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3D Coverage Enhancement Algorithm Based on WMSNs

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Summary

With the development of Multimedia Wireless Sensor Networks (WMSNs), the coverage of the sensors in network is one of the key technologies, which has a great influence on the monitoring ability, quality of service and network lifetime of the whole networks. The application environment of WMSNs is not only simple flat surface but also curved surface such as hills. In this paper, a new coverage enhancing algorithm based on 3D complex curved surface will be focused before. On the basis of the studies of former algorithms, aiming at the curved surface, a curve–to–flat method is proposed to describe the deployment accurately. Secondly, a discriminant method especially for 3D sensing model is proposed. In order to meet the request of complex 3D surface monitor task and based on the centralized coverage enhancing algorithm, Cuckoo Search algorithm, a new method of survival of the fittest, solution–division and evolution–division are combined together, being brought into the traditional Cuckoo Search. The simulation result demonstrates that the proposed algorithm improves the rate of convergence. And the deployment is more effective than existing methods, regarding the enhancement to the quality of network.

Keywords: Multimedia Wireless Sensor Networks; Coverage; Cuckoo Search

1. Introduction

With the development of embedded system and communication technology, Wireless Multimedia Sensor Network is in an important position 0]. As the higher version of WSNs, Wireless multimedia sensor networks win with its information acquiring method and processing technology, which acquire complete information in monitoring area, especially video data 0. They have been widely used in different application such as military affairs, public security, environment monitoring & forecast, home automation, and Intelligent Transportation etc. Different issues need to be addressed when deploying a network, such as localization, data fusion and deployment. The deployment problem is to guarantee the coverage of the monitoring area by corresponding to the sensors, and it is the foundation of application.

In WMSNs, the deployment is to find the problem and the goal is to find the optimal position and orientation of the sensors in the target environment 0. Normally, the detection area is defined by the condition of where the network is used. How to cover the space as much area as possible? While keep the lasting time of network is the key to coverage enhancement study. The study of coverage enhancement has normally three key points. First, which area could the sensor covered? Second, which kind of space needed to be monitored? The last point, which kind of algorithm is used to enhance the coverage. In former works, most of the coverage studies are based on the Omni–Directional Sensing Model. This means the sensors in WMSNs has the ability to monitor the information in a circle which center is the sensor itself. And based on this assumption, there are many algorithms proposed accordingly. With the increasing request of applied condition and the variety of sensing information, the direction–oriented sensing model draws much attention. It is assumed that the sensor could focus on one main direction with certain angles. Some of the researches are based on 3–D sensing model which could be used underwater. In this case, the sensing model is a sphere. Some studies focus on the coverage effect on ground, and due to the physical truth of virtual sensors such as camera or video monitor, a kind of directional sensing model in 3–D is proposed. The studies mainly focus on how to change the position or angle to maintain the coverage to the ground.

For the detection space, most of the formal works focus on 2–D space, which abstract the network task in a simple way. Some of the studies aim at solving problem in 3–D space, but with ordinary, untargeted sensing model. So, the coverage for complex surface in 3–D space based on 3–D sensing model is a big challenge.

The algorithms used in WMSNs coverage problem can be classified into distributed algorithm and centralized algorithm. Distributed algorithm is proposed by considering the calculating capability of each sensor. The sensor optimizes itself by communicating with neighbor sensors and aligns the position and parameters. The centralized algorithm assumes that the deployment of the network could be transfered to a super sensor or backend and re–arrange the sensors according to the result. For centralized algorithm, many optimizations including iterative algorithms are used for finding a good solution for coverage of WMSNs. How to find a proper method for approach the coverage goal and how to modify algorithms for better use in the application still remained a lot of space. From the above statement, we know that the study on coverage–enhancement algorithm is mostly based on 2–D sensing model for multimedia sensors in 3–D environment, a lot of space remains.

This paper is focusing on the coverage enhancement in Multimedia Wireless Sensor Networks, doing researches on different algorithms based on different sensing model and variety applications. And propose a 3D coverage enhancement algorithm based on complex surface monitoring.

The rest of the paper is organized as follows: In Section 2, the definitions of 3–D sensing model and the detection–distinguish method is presented. In Section 3, the coverage problem in 3–D practical condition is analyzed and a 3D coverage enhancement algorithm for complex surface is proposed to solve the problem in real application. The simulation experiments and evaluation are given in Section 4. And finally, the conclusion is offered in Section 5.

2. Distinguish Method of Sensing Model

2.1 3D Coverage Model

Most of the sensing models in coverage study are based on 2D space and are abstracted as sector sensing model and trapezoid model 0. But the deployed area of WMSNs is 3D space. In this paper, we assume that the camera sensors are deployed over the target with a random angle, whose projection on the surface could cover the target. In this paper, the 3D coverage enhancement algorithm is studied based on 3D sensing model below:

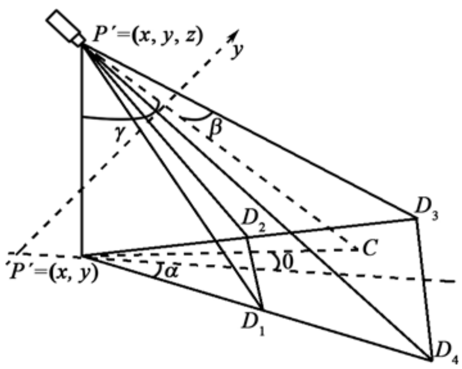

Figure 1. The multimedia sensor can be expressed as five elements $(P, \vec{D}, A, \alpha, \beta)$.

P=(x, y, z) denotes the coordinate of the sensor's position. $\vec{D}=(\gamma,\ \theta)$ denotes its sensing direction where γ denotes the angle between main direction and the negative direction of Z axis, where θ is the angle between main direction and the positive direction of X axis, as the picture shows. A denotes the maximum value of $\gamma(0\le\gamma\le A)$. 2α denotes the sensor's horizontal perception angle while β denotes vertical perception angle.

The complex surface can be defined as follows: The monitoring area is convex, which means that it can be expressed as a function $z=f(x, y)$ under the Cartesian coordinate system. The complex surface behaves as a plane, when $z=c$ only. It can behave as a bevel, when $z=ax+by+c$ only. When the position coordinates of the sensor meet the equation, it is considered to be on the surface.

2.2 Coverage for Curve

The focus of coverage is monitoring the area and catching information by using the Wireless Sensors 0, the sensing ability depends on the size of defected area 0 and detected result 0. The study on surface coverage is limited. The concept of surface coverage is presented by Zhao. Besides him also proved that the coverage problem in 3D space cannot be solved by 2D deployment algorithm. How many sensors are needed in minimum under the given random distribution and given desired coverage rate are studied. In Zhao's study, sensor nodes are assumed to be deployed exactly on the surface of the monitoring area such as the surface of the mountain. In precious studies, there's no 3D coverage method that is based on not only complex surface but also the 3D sensing model of Wireless multimedia sensors. This article will make up the gaps in this field.

This article will focus on 3D coverage problem based both on 3D sensing model and complex surface of monitoring area.

While the monitoring area is a plane, the projection is a trapezoid D_1, D_2, D_3, D_4. But consider the monitoring area is more realistic, we define a distinguish method for the curved surface coverage problem for the first time.

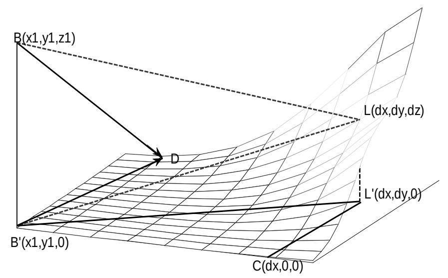

Figure 2. The schematic diagram of distinguishing the coverage for 3D model

Basically, B is the position of the sensor, B' is its projection on curved surface. $L=[L_1, L_2, \cdots, L_{num}]$ denotes a set of discrete points need to be distinguished. L'_i is the projection of L_i, C is the projection of L'_i upon X axis.

$$\angle\mathrm{BPL}=\frac{\arccos(|BB'|^2+|AL|^2-|BL|^2)}{2|AL|\cdot|BB'|} \tag{1}$$

$$\angle\mathrm{L'BC}=\begin{cases}\arctan\left(\frac{|BC|}{|L'C|}\right) & \overrightarrow{BC}>0\\ \arctan\left(\frac{|BC|}{|L'C|}\right)+\pi & \overrightarrow{BC}<0\end{cases} \tag{2}$$

Demand One: L_i should be in the range of the sphere whose center is B, whose radius is R. Besides, it is $L_i(z)<z_1$. The Fig. 1 shows the Euclidean distances between S_i and discrete points on the surface. The blue circles are the points $L=[L_1, L_2, \cdots, L_k]$ meet demand one.

Demand Two: $\gamma-\beta<\angle\mathrm{BAL}<\gamma+\beta$. L_i is in the range of the sensor's vertical sensing area.

Demand Three: $|\angle\mathrm{L'BC}-\omega|<2\alpha$, L_i is in the range of the sensor's horizontal sensing area.

The process of the distinguishing method is like this:

Step 1: input the position of sensor, the parameters of the sensing model and the information of the monitoring area;

Step 2: for each S_i in $S=[S_1, S_2, \cdots, S_{Nd}]$, get its $L=[L_1, L_2, \cdots, L_k]$.

Step 3: for each L_i And sensor S, determine if it match demand Two, if $\gamma-\beta<\angle BAL<\gamma+\beta$ go to step 4; if it doesn't match, reject L_i.

Step 4: determine if it matches Demand Three, if $|\angle L'BC-\omega|<2\alpha$, make $P(L_{ij})=1$; else make $P(L_{ij})=0$.

Step 5: distinguish all the sensors and discrete points. For all L, output the coverage C over the monitoring area. The focus of the method above is how the information of the monitoring area can truly reflect the realistic world. That means how the discrete points can be selected evenly. In the coverage of plane surface, the rate of coverage is represented by many discrete areas divided evenly on the plane. After calculating the coverage of each little area, the coverage rate can be defined as:

$$C=\frac{\sum_{i=1}^{p}\sum_{j=1}^{q}P(L_{ij})}{pq} \tag{3}$$

Different from plane surface, the coverage rate of curved surface cannot depend on the random selected points on the XoY plane but the terrain of the monitoring area. A shortcut method is used for transforming a curved surface into a plane, thus to describe the monitoring area with a low computation complexity.

In the smooth area of the mountain, its curvature is small, thus the area of curved surface is small. While in the steep area, its curvature is big, thus the area of each small curved surface is bigger. On the top of mountain, it become smooth again where the matrix coefficient is small accordingly.

3. 3D Coverage Enhancing Algorithm Based on Complex Surface

Cuckoo Search is a new Bio−inspired algorithm which was proposed by Yang 0. The Cuckoo Search algorithm is used for solving the optimization problem by learning from cuckoo the way those brooding eggs.

Cuckoo takes their eggs into other birds' nest, because the child cuckoo is hatches earlier than the other eggs in the nest. The little cuckoo will break all the other eggs out of the nest and singing louder than the others, which makes the big birds feeds more to little cuckoo. Thus, cuckoo can survive. Under other condition, the big birds will find out that the little cuckoo is not their own child. Thus, the big birds will leave the old nest and find a new place to build up a new nest. In this case, the little cuckoo eggs will die. In the competition for existence, the shape of cuckoo eggs and the sound of cuckoo sings will become similar as the host bird 0.

Cuckoo search is using Levy flight to describe the flying of cuckoo $X=[x_1, x_1, \cdots, x_D]$. X means the nest of each egg, which is used for finding new nest $X^{t+1}=X^t+\alpha S_L\otimes(X_i^t-X_b)\otimes r_n$.

$S_L L_D(\lambda)$, $r_n N^{D(0,\ 1)}$, α is the step factor which decide the distance between new nest and the old one. X_b is the optimum solution in history.

In case that some host find out that some nests are occupied by cuckoo, the new nest here is calculated by the following equation:

$$X^{t+1}=X^t+r_u(X_j^t-X_k^t)\otimes H(p_a-r_u)r_u U(0,\ 1) \tag{4}$$

$R_u U^{(0,\ 1)}$ x_i, x_j and x_k need to be different and they are selected randomly; $H(\cdot)$ means Function Heaviside. We can find out that Levy flight contains short jumps in small range and one big jump. Different from Brownian movement, Levy flight can reduce the sampling time and find the new nest efficiently 0.

Though cuckoo search has the ability to find the only optimum value, it is meaningless to find it in Engineering Problem with huge amount of calculation and energy. In consideration of the aspects above, a new method of finding the nest is presented as survival of the fittest.

3.1 Survival of the Fittest

The finding of the nest will no longer depends on Levy flight randomly but divides the nest into top nest X_{top}^t and abandon nest $X_{abandon}^t$. And strengthen the interaction inside X_{top}^t in order to get the X_{top}^{t+1} in an efficient way. For Top nest:

$$X_{top-i}^{t+1}=|X_{top-i}^t-X_{top-j}^t|/(1+\sqrt{5}/2)+X_{ware}^t \tag{5}$$

This means in the neighborhood of top nest, there's high possibility to find the next top nest. If $X_{top-i}^t=X_{top-j}^t$, then finding the nest by Levy flight:

$$X_{top}^{t+1}=X_{top}^t+\alpha_{top}S_L\otimes(X_{top}^t-X_b)\otimes r_n,\ \alpha_{top}=\alpha/t^2 \tag{6}$$

For abandon nest:

$$X_{abandon}^{t+1}=X_{abandon}^t+\alpha_{abandon}S_L\otimes(X_{abandon}^t-X_b)\otimes r_n \tag{7}$$

$\alpha_{abandon}=\alpha/\sqrt{t}$. The length of the step are different from top nest, which makes it possible to leaving the bad nest quickly and find the optimum value in a wild range. This would also improve the convergence of the algorithm.

3.2 Contract Solution Space

In 3D coverage problem, the searching space for each solution x_i is $[0,\ 2\pi]$. When dealing with the solution out−of−range, there is a way in normal cuckoo search to absorb the solution and make them being 0 or 2π. This leads the searching falling into the local optimum. In this paper, based on the feature of angle searching, the solution is converted from $[-\infty, +\infty]$ to $[0,\ 2\pi]$. Fig. 3 shows when D=3, the solution space before converted and after converted.

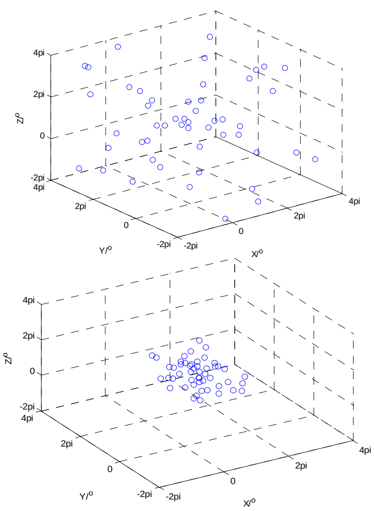

Figure. 3 The contracted solution space

4. Experiments and Evaluation

To compare the performance of algorithm with Particle Swarm Optimization we use the same initial deployment and fitness function for both.

Table 1. Parameter Setting of the Algorithm Simulation

Parameter settings	value
Monitoring Area	60×60
sensor amount Nd	50
Population amount n	10
Initial possibility Pa	0.25
Learning factor Sp	1.05
Success threshold Rth	0.2
Ratio of Top to abandon	3/7
Sensing angle 2α	$3/\pi$
Sensing angle 2β	$3/\pi$

The height of sensor is defined as 5m. The sensing radius of each sensor is 10m.The initial angle are randomly selected. The blue area which is detected is about 37.67% of the whole monitoring field.

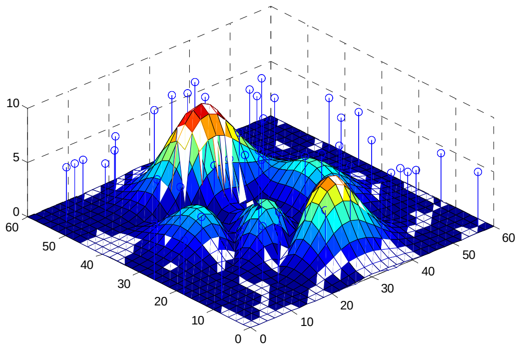

Figure 4. The final coverage after optimization

After iterated 200 times, the coverage enhanced to 48.06%, the enhancement improved 27.58%.

When changing the number of sensors in the monitoring area from 50 to 60, 70, 80, 90.

The result shows that the 3D coverage enhancement algorithm based on complex surface improves the coverage of complex surface such as mountains.

Table 2. The coverage enhancement ratio

Nd	C1(initial)	C2(final)	△C
50	0.376 7	0.480 6	27.58%
60	0.447 5	0.545 7	21.94%
70	0.48	0.601 8	25.38%
80	0.530 2	0.660 9	24.65%
90	0.586 3	0.702 2	19.77%

5. Conclution

In this paper, we proposed a new coverage enhancing algorithm based on 3d complex curved surface. Using the complex curved information, our 3D coverage enhancement algorithm could automatically find the best coverage solution through the modified cuckoo search algorithm. Our Cuckoo Search algorithm is highly robust and accurate because it uses new method of survival of the fittest and contract solution space. The experiment shows that our algorithm can work well in complex surface environment based on different parameter settings.

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