

Study of distributed algorithm for water sources monitoring based on wireless sensor networks

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Abstract

In order to improve the coverage of wireless sensor networks in the environment of water quality monitoring, the paper proposes a distributed algorithm which is based on diamond-shaped virtual force. In this algorithm, the differences between measurements and current calculated distances are modeled into forces, dragging the nodes close to their actual positions. Based on the diamond method, the algorithm can determine the predefined threshold of virtual force and optimize the global distribution. Compared with the simulation of existing algorithms, it is proved to have superior performance.

Keywords: Wireless sensor network, Diamond virtual force, Network coverage, Threshold.

1. Introduction

With the rapid economic development, pollution and destruction of water is increasingly serious. As one of the primary means of water resources management, water environmental monitoring is playing an irreplaceable role^[1]. Reasonable distribution of wireless sensor network can improve the coverage and connectivity of wireless sensor networks, and can reduce energy consumption and cost of network^[2,3].

In this paper, a distributed algorithm which is based on diamond virtual force

is putted forward. It solves the problem of traditional algorithm which is not adaptive to meet different measurements. Diamond virtual force algorithm can adapt to the distributed environment which contains obstacles and hotspots^[4]. And the search performance is still good with the sensor size increasing.

2. Diamond virtual force algorithm

The mode of wireless sensor node measurement includes binary and probabilistic measurement models. Due to the imprecision of binary model, we select probabilistic measurement model. Assume that the location of the wireless sensor node s_i is (x_i, y_i) and the target is located in (x, y) , then the distance between the target and s_i is given as Eq. 1.

$$d(s_i, P) = \sqrt{(x_i - x)^2 + (y_i - y)^2} \quad (1)$$

Probability measurement model^[5] of s_i is given by Eq. 2.

$$c_{xy}(s_i) = \begin{cases} 0 & r + r_e \leq d(s_i, P) \\ e^{(-\alpha_1 \lambda_1^{\beta_1} / \lambda_2^{\beta_2} + \alpha_2)} & r - r_e < d(s_i, P) < r + r_e \\ 1 & d(s_i, P) \leq r - r_e \end{cases} \quad (2)$$

Where r_e ($0 < r_e < r$) is reliability metric parameter of wireless sensor nodes, α_1 , α_2 , β_1 , β_2 is used for features measure of wireless sensor nodes, input parameters λ_1 , λ_2 are defined as follows Eq. 3, Eq. 4.

$$\lambda_1 = r_e - r + d(s_i, P) \quad (3)$$

$$\lambda_2 = r_e + r - d(s_i, P) \quad (4)$$

When r_e is larger than zero, the metrical process requires multiple wireless sensor nodes. The probability of joint measurement is given by Eq5.

$$c_{x,y}(S_{ov}) = 1 - \prod_{s_j \in S_{ov}} (1 - c_{x,y}(s_j)) \quad (5)$$

Where S_{ov} is the aggregate of wireless sensor nodes to be measured, assume that c_{th} is the probability threshold of wireless nodes, the effective measurement condition is that the least probability of joint measurement is less than c_{th} .

$$\min_{x,y} \{c_{x,y}(s_i, s_j)\} \leq c_{th} \quad (6)$$

Algorithm of virtual force assumes that all kinds of objects in wireless sensor networks can produce unequal force to wireless node. According to the forces, wireless sensor nodes move a corresponding distance until they reach the force balance. The forces it suffered are given by Eq. 7.

$$\vec{F}_i = \sum_{j=1, j \neq i}^k \vec{F}_{ij} + \vec{F}_{iR} + \vec{F}_{iA} \quad (7)$$

Where \vec{F}_i is total virtual force which is received by wireless node s_i , \vec{F}_{ij} is the force from sensor j to sensor i , \vec{F}_{iR} is the force from obstacle R to sensor i , \vec{F}_{iA} is the force from hot zone A to sensor i . \vec{F}_{ij} is given by Eq. 8.

$$\vec{F}_{ij} = \begin{cases} 0 & d_{ij} \geq C \\ (w_A(d_{ij} - d_{th}), \alpha_{ij}) & C > d_{ij} > d_{th} \\ 0 & d_{ij} = d_{th} \\ (w_R(\frac{1}{d_{ij}} - \frac{1}{d_{th}}), \alpha_{ij} + \pi) & d_{ij} < d_{th} \end{cases} \quad (8)$$

Where C is the communication radius of sensor node, d_{th} is the distance threshold, d_{ij} is the distance of two sensors, α_{ij} is the azimuth of wireless sensor nodes, w_A is the gravitational coefficient, w_R is the repulsive coefficient.

After the analysis of virtual force, the wireless nodes begin to move according to the size and direction of virtual force. They are given by Eq. 9, Eq.10.

$$x_{new} = \begin{cases} x_{old} & |F_{xy}| \leq F_{th} \\ x_{old} + \frac{F_x}{F_{xy}} \times \text{MaxStep} \times e^{\frac{-1}{F_{xy}}} & |F_{xy}| > F_{th} \end{cases} \quad (9)$$

$$y_{new} = \begin{cases} y_{old} & |F_{xy}| \leq F_{th} \\ y_{old} + \frac{F_y}{F_{xy}} \times \text{MaxStep} \times e^{\frac{-1}{F_{xy}}} & |F_{xy}| > F_{th} \end{cases} \quad (10)$$

Where F_{th} is the force threshold, F_{xy} is the total forces, F_x is the x-axis component of total virtual force, F_y is the y-axis component of total virtual force, MaxStep is the max removable distance.

When the distance threshold is too small, the distribution is dense and coverage can not be guaranteed; when the distance threshold is too large, the sparse distribution is easy to form blind spots. Diamond algorithm can determine the best distance threshold. It can be seen from Fig. 1.

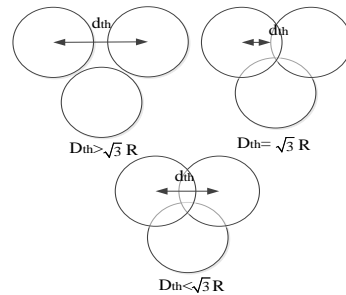


Fig 1. Compare of distance threshold

Assume that the distance of each center of a circle is d_{th} and the radius of cir-

cle is R, it can be seen that the best distance threshold is $\sqrt{3} R$.

3. Results and discussion

32 wireless sensor nodes are distributed in the square measurement area ($80 \times 80\text{m}$). The parameters of simulation are given by Table 1.

Table 1. Parameters of simulation

R[m]	C[m]	ω_A	ω_R	Max step[m]	
7	21	1	5	3.5	
$r_e[m]$	α_1	α_2	β_1	β_2	C_{th}
3.5	1	0	1	0.5	0.9

According to the table , the best predefined threshold of the diamond algorithm is 12m. Wireless sensor network nodes distribution of random initialization is given by Fig. 2a. The distribution of wireless sensor network nodes which is optimized by the virtual force is given by Fig. 2b, Fig.2c Fig. 2d when the predefined threshold is 10m, 14m, 12m.

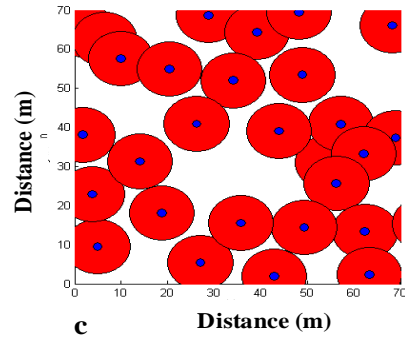
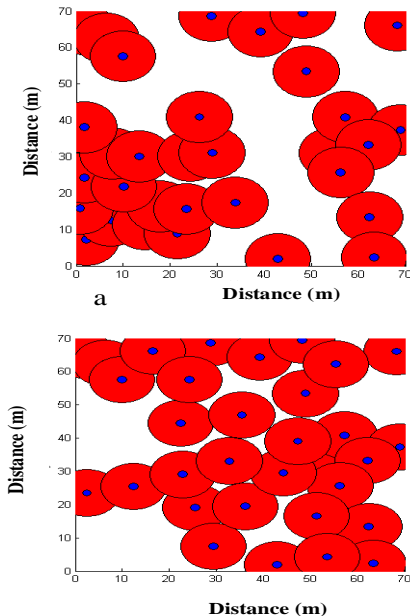
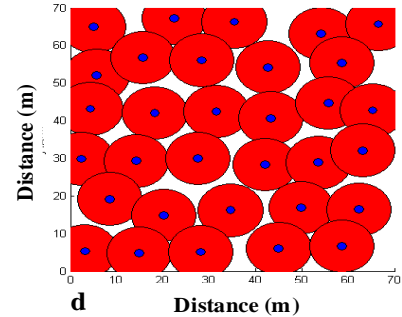


Fig. 4 Predefined threshold=14m



a: Random initialization, b: Predefined threshold=10m, c: Predefined threshold=14m, d: Predefined threshold=12m

Fig. 2 network coverage of different Predefined threshold

Wireless sensor network coverage of Fig. 2a is 59.22%, the coverage of Fig. 2b is 75.07%, the coverage of Fig. 2c is 69.30%, the coverage of Fig. 2d is 90.99%. When the predefined threshold equals to 12 m, it can get the largest network coverage.

Diamond virtual force algorithm can also be applied to the network coverage of the environment containing obstacles and hotspots. Predefined threshold equal to 12m the network coverage is shown in Fig.3. Here, green area stands for the obstacles, yellow area stands for the hotspots. From the Fig.3 we can see that the hotspots totally covered by the network signal, the network signal can be

transmitted over obstacles. Signals can be evenly cover the entire detection region.

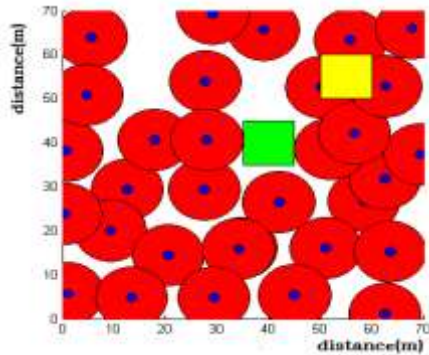


Fig. 3 Network distribution for the hotspots and obstacle based on Diamond virtual force algorithm

4. Conclusion

This paper presents an optimization algorithm which is based on diamond virtual force. The algorithm is applied for the distribution of wireless sensor nodes in the environment of water quality monitoring. It solves the problem of choosing predefined threshold, and provides a valuable reference for distributing wireless sensor nodes in the area of water sources.

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6. References

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