in relation to the object's moving direction in the three anchor sensing area.

As shown in Figure 5, from T9 to T10, the signal strengths obtained from anchor A and B decrease, while anchor C's increases. Therefore the object is moving towards anchor C, and the estimated location is at L9.

TABLE I. THE DIRECTION IN 3 NODES SENSING AREA

	Node A	Node B	Node C
Move to node A	Increase	Decrease	Decrease
Move to node B	Decrease	Increase	Decrease
Move to node C	Decrease	Decrease	Increase
Move to middle point of $\overline{AB}$	Increase	Increase	Decrease
Move to middle point of $\overline{AC}$	Increase	Decrease	Increase
Move to middle point of $\overline{BC}$	Decrease	Increase	Increase

D. Leaving the sensing range

Similar to an object entering a sensing range, the methods of detecting the signal of an object and the change in signal strength must also be applied to an object leaving the sensing range. When an object leaves the sensing range the signal will decrease in strength. The vectors 1, 4 and 5 shoes that, in Figure6, when an object moves from a two anchor sensing range to a one anchor sensing range it may move in one of two ways explained previously.

IV. SIMULATIONS AND RESULTS

The actual and estimated positions of an object entering and exiting one anchor, two anchor and three anchor sensing ranges is shown in Figure 7. Data is collected at a 0.04 Hz sampling frequency represented by the time points T1 to T16. The square points represent the object's actual position of the object while triangular points represent the estimated position.

The variances between the actual and estimated locations through time are shown in Figure 9. Notice, that as the object moves into the two anchor and three anchor sensor ranges the estimated locations of the object become more precise. This is demonstrated over time points T5 to T13.

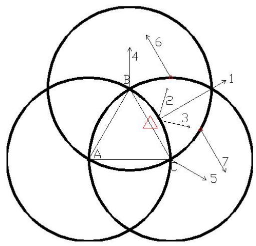

Fig. 6 Determine the directions that object leaves sensing range

TABLE II. INITIAL SIMULATION PARAMETERS

Number of anchors	3
Sensing radius	100 units
Sampling frequency	0.04 Hz

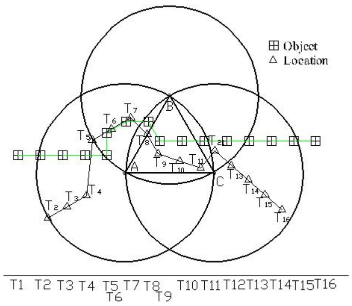

Fig. 7 The result of our algorithm

Szymanski's results are shown in Figure 8. The major difference in localization between our two algorithms can be reflected from T2 to T4. In our algorithms, T2 to T4 are updated according to the sampling frequency, allowing the estimated location to be dynamic with the object's movement. Szymanski's method does not update the estimated location until a new anchor sensing range is entered or exited. The estimated locations from T2 to T4 are therefore the same. In Table 3, the difference in localization performance between Szymanski's and our algorithm were measured and calculated using Eq (1).

$$\text{Difference in Accuracy} = (S_n - A_n)/\, S_n \times 100 \qquad (1)$$

Where Sn is the distance between the actual and estimated of Szymanski's method at time point n and An is the distance between actual and estimated of our method at time point n.

It is shown that in the single sensing range Szymanski's algorithm is 6.34% more precise than ours. However, our algorithm is 53.42% and 52.98% more precise than Szymanski's in the two-anchor and three-anchor sensing ranges respectively. Overall, our method outperforms Szymanski's method in precision by 22.71%.

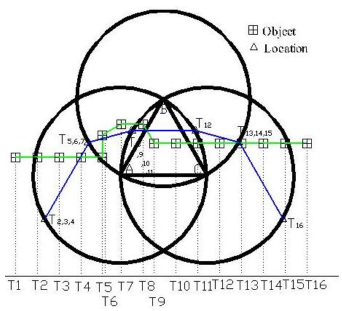

Fig. 8 Szymanski's algorithm

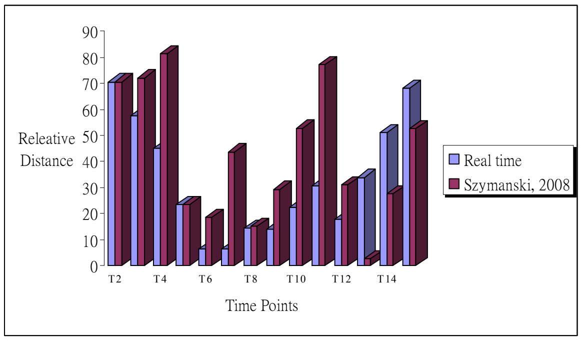

Fig. 9 Variance of actual and estimated locations

It is shown that in the single sensing range Szymanski's algorithm is 6.34% more precise than ours. However, our algorithm is 53.42% and 52.98% more precise than Szymanski's in the two-anchor and three-anchor sensing ranges respectively. Overall, our precision is better than Szymanski's by 22.71%.

TABLE III. COMPARING LOCALIZATION PRECISION

	Real time	[Szymanski, 2008]	Percentage of Difference (%)
One anchor	54.35	51.11	- 6.34
Two anchors	13.6	29.2	53.42
Three anchors	20.5	43.6	52.98
Over all	33	42.7	22.71

V. CONCLUSIONS AND FUTURE WORK

Real time performance was achievable due to the addition of periodic detection of signal strength. By detecting changes in signal strength over time, we were also able to estimate the direction of an object's motion. These additional properties provide our algorithm with superior localization performance to Szymanski's method.

Although better than the Szymanski's method, our algorithm is still less precise than the range based method. However, our method is less demanding on hardware performance, therefore reducing the cost of the overall localization system.

Being a centralized method, our algorithm requires a central base station. Future research should focus on expanding this algorithm to a distributed model to decrease communication cost and to enhance the overall scalability of the localization system.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "A Survey on Sensor Networks", IEEE Communications Magazine, Volume 40, Issue 8, pp. 102 – 114, Aug. 2002

[2] K. Ali, H. Hassanein, "Underwater Wireless Hybrid Sensor Networks", IEEE Symposium on Computers and Communications, (ISCC'08) Marrakech, Morocco, pp.1166 – 1171, 2008.

[3] K. Benkic, M. Malajner, P. Planinsic, Z. Cucej, "Using RSSI value for distance estimation in wireless sensor networks based on ZigBee", 15th International Conference on Systems, Signals and Image

Processing,(IWSSIP'08) Bratislava, Slovak Republic, pp. 303 – 306 , 2008.

[4] I. Bosch, S. Gomez, L. Vergara, "Automatic Forest Surveillance Based on Infrared Sensors", International Conference on Sensor Technologies and Applications,(SENSORCOMM'07) Valencia, Spain, pp. 572 – 577, 2007.

[5] Z. Chaczko, R. Klempous, J. Nikodem, J. Szymanski, "Applications of Cooperative WSN in Homecare Systems", Third International Conference on Broadband Communications, Information Technology & Biomedical Applications, Pretoria, Gauteng, South Africa, pp. 215 – 220, 2008.

[6] S.M. Diamond, M.G. Ceruti, "Application of Wireless Sensor Network to Military Information Integration", 5th IEEE International Conference on Industrial Informatics,(INDIN'07) Vienna, Austria, 2007.

[7] W.R. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks", 33rd Annual Hawaii International Conference on System Sciences,(HICCS-33) Island of Maui, 2000.

[8] N. Iwakiri, T. Kobayashi, "Joint TOA and AOA/AOD Spectrum for Ultra-Wideband Indoor Double-Directional Channel Estimation", IEEE 68th Vehicular Technology Conference,(VTC'08) Calgary, Alberta, pp. 1 -5, 2008.

[9] J. Lee, , S.K. Park, , Cho, Hong, S., W.D., "Object Tracking Based on RFID Coverage Visual Compensation in Wireless Sensor Network", IEEE International Symposium on Circuits and Systems,(ISCAS'07) New Orleans, USA, pp. 1597 – 1600, 2007.

[10] S. Lindsey, C. Raghavendra, K.M. Sivalingam, "Data gathering algorithms in sensor networks using energy metrics", IEEE Transactions on Parallel and Distributed Systems, Volume 13, Issue 9, pp. 924 – 935, 2002.

[11] N. Patawari, A.O. Hero III, "Location Estimation Precision in Wireless sensor Network", Thirty-Sixth Asilomar Conference on Signals, Systems and Computers,(ACSSC'02) Pacific Grove, California, pp. 1523 – 1527, 2002.

[12] W. Ren, "A Rapid Acquisition Algorithm of WSN-aided GPS Location", Second International Symposium on Intelligent Information Technology and Security Informatics,(ISI'09) Moscow, Russia, pp.42 – 46, 2009.

[13] B.K. Szymanski, E. Bulut, Z. Wang, "A Distributed Cooperative Target Tracking With Binary Sensor Networks", IEEE International Conference on Communications Workshops, Beijing,China, pp.306 – 310, 2008.

[14] F. Viani, L. Lizzi, P. Rocca, M. Benedetti, M. Donelli, A. Massa, "Object tracking through RSSI measurements in wireless sensor networks", Electronics Letters, Volume 44, Issue 10, pp.653 – 654, May 8 2008.

[15] R.H. Wu, Y.H. Lee, H.w. Tseng, Y.G. Jan, M.H. Chuang, "Study of characteristics of RSSI signal", IEEE International Conference on Industrial Technology, Bhubaneswar, India, pp. 1 – 3, 2008.

[16] P. Bahl and V. N. Padmanabhan. "RADAR: An In-Building RF-BASED User Location and Tracking System", IEEE INFOCOM ,pp. 775-784, 2000.

[17] Nirupama Bulusu, John Heidemann, and Deborah Estrin, "GPS-less Low CostOutdoor Localization For Very Small Devices," Proceedings of the IEEEPersonal Communications Magazine, vol. 7, no. 5, pp. 28-34, October 2000.

[18] T. He, C. Huang, B. M. Blum, J. A. Stankovic, and T. F. Abdelzaher, "Range-Free Localization Schemes in Large Scale Sensor Networks," MobiCom 2003, September 2003.

[19] L. Hu, D. Evans, "Localization for Mobile Sensor Networks", in Proceedings of Mobicom, 2004.

[20] M. Li and Y. Liu. Rendered Path: Range-Free Localization in Anisotropic Sensor Networks with Holes. In Proc. of ACM Mobicom'07, 2007.