Sector Scan Accurate Localization Algorithm in Mobile Wireless Sensor Networks

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Abstract

Localization is crucial to many applications in wireless sensor networks (WSN). In some applications, all nodes are constantly moving in the network. The current algorithms did not suitable for the nodes in mobile wireless sensor networks (MWSN) to determine their localization. To solve this problem, a new range-free localization algorithm based on the idea of sector scan for MWSN is proposed. By using sector scan, this algorithm could minimize the overlapping areas which can determine the localization of the unknown nodes. To do so, the localization accuracy can be improved. The simulation shows that SSML algorithm can obviously improve the localization accuracy compared to Convex and MCL, and the error of the SSML is lower than 10%.

Keywords: Distributed Localization; Wireless Sensor Networks; Mobility; Sector Scan

1. Introduction

Wireless Sensor network comes from the equation, which is: perception+CPU(computation)+wireless communication technology=thousands potential applications. In most of WSN applications, the location information of nodes is necessary, and the data is meaningful only when the location information has been known [1]. The sensor nodes can show what special incidents have happened in the area after the location of them has been determined, and then they could locate and track the targets. Attaining the localization of the sensor nodes can improve the efficiency of the routers, and provide the naming spaces of the net. The nodes can report the covering quality of the net to the deployment manager, and the self-configuration of the load balance and the net topology can be finished. However, the nodes can’t attain their localization by using the deployment patterns of self-organization net. On the other hand, manual deployment or assembling GPS receiver for all the nodes are restricted by the cost, power consumption and extension of net, even though it is impossible to achieve that in some cases. Therefore, the initial nodes in WSN need to determine its position by localization algorithms [2].

So far the localization of a stationary WSN has been extensively studied [3]. Recent years have growing interest in mobile sensor networks [4-5] where the sensor nodes have motion capability. Mobile sensor
networks have more flexibility, adjustability and even intelligence compared to stationary sensor networks. Localization for mobile sensor networks also is very important to facilitate the information collection and the movement of mobile sensors. Researchers solving the localization problem for mobile sensor networks usually approach it from a robotics perspective, which heavily relies on the sophisticated sensors such as GPS, sonar, laser, ranger, finder, or camera onboard the mobile platforms. However, for the restraints of the power consumption, communication and computation capability of the sensor nodes, it is impossible to assemble the GPS instruments on every anchor. Besides, due to the mobility of the sensors affect the sensor localization in a different perspective. Most current localization algorithms are not suitable for mobile wireless sensor networks. In this paper, based on the idea of sector scan method [6], a sector scan mobile localization algorithms (SSML) presented for mobile wireless sensor networks and simulation experiments to evaluate the performance of the algorithms by varying the number of anchors, number of nodes and velocity of nodes. Results show that SSML are more accurate than the original MCL, Convex[3] and CDL[4] algorithm.

The rest of the paper is organized as follows: In Section II, our proposed algorithm is presented. The performance evaluations of the algorithm are presented in Section III. We give the discussion on Section IV. The conclusions are drawn in Section V.

2. SSML ALGORITHM

In this section, the network model and some assumptions are described first, and then the SSML algorithm is presented

2.1. Network Model and Assumptions

In a MWSN, we suppose that a set of equipped omni-directional antennas sensors with unknown localization is randomly deployed with a density \( \rho_s \), sensor nodes and the anchors are allowed to move freely within the deployment area \( A \). And we also assume that a set of equipped \( M \) directional antennas anchors with known localization is randomly deployed with a density \( \rho_L \), \( \rho_s \gg \rho_L \). This set of anchors can change their antenna direction [7], either through changing their orientation or rotating their directional antennas. If \( LH_s \) denotes the set of anchors heard by a sensor \( S \), the probability that \( S \) hears exactly \( K \) anchors:

\[
p(LH_s = K) = \frac{(\rho_s \pi R^2)^K}{k!} e^{-\rho_s \pi R^2}
\]

(1)

Where, \( R \) is the communication range of the sensor or anchor.

The sensor network is modeled as a dynamic discrete-time system and the localization estimation of a particular sensor node at time \( t \) is denoted by \( \hat{l}_t \), that motion model as follows:
2271

\[ p(l_i | l_{i-1}) = \begin{cases} \frac{1}{\pi \Delta t \times \max v} & \text{if } d(l_i, l_{i-1}) \leq \Delta t \times \max v \\ 0 & \text{otherwise} \end{cases} \] (2)

Where \( \Delta t \) is the time interval and \( \max v \) is the supreme motion speed that a anchor or sensor node can travel between localization steps, and assume \( o_i \) denoting this localization observation.

2.2. The Design of SSML Algorithm

The localization process of SSML can be divided three steps, which are initializing system, predicting localization and filtering the prediction. After deployment, the unknown nodes estimate their localization first and predict the next one. After attaining the next prediction localization of the mobile nodes by \( p(l_i | o_i) \), the unknown nodes determine the current evaluation of the anchors’ localization by using the receiving information from the anchors and the overlapping areas of the sector scan. After that, the localizations not existing in the overlapping areas on the previous prediction are filtered by \( p(l_i | o_i) \), then using the random nodes to replace the deleted prediction localization in this area. Do these steps again and again until the localization process to end [5,8].

The filtering approach indicates that the probability of each prediction localization is 0 or 1. The prediction and filtering steps of the SSML need to be initialized. Details and considerations of such steps are described in the following subsections.

(1) Initialization: Supposing the deployment areas are determined by the origin and point \((X_{\max}, Y_{\max})\) in Descartes coordinates, the following shows the initialization sample of the nodes:

\[
\begin{align*}
  x_i &= \text{rand} \times X_{\max} \\
  y_i &= \text{rand} \times Y_{\max}
\end{align*}
\] (3)

(2) Prediction: Supposing the maximum velocity of the nodes in the net is \( \max v \) and the localization of the unknown node \( i \) is \( s_i^t \), as a result, the node \( i \) must be in the circle whose centre is \( s_i^t \) and radium is \( \Delta t \times \max v \), as \( \Delta t = \max s_i \), i.e.,

\[ p(l_i | l_{i-1}) = \begin{cases} \frac{1}{\pi \max v^2} & \text{if } d(l_i, l_{i-1}) \leq \max v \\ 0 & \text{otherwise} \end{cases} \] (4)

In the next paper, we denote \( s \) instead of \( S_i^t \) for short.
(3) Filtering Step: In this step, the node filters the impossible localizations based on observations information. In this paper we assume that time is discrete and all messages are received instantly. Hence, at time $t$, every node within sector area of a anchor scan will hear localization information from that anchor. We define that $LH_s$ denote the set of all anchors heard by $s$, and $LH_i \in LH_s$. Thus anchor $LH_i$ can transmits its current localization to $s$ and at the same time, the unknown node $s$ receives the transmitting information of neighbor nodes($c$ ) about anchor localizations. We suppose that $L_s$ is one of anchor in the WSN who can communicate to $c$, i.e.,

$$L \rightarrow s \quad HELLO | ID_{LH_i} | loc_{LH_i,t}$$

(5)

$$c \rightarrow s \quad HELLO | ID_c | \{(ID_{L2}, loc_{L2,t})\}$$

(6)

Where, ID means the symbol of node or anchor, $loc_{LH_i,t}$ is the localization of $LH_i$ in time $t$. The function $A \rightarrow B HELLO$ means handshake and transmit the massage from $A$ to $B$ .

Supposing $S_y(t)$ represents the sector transmitted by $j$th transmission of anchor $i$ in time $t$, and the anchor angular information $\theta_{i,j}(t) = \{\theta_{i,j,\min}(t), \theta_{i,j,\max}(t)\}$ represents the direction of the antenna, here $\theta_{i,j,\min}(t), \theta_{i,j,\max}(t)$ denote the lower and upper bunds of the sector $S_y(t)$. Thus, $S_y(t)$ is the function of the sector $\theta_{i,j}(t)$ and the communication range $R_j(t)$ in time $t$, i.e.

$$S_{i,j}(t) = S_i(\theta_{i,j}(t), R_j(t), j), j = 1, 2, \cdots, Q$$

(7)

As a result, the ROI (Region Of Interaction) of multiple sectors is

$$ROI(m) = \bigcap_{j=0}^{m} \bigcap_{i=1}^{LH_i} S_{i,j}(t)$$

(8)

Where, we suppose that in time $t$ the total number of the anchor transmission is $m$, and $LH_s$ denote the set of all anchors heard by $s$ during the $j$th transmission and WN denote the set of all nodes heard by $s$ neighbors but not by $s$. Then the filter condition of localization $b$ which is the prediction position of $s$ is:

$$filter(b) = \forall LH_i \in LH, \quad d(b, LH_i) \leq R \land \theta_{i,\min} < \eta < \theta_{i,\max}$$

(9)

$$filter(b) = \forall WN_i \in WN, d(WN_i, LH_i) \leq R \land \theta_{i,\min} < \eta < \theta_{i,\max} \land d(WN_i, b) \leq R$$

(10)
Where \( d(b, LH_i) \) is the distance between \( b \) and \( LH_i \), \( \eta \) is the angular between label X in Descartes coordinates and the line connecting \( b \) and \( LH_i \), \( \eta_2 \) is the angular between label X and the line connecting \( LH_i \) and \( WN_i \). As the coordinates of anchor nodes and the directions of the beams are given, the range of \( \eta \) can be determined. Here \( \theta_{i,\text{min}} \) and \( \theta_{i,\text{max}} \) represent the minimum and maximum angular, referring to the X label. The probability distribution \( p(l_i | o_i) \) is zero if the filter condition is false and evenly distributed otherwise. Thus, localizations that are inconsistent with observations from the possible localization set are eliminated. After filtering, there may be fewer than \( N \) possible localizations remaining. The prediction and filtering processes repeat, uniting the possible points found, until at least \( N \) possible localizations have been acquired. The whole process of the algorithms is described as below, in figure 1.

![Fig.1 Whole Process of the Algorithms](image)

3. Performance Evaluation

In this section, the performance between the SSML, Convex [3], CDL[9] and the original MCL algorithms [4-6] is compared. The localization algorithms are implemented by MATLAB. For our performance evaluation, the sensor nodes are initially randomly distributed over a square area of 100m \( \times \) 100m. Here the time interval between two localizations is 1s, and the maximum velocity is 20m/s. It means that, In this algorithms, the nodes velocity range is from 0 to 20 m/s, and we suppose that the velocity is chosen
randomly. The transmission range $R$ of both the sensor nodes and anchors is assumed to be a perfect circle with radio range of 20m. It should be noted that half-way stopping or turning around of the mobile nodes are not considered in the performance. In each simulation, the times of simulation run time in the experiment will be set as 1000 in order to improve the location accuracy and reliability.

The percent of the rate between the communication radius and the distance between the estimating coordinate $(x_e, y_e)$ of the nodes determined by the localization error $\delta_e$ and the actual coordinate $(x_r, y_r)$ is shown as the following,

$$\delta_e = \sqrt{(x_e - x_r)^2 + (y_e - y_r)^2} \times 100\%$$

(11)

3.1. Accuracy

The accuracy of SSML depends on the speeds of the anchors and nodes. As time passes, nodes will receive more anchor localization announcements and improve their localization estimates. Figure 2 compares the localization error of different localization techniques over time. The accuracy of SSML markedly exceeds the accuracy of the Convex and MCL technique. The conditions of this simulation are: $v = 20$m/s; 30 nodes with unknown location; 15 anchors; $R=20$m; the antennas angle is $\pi / 3$.

3.2. Localization Error vs. Anchors Heard

Figure 3 shows the impact to average estimate error by anchors density in different localization algorithm, and the conditions of this simulation are: $v = 20$m/s; 30 nodes with unknown location; $R=20$m; $t=2$s; the antennas angle is $\pi / 3$.

3.3. Localization Error vs. Motion Speed

Figure 4 shows the impact to average estimate error by node maximum velocity in different localization algorithm, and the conditions of this simulation are: 30 nodes with unknown location; 15 anchors; $R=20$m; $t=4$s; the antennas angle is $\pi / 3$.

3.4. Localization Error vs the Antennas Angle

In the paper, we assume that sensors are equipped with omni-directional antennas, able to transmit with the antennas, while anchors are equipped with M-directional antennas with a directivity gain $G>1$, and can simultaneously transmit on each antennas. We also assume that anchors can vary their direction either through changing their orientation or rotating their directional antennas. In the experiment above, we suppose the angle of the transmission beam is $\pi / 3$. That is to say, the M-directional antennas of anchor can scan $\pi / 3$ angle and form a sector with $\pi / 3$ centre angle and radii $R$. Thus, the angle of the transmission beam in M-directional antennas greatly impacts the accuracy of localization.

Figure 5 shows the impact to average estimate error by sector centre angle, and the conditions of this simulation are: $v = 20$m/s; 30 nodes with unknown location; 15 anchors; $R=20$m.
These simulations show the performances of SSML methods and show how to adapt in MWSN. We simulate in different network environment and nodes capabilities in order to provide good results. The results show the SSML algorithm can achieve the localization error lower than 10%. The algorithm minimizes the influence of the anchor density in some extent and the localization effect is obviously better than the algorithm of Convex and MCL for MWSN. The error of this localization algorithm mainly relates to the maximum velocity of a node or anchors. This algorithm can be utilized to the occasions in which the localization accuracy is emphasized by configuring adaptable parameter.

4. Conclusion

Many wireless sensor network applications depend on whether nodes can accurately determine their localizations. The work is to study range-free localization in mobile wireless sensor networks. Our main result is surprising: the localization estimate error can be minimized lower than 10%. Many issues remain to be explored in future work including how well assumptions hold in different MWSN applications, how different types of motion affect localization, and how our technique can be extended to provide security.

Acknowledgement

This paper is supported by the national Natural Science Foundation of China under grant No 60532030; National Science and Technology Major Project (2010ZX03006-002).

References

Fig. 2 Accuracy Comparison  
Fig. 3 Impact of Anchors Number in Different Localization Algorithm

Fig. 4 Impact of Motion Speed in Different Localization Algorithm  
Fig. 5 Impact of Sector Centre Angle