Coverage Strategy Based on Particle Swarm Optimization Algorithm for WSN Mountain Surface

Yongjie Si[a]
School of computer and information Qiannan Normal University for Nationalities Duyun, China
a.15185450507@163.com

Keywords: WSN, surface coverage, PSO.

Abstract: In this paper, a WSN mountain surface coverage strategy based on particle swarm optimization(PSO) is proposed. Due to the irregular nature of 3d surface, a directional gradient sensing model is introduced to transform the coverage problem of 3d surface onto that of 2d surface, and PSO is used to optimize the location of network nodes to achieve optimal coverage. Simulation experiments verify the correctness of the coverage strategy and effectively solve the coverage problem of WSN 3d surface.

1. Introduction

WSN is a self-organizing multi-hop network composed of a large number of sensor nodes deployed in the monitoring area. The sensor node perceives the information in the detection area and sends the information to the sink node, which then sends the data to the user terminal through the Internet. Therefore, the coverage connectivity of wireless sensor networks is the most basic problem.

Traditional wireless sensor network coverage research mainly focuses on two-dimensional plane area. With the demand of practical application, the coverage of three-dimensional space has begun to be paid attention to. Literature [1] proposed a multi-mobile node wireless sensor network 3d coverage algorithm, which used a node perception model based on false alarm rate to perceive target monitoring points, and calculated the 3d joint detection probability of target monitoring points to conduct coverage hole analysis. Literature [2] puts forward a three-dimensional coverage enhancement algorithm based on virtual force to ensure the uniform distribution of the transducer. The literature [3] established three-dimensional perception model of sensor nodes according to the surface irregularity, and differential evolution (DE) algorithm was used to optimize the location of nodes. Literature [4] proposes a radius of adjustable wireless sensor network (WSN) three-dimensional (3d-CAAR) covering algorithm, using virtual force and energy consumption threshold to realize the uniform deployment and adjustable radius of nodes. Literature [5] proposed the node selection and settlement method of weighted bisection graph matching, a cover hole detection algorithm based on tyson polyhedron and a hole point clustering algorithm based on k-means to complete the cover hole repair.

Most of the above algorithms are focused on the coverage of three-dimensional space and has few studies on the coverage of three-dimensional surface. In this paper, a directional gradient sensing model is used to transform the problem of 3d surface coverage into the problem of 2d surface coverage, and particle swarm optimization algorithm is used to optimize the location of nodes to solve the problem of 3d surface coverage.

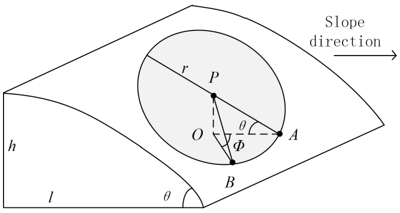

Figure1: Direction Gradient Sensing Model.

2. Coverage Model

2.1. Network Model

This paper adopts the following assumptions:

- The detection capability of sensor nodes is isotropic, with the same sensing radius and communication radius, and the ideal detection radius is r.
- If the WSN network can achieve full coverage, it must be connected [6], when the communication radius is greater than or equal to twice the sensing radius,.
- Take the surface within the coverage area of nodes as a plane, without considering the impact of concave and convex points on the coverage model.

2.1.1. Direction Gradient Sensing Model

In the three-dimensional space, the sensing range of a node is a sphere, so it is difficult to determine the coverage area of the node in the irregular three-dimensional surface. Therefore, the WSN three-dimensional surface is projected onto the two-dimensional plane. In order to avoid coverage holes, the sensing model based on direction gradient is adopted in this paper.

As shown in Fig.1, on the surface z = f(x,y), the gradient direction at P is the direction in which the slope height decreases the fastest, which is called slope direction. The modulus of the gradient represents the elevation rise and fall on the unit length, which is called slope β, i.e

$$|\boldsymbol{gradf}(x,y)| = \beta = \frac{h}{l} = tan\,\theta \qquad (1)$$

Where, h is the vertical height of slope, l is the ratio of horizontal distance, and θ is the Angle between slope and horizontal plane.

According to the mathematical analysis, the directional derivative g along any L direction on surface z = f(x,y) is

$$g = \frac{\partial z}{\partial L} = \boldsymbol{gradf}(x,y) \times \boldsymbol{eL} = |\boldsymbol{gradf}(x,y)| \cos \emptyset = \beta \cos \emptyset \qquad (2)$$

Where, eL is the unit vector of L, and the Angle ∅ is the Angle between gradf(x,y) and L in the clockwise direction which is called the direction Angle.

According to equations (1) and (2), the actual sensing radius of any point on the surface projected into the plane along the $\emptyset$ direction is[7,8]

$$r' = r\cos[arc\tan(\beta\cos\emptyset)] \tag{3}$$

According to equation (3), the coverage area of nodes on a 3d surface projected on a 2d plane is an ellipse whose long axis is 2r and short axis is $2r\cos[arc\tan(\beta)]$.

2.1.2. Coverage Model Description

The target covering surface is projected onto a two-dimensional plane, and the measured area in the two-dimensional plane is discretized into m×n pixels. It is assumed that the number of sensor nodes isM, and the collection of sensor nodes is $ND = \{nd_1,nd_2,...,nd_M\}$, Where the ith sensor node is $nd_i(i = 1,2,...,M)$,which coordinates of (x_i,y_i).Let the coordinate of grid pixel point E be(x_E,y_E), Then the distance between nd_i and E is

$$d(ND,E) = \sqrt{(x_E - x_i)^2 + (y_E - y_i)^2} \tag{4}$$

Then the probability of pixel E covered by node i is:

$$p(nd_i,E) = \begin{cases} 1 & d(ND,E) \le r' \\ 0 & d(ND,E) > r' \end{cases} \tag{5}$$

Then the Joint probability of E covered by ND is:

$$p(ND,E) = 1 - \prod_{nd_i \in ND}[1 - p(nd_i,E)] \tag{6}$$

Then the probability of the monitoring area covered set ND is as follows[9]:

$$COV(ND) = \frac{\sum_{E \in m\times n} p(ND,E)}{m\times n} \tag{7}$$

3. Particle Swarm Optimization Algorithm

Particle swarm optimization (PSO) algorithm is initialized as a group of random particles, and then the optimal solution is found through iteration. In each iteration, the particle updates itself by tracking individual and global extremes.

Suppose N particles form a community in a D-dimensional target search space $X = (x_1,x_2,...x_N)$, Where the ith particle is expressed as

$x_i = (x_{i1},x_{i2},...x_{iD}),(i = 1,2,...,N)$, Its flight speed is $v_i = (v_{i1},v_{i2},...v_{iD}),(i = 1,2,...,N)$ .The individual extremum is the optimal solution of the particle itself in the iterative process $locbest = (x_{l1},x_{l2},...x_{ln})$. The global extremum is the optimal solution generated by all particles in the iterative process $globest = (x_{g1},x_{g2},...x_{gn})$. The velocity and position of particles in the d-dimension of the k+1 iteration updates as follows[10]:

$$v_{id}^{k+1} = wv_{id}^{k} + c_1r_1(x_{ld}^{k} - x_{id}^{k}) + c_2r_2(x_{gd}^{k} - x_{id}^{k}) \tag{8}$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1} \tag{9}$$

Where, w is inertia weight factor, c_1 and c_2 are learning factors, and r_1 and r_2 are uniform random numbers within the range of [0,1].

4. Wsn Surface Coverage Strategy Based on Particle Swarm Optimization Algorithm

A coverage distribution of the monitoring area is regarded as a particle in the particle swarm, and equation (9) is taken as the objective optimization function. Through iterative update of particles, the optimal particle and the optimal objective function value are found in the mesh nodes of the surface division.

Algorithm 1 WSN surface coverage algorithm based on PSO

Input: sensing radius r, plane grid division size m×n, particle swarm size N, search space dimension D, iteration number Q

Output: optimal particle x_v, maximum network coverage P

- Step 1 Initialization
- Divide the grid and obtain grid point coordinates
- Obtain the coordinates of grid points corresponding to the 3d surface and its slope matrix and slope direction matrix
- Randomly select D/2 nodes from the planar grid nodes as a particle, and initialize the particle swarm of size N
- Initializes individual and global extremum
- Step 2 while(number of iterations ≤Q)
- calculate the objective function value of each particle according to the above coverage model and initialization information
- update individual optimal value and global optimal value
- update particle position and velocity according to formula (8) and (9)
- Step 3 Return x_v, P

5. Simulation Analysis

This paper adopts Matlab for simulation analysis and nodes are deployed on the 3d surface as shown in Figure 2.

5.1.Simulation Parameters

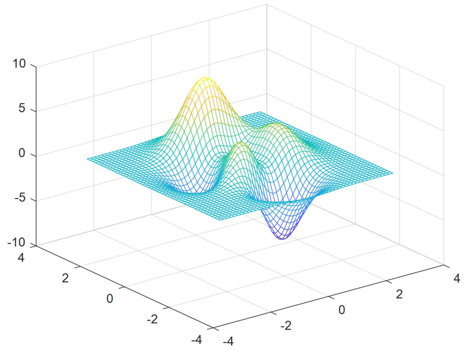

Figure 2: Surface.

Table 1: Setting of simulation parameters.

Parameters	values
learning factors c1、c2	2
inertia weight factor w	0.7
Particle swarm size N	30
Sensing radius	0.5
Monitoring area size	6×6
Mesh size	60×60

5.2 Simulation Results and Analysis

First, deploy the network nodes in three dimensional space area randomly as shown in Fig.3, and then optimize the location of nodes through the particle swarm optimization algorithm. set the initial actual required number of sensor nodes N = 101, and then add 5 successive, contrast coverage as shown in Figure.4 , the data for multiple simulation.

As shown in Fig.4, with the increase of the number of nodes, both the initial coverage rate and the final coverage rate increased. When the number of nodes was 116, the coverage rate was above 95%, which was considered to be full coverage.

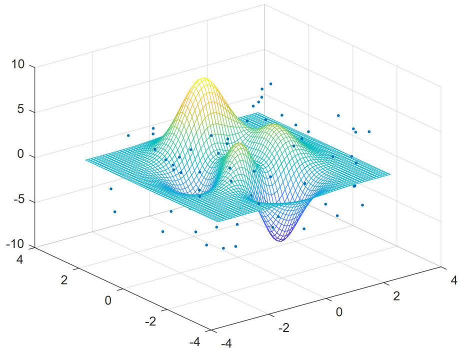

Figure 3: Initial deployment.

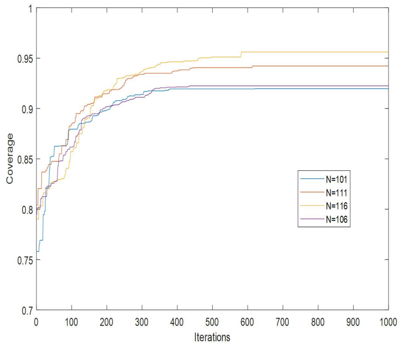

Figure 4: Coverage propotion.

Figure.5 shows the distribution of sensor nodes optimized by PSO on the 3d surface when the number of nodes is 116.

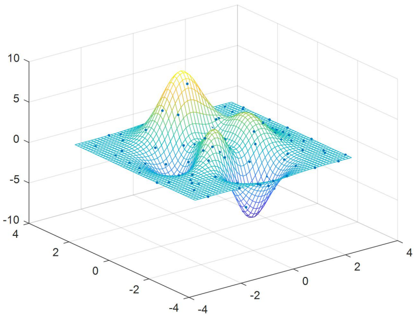

Figure 5: Optimized node distribution.

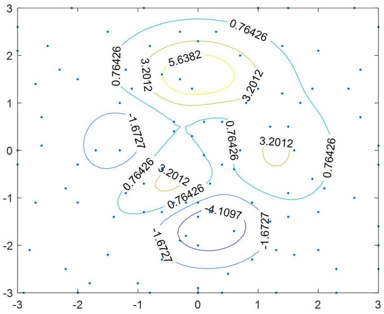

Figure 6: Optimized node plane distribution.

Figure.6 shows the projection distribution of 3d nodes projected onto 2d plane. The curve is contour line of the surface. It can be seen that, the distribution of nodes is dense due to the reduction of projection coverage area at the position with a large surface slope, while the distribution of nodes is sparse at the position with a small slope.

6. Conclusions

Using the directional gradient induction model to convert the 3d curved surface coverage problem to the 2d curved surface coverage problem and using PSO to optimize the position of the network nodes can achieve the best coverage. Through simulation experiments, we verified the correctness of the mountain coverage strategy of wireless sensor networks based on particle swarm optimization, and effectively solved the problem of WSN 3d surface coverage.

Acknowledgments

Guizhou education department youth science and technology talent growth program (QianJiaoHe KY Number[2017]342), University-level key project of qiannan normal college for nationalities(qnsy2017005).

This paper proposes a covering strategy of 3d complex surface based on particle swarm algorithm. the three-dimensional surface covering problem is converted into a 2d plane coverage problem based on gradient direction perception model, and realize the three dimensional surface coverage optimization by PSO. A large number of experiments prove the correctness of the proposed covering strategy, but how to improve the algorithm convergence and avoid "premature" remains to be further research.

References

[1] HAO Zhan-jun, QU Nan-jiang, DANG Xiao-chao. A Three-dimensional Coverage Algorithm for WSN with Multiple Mobile Nodes in Complex Environment [J]. Computer Engineering, 2019, 45(2):114-121,128.

[2] ZHOU Ting. Three-Dimensional Coverage Enhancing Algorithm Based on Virtual Force in All-Directional WSN [J]. Journal of Inner Mongolia Normal University(Natural Science Edition), 2017,46(4):566-570.

[3] HEN Shu, JI Zhong-jun. Algorithm research for complex 3-D surface coverage [J]. Computer engineering and applications, 2016, 52(20):127-131.

[4] DANG Xiao-chao, SHAO Chen-guang, HAO Zhan-jun. 3D-coverage algorithm based on adjustable radius in wireless sensor network [J]. Journal of Computer Applications, 2018, 38(9):2581-2586,2615.

[5] WU Ke-qi, ZHENG Run-gao, WANG Zhong-si. Coverage method for 3D underwater WSNs [J]. Transducer and Microsystem Technologies 2018,37(10):25-27,31.

[6] hang Hong-Hai, Hou Jennifer C. Maintaining Sensing Coverage and Connectivity in Large Sensor Networks[J].2005, 1(1-2): 89-124.

[7] LIU Xue-jun, REN Zhi-feng, WANG Yan-fang. Slope Model at Arbitrary Direction Derived from Grid-based DEM [J]. Areal Research And Development,2009,28(4):139-141.

[8] HEN Xian-hao, LI Jun, NAI He. Detection of Coverage Hole in WSN Based on Three-Dimensional Terrain Correction [J]. Chinese Journal of Sensors and Actuators,2016,29(1):109-115.

[9] WU Yile, HE Qing, XU Tongwei. Application of Improved Adaptive Particle Swarm Optimization Algorithm in WSN Coverage Optimization [J]. Chinese Journal of Sensors and Actuators, 2016,29(4):559-565.

[10] TENG Zhi-jun, Lü Jin-ling, GUO Liwen. Coverage Strategy of Wireless Sensor Network Based on Improved Particle Swarm Optimization Algorithm [J]. Journal of Guangxi Normal University(Natural Science Edition),2018,36(3):9-16.