A new Localization Scheme for Cricket nodes

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Abstract: Many sensor network applications require that each node’s sensor data stream be annotated with its physical location in some coordinate system. Equipping GPS on every sensor node is often expensive and does not work in indoor deployments. Recently, cricket-based localization system is often used for indoor localization. It is very important to know the exact position of beacons in cricket-based localization system for identifying moving sensor node’s position. In this paper, a new method, Mobile Listener Detect Algorithm (MLD) which can automatically calculate the unknown newly installed beacons is proposed. For the verification of the feasibility of the proposed scheme, we have conducted several experiments.

Keywords: Cricket-based localization, Mobile Listener Detect Algorithm (MLD), PDA

1. Introduction

One of the critical issues in Wireless Sensor Network (WSN) is to determine the physical positions of sensor nodes. It is because sensed data are meaningful only when they are annotated with geographical position information. Also position information is essential to many location-aware sensor network communication protocols, such as packet routing and sensing coverage [1].

In non-urban outdoor environment, sensor nodes may obtain location information using an existing infrastructure such as GPS. GPS may be too expensive, too large for the desired applications. Therefore, in most indoor environments, GPS is not available. One solution to this problem is an alternative location infrastructure such as Active Bat [2] or Cricket [3] that works in places that GPS does not work.

Recently, Cricket which employs hundreds or thousands of inexpensive position beacons to provide location information over extended areas has got used for indoor localization. It uses TDoA between a radio and an ultrasonic signal (together termed as a beacon signal) for distance ranging [4].

For Cricket system to be successful, it must be pervasive. The installation procedure should be quick and easy according as the usage of Cricket system becomes widespread.

However, large number of beacon nodes in Cricket raises a deployment issues: how can an extended deployment be efficiently configured for initial operation, and efficiently maintained for continuous operation. Autonomously operating location-aware sensor network faces the same problems.

In this work, an effective method called Mobile Listener Detect Algorithm (MLD) to facilitate large-scale deployment of location-aware sensor network is presented. The proposed MLD does not require any extra hardware except for three fixed beacons and one mobile listener initially. A mobile listener can run an MLD algorithm with the PDA locally, interacting only with neighboring beacon nodes to calculate the position of a newly introduced beacon node. By doing this in an automated manner, large-scale sensor networks can eliminate the cumbersome and unscalable process of manually configuring beacon nodes with their location.

This paper is composed of 5 Sections. Section 1 introduces the overall content of this paper. Section 2 overviews the Cricket and compares with the existing beacon auto-localization algorithms. Section 3 introduces the basic concept and details of MLD. Section 4 practically implements the new method into Cricket system, and certifies its performance through beacon auto-localization results. Section 5 provides a conclusion of this paper.

2. Basics of Cricket and related work

Traditional location system such as GPS requires a dozens of satellites and ground-based monitoring centers to provide location information for outdoor navigation. However, GPS is quite ineffective especially for indoor
application because walls in buildings block the signals transmissions. To overcome this problem in GPS, location infrastructure such as Cricket has been proposed.

Cricket is an indoor location system that provides two kinds of information, space identifiers and position coordinates. The position coordinates are \((x, y, z)\) Cartesian coordinates [5-6].

According to the state of nodes, Cricket nodes can be divided into two categories: beacons and listeners. Actively transmitting beacons are fixed on the indoor ceilings with their own definite coordinates and listeners are attached to host devices (handhelds, laptops, etc.) whose location needs to be obtained. The coordinates of any listener is still unknown before being computed whether it is moving or static.

Each beacon is equipped with ultrasonic, RF and temperature sensors. Because RF travels about \(10^6\) times faster than ultrasonic, the listener can use the time difference of arrival between the start of the RF message from a beacon and the corresponding ultrasonic pulse to infer its distance from the beacon.

![Fig.1 A listener calculates its position by using distance measurements from nearby beacons.](image)

For the listener to determine its latitude and longitude, the beacons need to know their respective latitudes and longitudes. In the same manner, when an application calls for an \((x, y, z)\) Cartesian coordinate of listener, the each beacons must know their \((x, y, z)\) Cartesian coordinate [7].

Triangulation algorithm is generally used for determining the absolute position of listener.

Cricket-based location system which is composed of three beacons and one listener only can cover a small area. If we want to extend the coverage of listener’s locations, some more beacons should be additionally installed. There have been many researches on the distributed localization problems. Distributed localization algorithm can be classified into two categories. The first one is according to whether or not they rely on anchor nodes, which are nodes that are preconfigured with their true position. The second one is based on whether they are incremental or concurrent.

2.1 Anchor-based Algorithms

Anchor-based algorithms assume that a certain minimum number of fraction of the nodes know their position, e.g., by manual configuration or using some other location mechanism [8-11]. The final coordinate assignment of individual nodes will be valid with respect to another global coordinate system. There are three drawbacks in this localization algorithm: First, establishing anchors is a manual deployment task, and may be cumbersome. Second, the numerical stability of anchor-based approaches is questionable, since they give more weight to anchor position estimates, and errors in those estimates will have undue effect on the global solution. Finally, anchor-based approaches may not scale well, since to combat the instability described above, a large number of anchors may be required to configure an unbounded working area.

2.2 Anchor-free Algorithms

Anchor-Free Localization (AFL) [12] is a decentralized algorithm to determine a consistent coordinate system for nodes in a network, using only distances between neighboring nodes. AFL works by initially assigning a rough polar coordinate system to beacons by counting connectivity “hops” around the network. (A node is considered to be 1 hop away from its neighbor if it can measure the distance between itself and its neighbor). Following the initial coordinate assignment, AFL works by incrementally decreasing the global energy, calculated using the sum of errors between estimated and measured distances between nodes. Nodes must cooperate continuously to calculate the global energy. AFL has the advantage of being completely decentralized, so it can work without any human intervention. Additionally, AFL almost always converged on the correct graph. Unfortunately, due to Cricket hardware limitations, AFL cannot be applied if beacons are coplanar on the ceiling. The ultra sound
transmitters and receivers are directional, which prevents lateral distance measurements between coplanar beacons if the beacons are facing the direction normal to the plane \[7\].

2.3 Incremental Algorithms

Another class of algorithms proceeds incrementally, starting from a small core set of nodes that know their location, and adding nodes to the existing nodes, and configures network one at a time or in groups [11]. This can be done if a node attempting to join the existing network can successfully estimate its distances to three or four nodes that are already configured.

However, there are two major problems in such incremental approaches: first, they may not solve the problem even when a valid coordinate assignment exists, and second, errors in local distance estimates often tend to cascade, leading to large global error. Due to the Cricket node using the method TDoA to measure the distance, the TDoA requires the line-of-sight between the transmitter and receiver.

In these three existing algorithms, this shortage may prevent the Cricket nodes from obtaining direct node-to-node distances.

Therefore, for improving the performance of the previous works, we propose a new type of Beacon auto-localization. The key point of this algorithm is to use a mobile listener and the existing framework of the Cricket system to calculate the position of the unknown beacons.

3. Mobile Listener Detect (MLD) Algorithm

In many applications based on the Cricket system, it is very important to know each node’s physical position in some coordinate system. Manual measurement and configuration methods for obtaining location are not suitable for scale and are error-prone, and equipping sensor nodes with GPS is often expensive and does not work in low-cost Cricket system. As the last section introduces, the previous work to solve the beacon auto-localization problem has their shortages. Comparing with the other existing algorithms, we want to contribute a new method MLD.

Our new method considers the constraints that are imposed on sensors, such as hardware framework, limited power, low cost. We want to just use the Cricket system itself to solve this problem. With the help of the accuracy of the localization from the Cricket system and the mobile listener, we don’t need to add any extra hardware. Different from the traditional localization problems using static location-aware sensor nodes to supervise a moving target, in our proposed scheme, each location-unaware sensor node discovers its position assisted by the moving listener. The MLD algorithm is composed of the following steps.

Step 1. Fix three beacons which can act as a reference node on the ceiling. These beacons are called initialization beacons. We can manually measure the initialization beacons’ positions with a scale. With these beacons, the basic Cricket localization system can be built up. Therefore, a mobile listener which can move around the space that initialization beacons generate can get its own real-time position in the limited area with the consistent coordinate system of initialization beacons.

Step 2. The listener continues to move around the covering space which is generated by initialization beacons. During this period, listener can know its corresponding positions. And at the same time, the listener can get the distance value from the newly installed beacon fixed on the other place. After the listener measures the distance between itself and the newly introduced beacon at three different places, triangulation algorithm is utilized to calculate the newly installed beacon’s position.

Step 3. If a newly installed beacon’s position is calculated by step 2, the area which Cricket can cover gets wider than before. By using the step 2, we can successively calculate another newly installed beacon’s position.

The details on MLD are as follows:

We assume that three initialization beacons’ coordinates are \((X_{11}, Y_{11}, Z_{11})\), \((X_{21}, Y_{21}, Z_{21})\), \((X_{31}, Y_{31}, Z_{31})\), and the listener’s coordinates at three different points are \((X_{1L}, Y_{1L}, Z_{1L})\), \((X_{2L}, Y_{2L}, Z_{2L})\), \((X_{3L}, Y_{3L}, Z_{3L})\). A newly introduced beacon’s coordinate which is to be calculated is \((X_{4}, Y_{4}, Z_{4})\).

\(D_{1}, D_{2}\) and \(D_{3}\) are the distance value between the listener and the newly installed beacon at three different points. Because the listener moves on the floor, \(Z_{1L} = Z_{2L} = Z_{3L} = 0\), and \(Z_{4}\) is equal the height of the hall.
Fig. 2 Three initialization beacons (B1, B2, B3) and one newly introduced beacon (B4) which is unknown their coordinates and one mobile listener.

\[
\begin{align*}
D_1^2 &= (X_{L1} - X_4)^2 + (Y_{L1} - Y_4)^2 + (Z_{L1} - Z_4)^2 \quad (1)
\\
D_2^2 &= (X_{L2} - X_4)^2 + (Y_{L2} - Y_4)^2 + (Z_{L2} - Z_4)^2 \quad (2)
\\
D_3^2 &= (X_{L3} - X_4)^2 + (Y_{L3} - Y_4)^2 + (Z_{L3} - Z_4)^2 \quad (3)
\end{align*}
\]

According to the formulas, we can easily calculate the newly installed beacon’s coordinate \((X_4, Y_4, Z_4)\):

\[
\begin{align*}
X_4 &= \left\{ \left[ D_2^2 - (Z_{L2} - Z_4)^2 - D_3^2 + (Z_{L3} - Z_4)^2 \right] \right. \\
Y_4 &= \left\{ \left[ D_1^2 + (Z_{L1} - Z_4)^2 - D_3^2 - (Z_{L3} - Z_4)^2 \right] \right. \\
Z_4 &= \left\{ \left[ (X_{L2} - X_{L3})(Y_{L3} - Y_{L2}) - (Y_{L3} - Y_{L2})(X_{L3} - X_{L2}) \right] \right. \\
&\quad \left. + (X_{L1}^2 - X_{L2}^2)(Y_{L3} - Y_{L2}) + (Y_{L1}^2 - Y_{L2}^2)(X_{L3} - X_{L2}) \right\}
\end{align*}
\]

\[
\begin{align*}
2(D_1^2 + D_2^2 + D_3^2) = (X_{L2} - X_{L1})^2 + (Y_{L2} - Y_{L1})^2 + (Z_{L2} - Z_{L1})^2 \\
&\quad + (X_{L3} - X_{L2})^2 + (Y_{L3} - Y_{L2})^2 + (Z_{L3} - Z_{L2})^2 \quad (4)
\end{align*}
\]

We can replace one of the initialization beacons to the new identified beacon, and the listener moves to the new coverage area generated by the two initialization beacons and the newly identified beacon, so the movement area is larger. With the new compositive localization system, the listener can get its own real-time position in the extended area. And at the same time, the listener can get the distance from another newly installed beacon, and uses the same method introduced before to detect the new beacon’s position. By repeatedly applying this MLD algorithm, more and more beacons’ position can be calculated, and the listener’s movement area is getting larger. The more beacons are assigned with the consistent coordinates, the more beacons can support the listener to enhance its localization area.
4. Experiment of MLD Algorithm

In this section, to verify the feasibility of the proposed MLD algorithm, several experiments are executed.

We first installed three initialization beacons (B1, B2, B3) on the ceiling with the known coordinate in the building, like in Fig.5. And we use a PDA equipped with Cricket listener via RS232 interface to calculate the listener’s real-time position. The PDA can be thought of mobile listener in this experiment. The listener’s real-time position which is calculated by the triangulation algorithm will appear on the GUI screen.

In this experiment, the height of the hall is 250 centimeters. We assume that the coordinates of initialization beacons’ position is B1(0, 0, 250), B2(0, 100, 250) and B3 (100,100,250).

The listener’s position (black diamond in Fig.6) can be easily calculated by using triangulation algorithm and the calculated real-time position of the listener appears on the GUI screen of PDA. In the Fig.6, B4 is a newly introduced beacon of which coordinate should be calculated by MLD algorithm. Listener moves around the coverage of the initialization beacons, and stops at three different places to get three different distances between B4 and the listener. In the Cricket View program, we can get the listener’s coordinate values as the listener moves. We can get the newly introduced beacon’s coordinate by using equation (4), (5) in the section 3.

If coordinate of B4 is known, B4 can be used as a reference beacon like B1, B2, and B3 at the beginning time. From this moment on, B2, B3, B4 can be utilized to calculate the coordinate of B5 successively.

With the help of MLD algorithm, the listener’s movement area can be extended and at the same time, the listener can detect many newly introduced beacons.

We programmed GUI for MLD algorithm and it is shown in Figure 7, 8.

In the Fig.8 the B4, B2, and B3 make up of the basic localization system like the B1, B2, and B3 do at the beginning time. And the listener detects the B5’s position with the new localization system.

As you can see Fig.7 and Fig.8 the error between the actual coordinate and the calculated one by using MLD is within the desirable range.
5. Conclusion

Beacon auto-localization in the Cricket based location system is an important problem. Cricket system applications usually require that each node can be annotated with its physical location in some common coordinate system. In our paper, we describe a new method MLD to solve this problem. We only use the existing Cricket system framework and the mobile listener to calculate the newly installed beacons by the triangulation algorithm. There is one important advantage that MLD doesn’t need any extra hardware. And furthermore, the speed of the implementation of MLD is faster. From the result of the experiment, the accuracy of MLD has been proved to be good. In the future work, MLD will be applied to a mobile robot or mobile car applications which can automatically enlarge covering area.

Reference


This research was financially supported by the Ministry of Commerce, Industry and Energy (MOCIE) and Korea Industrial Technology Foundation (KOTEF) through the Human Resource Training Project for Regional Innovation.