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A Distributed Sensor Management Algorithm Based on Auction

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Abstract

Considering the disadvantages of centralized algorithms and limitation of energy in wireless sensor networks (WSN), a distributed auction algorithm is proposed to realize the target tracking sensor management. The method introduces the auction theory in economics and adjusts the price of the sensor resources to solve the target-sensor assignment problem. In order to shorten the decision-making time and save the energy consumption, the CSMA mechanism is introduced and the decision-making can be completed with local information and a few interactions. The convergence and effectiveness of the algorithm are proved, and the simulation results show that the algorithm is superior.

Keywords: wireless sensor networks; sensor management; auction; distributed optimization

1. Introduction

With the development of micro-electro-mechanical system (MEMS) technology and the emergence of cheap, multifunctional sensor nodes with low energy consumption, wireless sensor network has been widely used in environmental monitoring, target tracking, space exploration and disaster rescue[1]. In the sensor management problem of multi-target tracking, which means choosing the right sensor tracking the right target at the right time[2], tracking accuracy and algorithm complexity are the two important indexes focused on[3,4].However, WSN nodes are usually powered by battery which cannot be replaced, then the network energy is greatly limited. Most energy consumption in WSN comes from the communication between nodes, so the communication mechanism determines the effectiveness of the network energy, and affects the network lifetime directly. So designing a sensor management algorithm with high tracking accuracy, low communication cost and complexity is particularly important.

Domestic and foreign scholars put forward many solutions for sensor management problem in recent years. Considering the sensor management problem based on covariance control, a greedy algorithm[5] was used to complete the sensor-target assignment; authors[6] took the Geometric Dilution of Precision (GDOP) as criterion and solved the sensor management problem through global node selection algorithm. In allusion to sensor management problem in large-scale wireless sensor network, authors[7] established the objective function with generalized information gain

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and the optimization model was solved by quadratic programming theory. The binary particle swarm optimization (BPSO)[8] algorithm is introduced to solve the sensor management problem.

The researches above are all in centralized ways, considering their disadvantages such as high computation complexity, difficulties to get global information and poor robustness, the distributed sensor management algorithm gradually caught the scholars' attention[4,10], which improved the problem of complexity and system robustness, but the communication costs didn't be considered. This paper improves the multi-assignment strategy based on auction algorithms[11,12], and assigns multiple sensors to multiple targets through a forward-reverse auction algorithm. CSMA mechanism is introduced to receive less useless information, and the algorithm reduces the announcement of sellers' actual price and allows buyers to make decisions with local information, sensor-target assignment will be completed with a small amount of interactions between buyers and sellers.

2. Sensor management model

Considering a WSN with N_T targets and N_S sensors, sensors' coordinates is fixed. The state of target j at time k is $\boldsymbol{X}_j(k)=[x_j(k),\dot{x}_j(k),y_j(k),\dot{y}_j(k)]^T$. The observation equation of sensor i to the target j is $\boldsymbol{z}_{i,j}(k)=\boldsymbol{h}^i(\boldsymbol{X}_j(k))+\boldsymbol{v}_{i,j}(k)$, Where $\boldsymbol{v}_{i,j}(k)$ is the observation noise with variance matrix of $diag[\sigma_\theta^2\ \sigma_r^2]$,

$$\boldsymbol{h}^i(\boldsymbol{X}_j(k))=\begin{cases}\arctan\left(\dfrac{y_j(t)-y_i(t)}{x_j(t)-x_i(t)}\right)\\ \sqrt{(y_j(t)-y_i(t))^2+(x_j(t)-x_i(t))^2}\end{cases} \tag{1}$$

where $x_i(k)$, $y_i(k)$ are the position coordinates of sensor i and j at time k respectively.

Due to the nonlinearity of the observation equation, the Extended Kalman Filter(EKF) is used to get

$$h^i(\boldsymbol{X}_j(k))=\boldsymbol{H}_{i,\ j}(k)\boldsymbol{X}_j(k)+\boldsymbol{w}_{i,\ j}(k) \tag{2}$$

$$\boldsymbol{H}_{i,\ j}(k)=\frac{\partial \boldsymbol{h}_{i,\ j}}{\partial \boldsymbol{X}_j}\Bigg|_{\boldsymbol{X}_j=\hat{\boldsymbol{X}}_j(k/k-1)}=\begin{bmatrix}-\dfrac{\sin\theta_k^{i,j}}{r_k^{i,\ j}} & 0 & \dfrac{\cos\theta_k^{i,j}}{r_k^{i,\ j}} & 0\\ \cos\theta_k^{i,j} & 0 & \sin\theta_k^{i,j} & 0\end{bmatrix} \tag{3}$$

where $r_k^{i,\ j}$, $\theta_k^{i,\ j}$ are the distance and azimuth of the target j relative to the sensor i .We can get the expression $\boldsymbol{P}_j^{-1}(k+1/k+1)=\boldsymbol{P}_j^{-1}(k+1/k)+\sum_i \boldsymbol{H}_j^T(k+1)\boldsymbol{R}_{ij}^{-1}(k+1)\boldsymbol{H}_{ij}(k+1)$ in the filtering estimation[10]

Where $\boldsymbol{P}(k\,|\,k)$ and $\boldsymbol{P}(k+1\,|\,k)$ are the estimation and prediction error covariance matrix, $\boldsymbol{R}(k)$ is the observation noise error matrix. $a_{ij}=\left|\boldsymbol{H}_{ij}^T(k+1)\boldsymbol{R}_{ij}^{-1}(k+1)\boldsymbol{H}_{ij}(k+1)\right|$ indicates the information gain after observation, the larger the value is, the higher location accuracy can be gotten.

Define $\boldsymbol{S}_i$ as the sensor i 's selection vector, $\boldsymbol{S}_i=[s_{ij}]_{1\times N_T}$, $s_{ij}\in\{0,1\}$, $s_{ij}=1$ indicates that sensor i will track target j, on the contrary, the sensor i does not track the target j. For the tracking performance of the whole system, the objective function and constraint conditions are

$$\begin{aligned}&R=\max\sum_i\sum_j a_{ij}s_{ij}\\ &s.t.\sum_i s_{ij}\ge 1,\sum_j s_{ij}=1, s_{ij}=\{0,1\}\end{aligned} \tag{4}$$

3. Distributed sensor allocation algorithm based on auction

We use auction theory to analyse the problem, if the price of the sensor i is p_i, the income of using sensor i to