Localization using Mobile Anchor Trajectory in Wireless Sensor Networks

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***Abstract*—Due to increasing applications using location information, localization has been one of important research issues in wireless sensor networks (WSN). A straight-forward approach is to add the GPS receivers to all nodes. Because of the strict H/W restrictions of WSN applications, localization schemes, which do not need expensive H/W devices, may be feasible in WSN. We propose a localization method using mobile anchor trajectory. When the mobile anchor broadcasts its locations periodically, sensor nodes pair them with RSSIs and estimate the trajectory of the mobile anchor. If sensor nodes have two different trajectories, their locations can be calculated. In our method, sensor nodes do not need additional H/W devices. The experimental results show better performance compared with other mobile anchor based methods.**

***Index Terms*—Geometry, localization, mobile anchor, wireless sensor networks.**

I. INTRODUCTION

Many applications of WSN need the location of sensor nodes to collect sensing data. For some target tracking or detection applications, location information should be associated with the sensing data to generate meaningful information. It has been said that adding the GPS receiver to sensor nodes is a solution, which may not be always applicable in WSN. First, wireless sensor applications have strict H/W restrictions such as physical form factor and battery power, depending on the working environment. Second, unlike other embedded systems, a large number of sensor nodes can be deployed in the field. Adding the GPS receivers to all sensor nodes can increase the overall cost.

There have been many published literatures that localization methods applicable to WSN applications suggested. The localization methods can be usually categorized to range-based and range-free schemes. The range-based schemes give the high accuracy, but they need additional H/W devices to measure distances or angles. Moreover, the errors of measurements between two nodes are accumulated in multi-hop deployment [2]. Range-free schemes use the relative positions, received signal strength indicator (RSSI), and connectivity of the references without H/W assistance. However, range-free methods work well only when many anchors are included, or sensor nodes are densely deployed in the field [2][4][5].

Localization with mobile anchor points, which Ssu *et al.* propose, is a range-free scheme [1]. If the radio range is a circle and more than two mobile anchor points on the circle are given, the equation of the perpendicular bisector of the chord can be derived. If two different chords are known, the center of the circle can be calculated from their perpendicular bisectors as shown in Fig. 1. Although the idea is quite good, it may not be applicable in practice. First, it is assumed that the radio transmission range is a circle, although it is not always in reality. Second, even though the concentric circle concept is adapted, it is not always guaranteed that mobile anchor points are placed on the identical circle.

We propose a hybrid scheme that uses the closest point on the mobile anchor trajectory to the sensor nodes rather than the endpoints of a chord on the radio transmission circle to derive the perpendicular bisector equation. The mobile anchor broadcasts its locations periodically while it moves. If sensor nodes receive them, they pair all the locations with RSSIs. The sensor nodes calculate the trajectories of the mobile anchor from the paired data and estimate the closest points on the trajectories to themselves using an estimation algorithm that we propose. The intersection points of two perpendicular lines of different trajectories become the locations of the sensor nodes. While the scheme of Ssu *et al.* can use only two points to calculate a perpendicular bisector equation, our scheme can use as many points as a sensor node can get in order to increase the accuracy of the location. Our experiments show better results without additional H/W.

II. RELATED WORK

Range-free schemes use the locations and connectivity of the references without estimating the distances. The representatives are Centroid, APIT, and multi-dimensional scaling (MDS) methods, which require sensor nodes to be deployed densely [2][4][5].

Mobile anchor assisted localization mechanisms use the positions and RSSIs of the mobile beacons. A mobile anchor with the GPS receiver broadcasts its own positions while moving in the field, so that sensor nodes can update their own locations with received mobile beacons. Each mobile beacon contains all information that general anchors for the localization send. In this case, the position accuracy relies on the number of received beacons and the RSSI accuracy [2][6]. As long as distances between nodes are available, the positions of sensor nodes can be calculated by a range-based scheme. The accuracy of estimated positions always depends on the ranging method.

Ssu *et al.* suggest a range-free mobile anchor based localization using the perpendicular bisector of a chord conjecture [1]. It uses a basic principal that the perpendicular bisector of

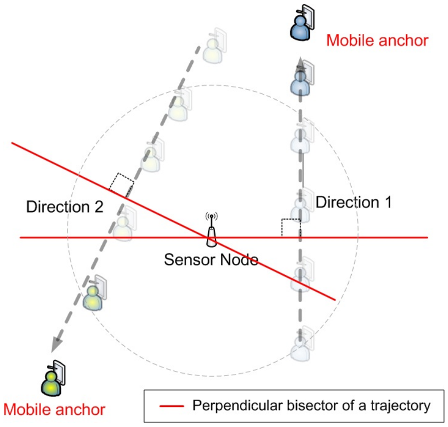

Fig. 1. The concept of the system

any chord always passes through the center of a circle. With more than two chords of the same circle, the intersection point of those perpendicular bisectors is the center of the circle. The method assumes that a position of the sensor node is the center of the circle, its radius is a radio range, and the endpoints of a chord are footsteps of the mobile anchor. This method does not need any special H/W device such as an ultrasonic emitter/receiver. Each sensor node can update its own position in distributed manner.

Ssu *et al*. provide a beacon selecting method with similar RSSIs [1]. The mobile anchor cannot continuously transmit its own position and the sensor node cannot receive all of the mobile beacons because of the limit of the GPS receiver and RF interferences. It causes that the beacon points, which are chosen as the endpoints of the chord, are not always placed on the circle. To select the appropriate beacons, the sensor node has to receive all the packets, especially from the side of the radio range. However, the antenna irregularity and the mobile anchor's discontinuous packet transmitting make it worse in the edge of the sensor node's radio range. Even if adapting the beacon selection method, problems of estimating a chord directly still exist in practice.

III. MOBILE ANCHOR ASSISTED LOCALIZATION WITH POLYNOMIAL MODELING

A. System Environments

Fig. 1 illustrates the concept of the system. After sensor nodes are deployed with respect to the purpose of the application, a mobile anchor periodically broadcasts its position when it moves through the field in several directions. The sensor node can receive mobile beacons within the radio range. Due to the GPS receiver, we assume that the localization system is placed in outdoor environment.

The GPS position is defined geographic coordinates with a longitude and latitude in a degree unit. To avoid the limited precision and adapt the proposed modeling, we transform the geodetic coordinates to the Cartesian coordinates with Transverse Mercator (TM). The Geodetic Reference System 1980 (GRS80) Korea TM is a standard for the map and its unit is a meter.

B. Perpendicular Line Equation

As described, it is difficult to estimate a chord with two mobile anchor points selected. For more accurate results, we calculate the perpendicular line from the trajectory at the the closest point on the trajectory, instead of estimating the perpendicular bisector of a chord. In the algorithm, we estimate the slope and closest point of the trajectory first, and calculate the node locations with the intersection of the equations.

A sensor node which receives mobile beacon from the mobile anchor can predict the time of its next packet. If the sensor node cannot receive the expected packet more than d times, it decides that the mobile anchor is not in the radio range anymore. The sensor node estimates the slope of the trajectory when the number of received packets is larger than pre-selected n. To estimate the closest point on the trajectory, the proposed method uses stored RSSIs of mobile beacons. If a mobile anchor moves through the field in a certain direction, the RSSI grows until the mobile anchor reaches the closest point to the sensor node, and it decreases after the sensor node does not receive the mobile beacons anymore. The pattern of RSSIs makes a curve because the signal strength is inverse proportional to the distance. To calculate the closest point on the trajectory, we set the stream of RSSIs as a 2nd order polynomial and calculate the minimum value with a 1st differentiation of the equation. At this modeling, RSSIs are placed on the Y-axis, and one of the 2-dimensional positions of mobile beacons in GRS80 Korea TM is placed on the X-axis. For reducing the error, we select one of them that has more variation than the other.

We use the 1st and 2nd order polynomial curve fitting to estimate the slope and the closest point on the trajectory of the mobile anchor. The general polynomial curve fitting method is described below. Equation (1) denotes a general k-th order polynomial.

$$y = a_0 + a_1 x + a_2 x^2 + \cdots + a_k x^k \tag{1}$$

For estimating the parameters of (1), we apply received n positions of the mobile anchor to (1), and calculate the mean square error by (2).

$$E^2 = \sum_{i=1}^{n} \{y_i - (a_0 + a_1 x_i + \cdots + a_k x_i^k)\}^2 \tag{2}$$

Equation (3) presents differential equations of (2) by the coefficients of (1).

$$\begin{aligned}\frac{\partial(E^2)}{\partial a_0} &= -2\sum_{i=1}^{n}\{y_i-(a_0+a_1x_i+\cdots+a_kx_i^k)\}\\ \frac{\partial(E^2)}{\partial a_1} &= -2\sum_{i=1}^{n}\{y_i-(a_0+a_1x_i+\cdots+a_kx_i^k)\}x\\ &\vdots\\ \frac{\partial(E^2)}{\partial a_k} &= -2\sum_{i=1}^{n}\{y_i-(a_0+a_1x_i+\cdots+a_kx_i^k)\}x^k\end{aligned} \tag{3}$$

To find the coefficients in (1) which minimize the mean square error, we set all the equations in (3) to zeros. After arranging both sides of equations, we can get a Vandermonde Matrix (4).

$$\begin{bmatrix} 1 & x_1 & \cdots & x_1^k \\ 1 & x_2 & \cdots & x_2^k \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_n & \cdots & x_n^k \end{bmatrix}\begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_k \end{bmatrix} = \begin{bmatrix} y_0 \\ y_1 \\ \vdots \\ y_n \end{bmatrix} \tag{4}$$

We can rewrite (4) to Y=XA in matrix form. After normalizing the equation, we can get the equation of least square solution as follows.

$$\mathbf{A} = (\mathbf{X^T X})^{-1}\mathbf{X^T Y} \tag{5}$$

The trajectories of each mobile anchor do not usually make straight lines due to the errors of the GPS receiver and the actual moving pattern of the mobile anchor. For more accurate modeling of a trend line, we use a statistical filtering. After getting the trend line, the sensor node calculates distances between received positions of the mobile anchor and the estimated trend line, and sorts the results in ascending order. We can remove the data whose differences are bigger than the standard deviation of calculated distances and the sorted order is bigger than pre-configured n. In other words, we only use the positions that have smaller differences than the standard deviation, if the number of remains is larger than n, or only use the n positions that have smaller differences. After filtering out the data, the node recalculates the trend line with useful data as shown in (6).

$$y = a_0 + a_1 x \tag{6}$$

In the stage of estimating the closest point on the trajectory, the sensor node only uses the trusted data derived from the statistical filtering to apply the 2nd order polynomial curve fitting. As we mentioned, the RSSIs of received beacons are placed on the Y-axis and one coordinate of positions are placed on the X-axis. We set a new coordinates of X and Y for clearness. After getting the 2nd order polynomial equation, we can differentiate it by X. Equation (7) indicates the differentiation and the solution.

$$\begin{aligned} &Y = aX^2 + bX + C \\ &\frac{dY}{dX} = 2aX + b = 0, \qquad X = -\frac{b}{2a} \end{aligned} \tag{7}$$

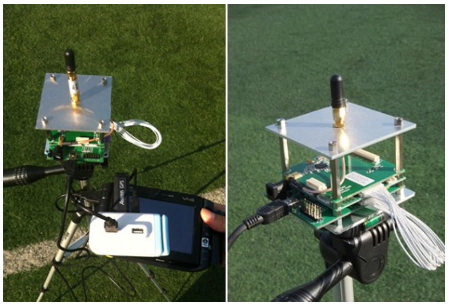

Fig. 2. Mobile anchor(left) and sensor node(right)

Applying the X to (6) in the right coordinate, we can get the closest point (x_c, y_c) on the trajectory. With the calculated slope and the closest point, we can get an equation of a perpendicular line, $y = ax + b$, which passes through the position of the sensor node.

C. *Localization*

If a sensor node has more than two independent trajectories, it can calculate the intersection points of perpendicular lines. Equation (8) denotes m perpendicular lines.

$$\begin{bmatrix} a_0 & -1 \\ a_1 & -1 \\ \vdots & \vdots \\ a_{m-1} & -1 \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} -b_0 \\ -b_1 \\ \vdots \\ -b_{m-1} \end{bmatrix} \tag{8}$$

To minimize the mean square error, we normalize (8) and apply the least square solution (9).

$$\begin{aligned} &\mathbf{AX} = \mathbf{B} \\ &\mathbf{X} = (\mathbf{A^T A})^{-1}\mathbf{A^T B} \end{aligned} \tag{9}$$

The solution X is the position of the sensor node.

IV. EXPERIMENTAL RESULTS

For experiments, we use the TI MSPF2618 and CC2420-based nodes that we made. We use the UMPC with the GPS receiver as a mobile anchor. Fig. 2 shows a mobile anchor and a sensor node. The GPS receiver, ASCEN GPS660, updates its position every second. The sensor node is placed in the middle of the football field and the mobile anchor moves

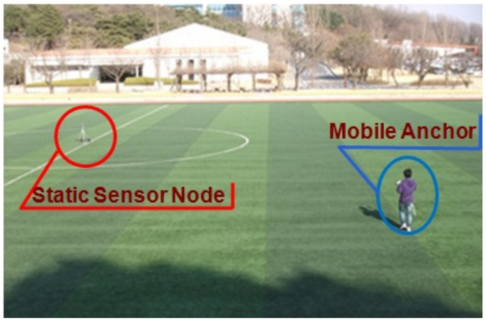

Fig. 3. Experimental environment: Football ground

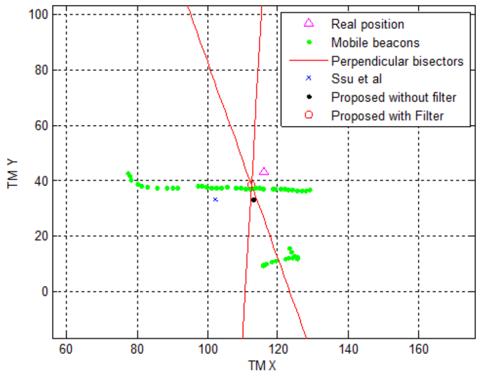

Fig. 4. Experimental result with two trajectories

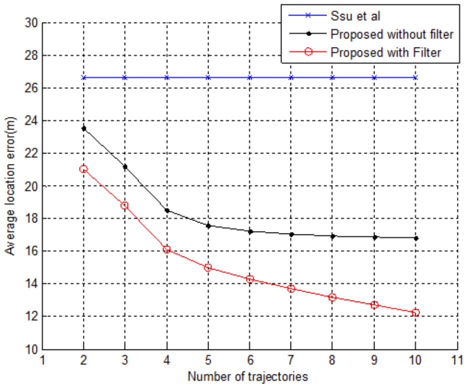

Fig. 5. Average location error versus number of trajectories

in several different directions. Fig. 3 shows the experimental environment.

Fig. 4 shows one of the results. The original position of the sensor node is measured by the identical GPS receiver. In Fig. 4, the triangle is the actual position, and the dot and circle are an estimated position without and with the data filtering which described in Section 3 respectively. The experimental results are compared with the method of Ssu *et al*. To avoid parallel lines, we only use lines that make an angle greater than 10 degrees. Fig. 5 and 6 show the average location errors and the standard deviations of location error versus the number of trajectories. Ssu *et al*. only uses two bisectors of different chords. In the experiment, we measure 14 independent trajectories and apply the combinations of them. Fig. 5 and Fig. 6 show that the proposed method outperforms the previous method in average location error and the variance of it. If a sensor node has more independent trajectories, the location error can decrease. The desirable number of trajectories is generally less than six in actual application.

In the result, the absolute location error is still large due to the errors of the GPS receiver. The GPS data is sometimes biased with changing of the direction of the mobile anchor, and it causes worse in the case of less than three trajectories. Removing some of the biased data makes results more accurate.

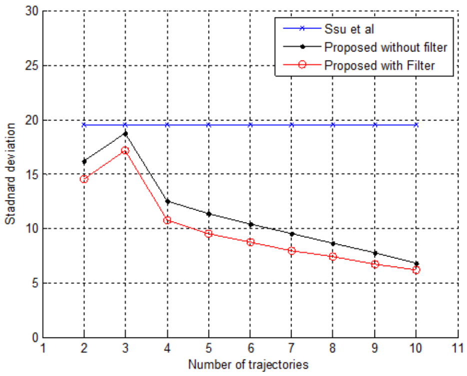

Fig. 6. Standard deviation of location error

V. CONCLUSION

We have presented a hybrid localization scheme that uses the slope of the trend line and the closest point on the trajectory of the mobile anchor to the sensor node rather than the endpoints of a chord in the radio range to derive the perpendicular bisector. Sensor nodes calculate the trajectories of the mobile anchor from the positions and RSSIs of the mobile beacon paired, and estimate the slopes and the closest points to themselves with a polynomial curve fitting. After calculating the perpendicular lines from the trajectories at the closest points, the sensor nodes estimate the intersections of more than two independent perpendicular lines as their position.

In the experiment, our method shows better performance than other mobile anchor assisted methods. If there are various trajectories moving in different directions, the estimated position would be more accurate. For our future works, we will improve the performance with experimenting in various fields, such as an urban area.

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REFERENCES

[1] K-F. Ssu, C-H. Ou and H. C. Jiau, ”Localization With Mobile Anchor Points in Wireless Sensor Networks,” *IEEE Trans. Vehicular Technology*, Vol. 54, No. 3, May 2005.

[2] A. Pal, ”Localization Algorithms in Wireless Sensor Networks: Current Approaches and Future Challenges,” *Network Protocols and Algorithms*, Vol. 2, No. 1, pp. 45-74, 2010.

[3] L. Dong and F. L. Severance, ”Position Estimation With Moving Beacons in Wireless Sensor Networks,” *in Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 2319-2323, March 2007.

[4] N. Patwari, J. N. Ash, S. Kyperountas, A. O. Hero, R. L. Moses, and N. S. Correal, ”Locating the nodes: Cooperative localization in wireless sensor networks,” *IEEE Signal Processing Magazine*, Vol. 22, No. 4, pp. 54-69, July 2005.

[5] T. He, C. Huang, B. M. Blum, J. A. Stankovic, and T. Abdelzaher, ”Range-Free Localization Schemes for Large Scale Sensor Networks,” *in Proc. ACM MobiCom 03*, pp. 81-95, September 2003.

[6] M. L. Sichitiu and V. Ramadurai, ”Localization of Wireless Sensor Networks with A Mobile Beacon, *in Proc. First IEEE Intl Conf. on Mobile Ad-Hoc and Sensor Systems (MASS 04)*, pp. 174-183, October 2004.