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Localization Algorithm Based on Sector Scan for 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 do not appropriately address the problem of enabling nodes of mobile wireless sensor networks (MWSN) to determine their locations. To solve this problem, a new range-free localization algorithm (SSML) based on the idea of sector scan for MWSN is proposed. By using sector scan, the proposed algorithm minimizes the overlapping areas determining the location of the unknown nodes. Therefore, the localization accuracy can be improved. The simulation results shows that SSML algorithm can obviously improve the localization accuracy compared with Convex and Monte Carlo Localization (MCL), and the accuracy of the SSML is lower than 10%.

Keywords: Mobile wireless sensor network; localization; Sector Scan.

1 Introduction

So far, the localization of a stationary WSN has been extensively studied [1]. Recent years, much interest has been attracted by mobile sensor networks [2-4] where the sensor nodes have motion capability. Mobile sensor networks have more flexibility, adjustability and even intelligence compared with 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.

On the other hand, 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 [5], a sector scan mobile localization algorithms (SSML) is presented for mobile wireless sensor networks, and then simulation experiments is conducted to evaluate the performance of the proposed algorithm by changing the number of anchors, number of nodes and velocity of nodes. Results show that SSML are more accurate than the original MCL and Convex algorithm.

2 SSML algorithm

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

2.1. Network Model and Assumptions

In a MWSN, we suppose a set of equipped omni-directional antennas sensors with unknown localization is randomly deployed with a density ρ_s, sensor nodes and the anchors move freely and randomly within the deployment area A. Further, we assume that there are a set of anchors with known location that each anchor has M directional antennas which can change their antenna direction [6], either through changing their orientation or rotating their directional antennas; these anchors are also randomly deployed with a density ρ_L, where $\rho_s >> \rho_L$. Let LH_s denote the set of anchors heard by a sensor *S*, the probability that *S* hears exactly *K* anchors:

$$p(\left|LH_s\right| = K) = \frac{(\rho_L \pi R^2)^k}{k!} e^{-\rho_L \pi R^2} \tag{2.1}$$

The sensor network is modeled as a dynamic discrete-time system and the location estimation of a particular sensor node at time *t* is denoted by l_t. The motion model is expressed as follows:

$$p(l_t \mid l_{t-1}) = \begin{cases} \dfrac{1}{\pi(\Delta t \times v)^2} & if \quad d(l_t, l_{t-1}) \le \Delta t \times v \\ 0 & otherwise \end{cases} \tag{2.2}$$

Here, Δt is the time interval and $v_{\max}$ is the maximum motion velocity that an anchor or sensor node can travel between localization steps, and o_t denotes this localization observation.

2.2. The Design of SSML Algorithm

The localization process of SSML can be divided into three steps, including initialization, location prediction and filtering the prediction. After deployment, the unknown nodes estimate their locations first and predict the next locations. After attaining the next prediction locations of the mobile nodes by $p(l_t \mid l_{t-1})$, the unknown nodes determine the current evaluation of the anchors' locations by using the received information from the anchors and the overlapping areas of the sector scan. Then, the locations not existing in the overlapping areas on the previous prediction are filtered by $p(l_t \mid o_t)$, and then the random nodes are used to replace the deleted prediction location in this area. The filtering approach indicates that the probability of each prediction location 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 formula shows the initialization process of the nodes:

$$\begin{cases} x_i = rand \times X_{\max} \\ y_i = rand \times Y_{\max} \end{cases} \qquad i = 1, 2, \cdots, N \tag{2.3}$$

(2) Prediction: Supposing the maximum velocity of nodes in the network is $v_{\max}$ and the location of the unknown node *i* is s_{t-1}^i, as a result, the node *i* must be in the circle whose centre is s_{t-1}^i and radium is $\Delta t \times v_{\max}$, where $\Delta t = 1s$, i.e.,

$$\rho(l_t \mid l_{t-1}) = \begin{cases} \dfrac{1}{\pi v_{\max}^2} & if \quad d(l_t, l_{t-1}) \le v_{\max} \\ 0 & otherwise \end{cases} \tag{2.4}$$

(3) Filtering Step: In this step, the node filters the useless location estimation based on observed 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 an anchor scan will hear location information from the anchor and any anchor LH_1 transmits its current location information, at the same time, the unknown node *S* receives the transmitted information of neighbor nodes(c) about anchor (LH_2) localizations, i.e.,

$$L \rightarrow s \qquad HELLO \mid ID_L \mid loc_t \tag{2.5}$$

$$c \rightarrow s \qquad HELLO \mid ID_c \mid \{(ID_{L2}, loc_{L2_t})\} \tag{2.6}$$

Supposing $S_{ij}(t)$ represents the sector area scanned by the directional antenna of anchor i for the j-th time in time t, and the anchor angle information $\theta_i(j)=\{\theta_{i,j,\min}(t),\theta_{i,j,\max}(t)\}$ represents the direction of the antenna, here $\theta_{i,j,\min}(t),\theta_{i,j,\max}(t)$ represent the minimum and maximum values of angle in the sector respectively. The sectors' information collected by the sensors from the multiple scan results of all anchors is, as a result, the ROI (Region of Interaction) of multiple sectors is

$$S_i(j)=S_{i,\ j}\left(\theta_{i,j}(t),j\right),\ j=1,2,\cdots,Q \qquad (2.7)$$

$$ROI(m)=\bigcap_{j=0}^{m}\left(\bigcap_{i=1}^{|LH_s|}S_{i,j}(t)\right) \qquad (2.8)$$

Let LH denote the set of all anchors heard by s and WN denote the set of all nodes heard by neighbors of node S, but not by s. Then the filtering condition to locate the node b is

$$\begin{aligned} filter(b) &= \forall LH_i \in LH, \\ & d(b,LH_i)\le r\wedge\theta_{i,\min}<\eta<\theta_{i,\max} \end{aligned} \qquad (2.9)$$

$$\begin{aligned} filter(b) &= \forall WN_i\in WN, d(WN_i,LH_i)\le r \\ &\wedge\theta_{i,\min}<\eta_2<\theta_{i,\max}\wedge d(WN_i,b)\le r \end{aligned} \qquad (2.10)$$

Here η is the angle between X axis and the line connecting b and LH_i, η_2 is the angle between X axis and the line connecting LH_i and WN_i. As the coordinates of anchor nodes and the directions of the beams are already abstained, the range of η can be determined. Here $\theta_{i,\min}$ and $\theta_{i,\max}$ represent the minimum and maximum angle referring to the X axis. The probability $p(l_t \mid o_t)$ is 0 if the filtering condition is false, or else the probability $p(l_t \mid o_t)$ is 1. Thus, locations which are useless for localization should be eliminated using the filtering condition. After filtering, there may be fewer than N possible locations remaining. The prediction and filtering processes repeat, until at least N possible locations have been acquired.

3 Performance Evaluation

In this section, the performance evaluations of SSML, Convex1 and the original MCL algorithms are demonstrated [2-4]. The localization algorithms are implemented by MATLAB. For performance evaluation of SSML, the sensor nodes are initially randomly distributed over a square area of 100m × 100m. Here, the time interval between two localizations is 1s, and the maximum velocity is 20m/s. The communication radium r of both the sensor nodes and anchors are assumed to be a perfect circle with radium of 20m.

The percent of the rate between the communication radium and the distance between the estimated coordinate (x_e,y_e) of the nodes determined by the localization error δ_e and the actual coordinate (x_r,y_r) is shown as the following,

$$\delta_e=\frac{\sqrt{(x_e-x_r)^2+(y_e-y_r)^2}}{r}\times 100\% \qquad (2.11)$$

3.1. Accuracy

The accuracy of SSML depends on the velocity of the anchors and nodes. As time elapses, nodes will receive more anchor location announcements and improve their location estimations. Fig.3.1 shows the convergence of SSML algorithm. The results show SSML can quickly converge. Fig.3.2 presents the localization error vs. time of different localization algorithms. The accuracy of SSML highly exceeds the accuracy of the Convex and MCL algorithms.

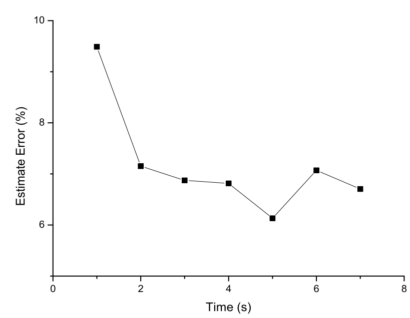

Figure 3.1: Algorithm Convergence

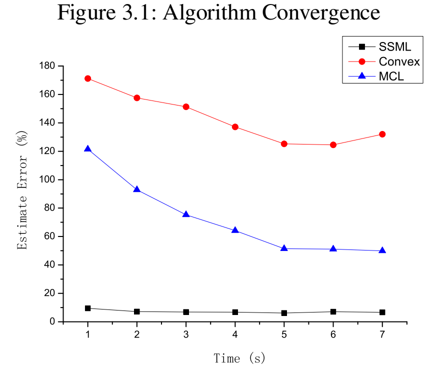

Figure 3.2: Accuracy Comparison

3.2. Localization Error vs. Anchors Heard

Fig. 3.3 shows the average estimation error when anchors density varies. For the SSML algorithm, the accuracy does not improve as anchor density increases. Therefore, SSML algorithm is affected little by the density of anchor nodes. So, it is very suitable for the MWSN with limited deployment cost.

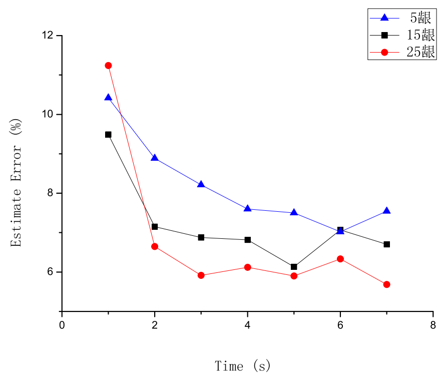

Figure 3.3: Impact of anchors number

3.3. Localization Error vs. motion speed

Fig. 3.4 shows the estimation error by change the maximum velocity of a node or anchors. The maximum velocity of a node or anchors is 10m/s, 20m/s, 30m/s, respectively. Although the location information may become obsolete when nodes and anchors move, the sensor node has more chance to obtain new information from the anchors than it has encountered.

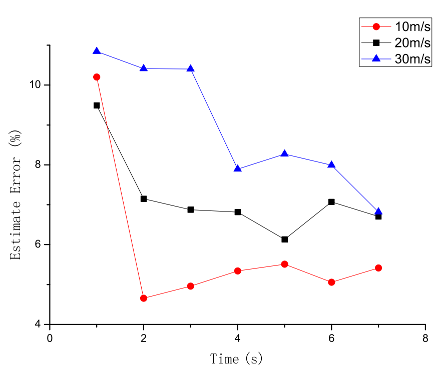

Figure 3.4: Impact of motion speed

3.4. Localization Error vs. motion speed

Fig. 3.5 shows the average estimation error when prediction node number varies. For the SSML algorithm, the accuracy improves as prediction node number increases. Therefore, the algorithm is affected by the number of prediction nodes.

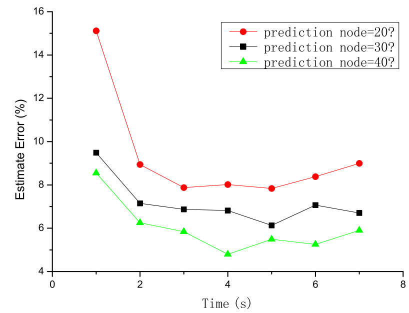

Figure 3.5: Spectra Impact of prediction node number

Simulations conducted above demonstrate the performances of SSML algorithm and show that SSML algorithm is highly suitable for MWSN, related to the network environment and nodes capabilities in order to provide good results. The results show SSML algorithm can achieve the localization accuracy lower than 10%. The algorithm minimizes the influence of the anchor density in some extent. Besides, the localization performances are obviously better than Convex and MCL algorithms for MWSN. The error of SSML algorithm mainly depends on the maximum velocity of a node or anchors. This algorithm of which parameters are configurable, is can be utilized in occasions when the localization accuracy is emphasized.

4 Summary

Many WSN applications depend on nodes being able to accurately determine their locations. This paper studies range-free localization in the presence of mobility. Our main result is satisfactory: the localization accuracy can be minimized lower than 10%. Many issues remain to be explored in future work, including the algorithm applicability in different MWSN applications, the effect of motion model on localization performance and the improvement of the algorithm security.

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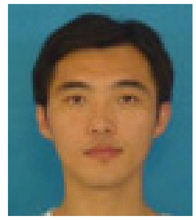

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