Abstract- With the foundation of the video probabilistic sensing model that sensing direction is steerable, the study on path coverage enhancement algorithm for video sensor networks has been improved. Analysis the position of effective center of mass in the sensor’s model, the network calculates the gravitation between the target track points and the trace nodes, and the repulsive force between both trace nodes of the target track points, then the trace node adjusts its sense direction, make the probability of the target track points which is perceived by the sensor network equals or exceeds the perception threshold. The simulation result shows that, this improved algorithm has make further improvement on the perception of the target which is move in the coverage area, it uses more fewer directional video nodes, but the video sensor networks is fully and high effectively covering the target trajectory.

Keywords: Probability sensing model; video sensor nodes; virtual force.
I. INTRODUCTION

WSNs (Wireless Sensor Networks) [1] can monitor, sense and collect information of all kinds of environments and monitored objects with the collaboration of various types of integrated micro sensors. Such as the application in warfare surveillance of military battlefield, maintenance and management of civil public facilities, inspection and maintenance of industrial equipment, scientific observation of gathering place of animal and plant, etc. Coverage problem is a basic problem of any type of WSN, and is closely related to sensor node deployment which has a direct influence on the coverage performance of network. Sensor node deployment reflects the cost and performance of wireless sensor network, and reasonable deployment scheme can greatly enhance the sensing effect of wireless sensor network (WSN) and reduce the use cost [2][3]. The current research of coverage control is focused on omnidirectional sensing model [4][5] . However, the way of sensing targets and acquiring the target information for some sensor nodes, such as video sensors, infrared sensors, ultrasonic sensors and so on, is obviously directional, which are called directional sensor nodes. In the practical application, the sensing probability of targets sensed by directional sensor network is different with the change of time and location, namely, the node detects targets according to a certain probability. The directional sensor is affected by various factors, so the target detection probability is not guaranteed, may even make false alert.

Boolean perception model is mostly used in the current research of directional sensors. Lu kezhong and Feng Yuhong [6] propose a kind of greed iterative algorithm aiming at the problem of enhancement of the sensor network coverage. In each iteration, adjust the sensors' direction so that the total coverage of a sensor network increases; repeat the iterative process until the total coverage can no longer increase with adjusting the direction of any node. According to Voronoi diagram and the direction adjustable characteristic of directional sensors and without global information of network, a distributed greedy algorithm is designed by Sung[7], which divides sensor nodes into Voronoi polygon, and considers the contribution degree of convex polygon and the overlap coverage ratio of each neighbor node in the sensing direction, finally makes the node working direction the best to expand the coverage effect. The literature[8], aiming at the problems of node energy waste and coverage redundancy
which occur in current directional sensor network algorithms when the sensing direction of the sensor is adjusted to achieve the maximum coverage of targets, puts forward a distributed clustering algorithm to complete the maximum coverage of the target with the least nodes and reduce the node energy consumption. The literature[9] presents two greedy algorithms based on priority to optimize the coverage area. In this algorithm the node needs convey messages many times to determine its working status and priority, so that the node energy consumption is increased. However, the detection probability of actual sensor nodes to target is usually uncertain, and the node's perception probability is varied with different distance. Deterministic sensing is approximately equivalent to the situation that the nodes based on probabilistic sensing model work in the ideal environment.

In order to reduce the complexity of time, the literature[10] , combining the virtual force with the concept of node centroids, proposes a enhancement algorithm based on sensing connected subgraph, in which the centroid position is adjusted on the action of virtual force and then the sensing direction of directional sensor node is adjusted to rotate and optimized, to reduce the covered hole and overlapped coverage of network. The literature[11] , researching on the problem of coverage to the target path, presents PFPCE(Potential Field based Path Coverage Enhancement) algorithm, which analyses the virtual force between node centroids and trajectory points and between the centroids of neighbor nodes, enhances the detection and tracking of directional sensor network to targets, but it uses deterministic sensing model. The literature[12] , by utilizing the repulsion force between the centroids of the effective monitored area and the overlapped area and that between the centroids of the effective monitored area and the barrier area, proposes a dynamic optimization algorithm of coverage ratio without blind area coverage based on virtual force. The algorithm solves the problem of network coverage limitation when obstacles exist in the monitoring area , optimizes the coverage of the video sensor and reduces blind area coverage, but at the stable instant of network, due to the virtual force still acting on "centroid", nodes exists the phenomenon of shock and new nodes are awakened , so the algorithm is needed to be re-executed and some nodes need to re-rotate, maybe resulting in greater energy consumption . J. Zhao[13] et al. present a algorithm to optimize the directional sensor network coverage based on virtual force. The algorithm closes the redundant nodes by analyzing the overlapped coverage ratio od
nodes and the force situation of centroid, and the experiment indicates that compared with PFCEA, this algorithm improves coverage quality of sensor network greatly and reduces the amount of calculation. The literature[14] defines the attractive force of uncovered points in the area to the node and proposes a distributed virtual force algorithm, which makes the node moving, reduces the overlapped coverage, minimizes overlapped area, makes sensors observe in the direction that users are interested in and can quickly converge within 5~6 iterations to achieve the expected coverage effect. The literature [15] discusses the three-dimensional model with the existence of obstacles, and eventually schedules the sensor network with initial low coverage and low connectivity through composite virtual force for a network with high coverage rate, heavy connectivity. Meanwhile the algorithm calculates the node movement energy consumption and discusses the termination conditions of the algorithm control. The literature[16] proposes a deployment algorithm based on the electrostatic field theory for mobile wireless sensor networks. The nodes and obstacles in the deployment area are taken as the charged particles; and the particles will move due to the Coulomb’s force from other particles or obstacles. Finally, the nodes automatically spread to the whole area by the resultant action and complete the deployment. The literature [17] focuses on the wireless sensor network communication radius in the high density of sensor nodes deployed randomly and two times smaller than the sensing radius; put forward a distributed k coverage multi connected node deployment algorithm based on grid. That can guarantee the wireless sensor network coverage and connectivity can reduce the number of the active state nodes effectively, prolong the wireless sensor network lifetime. The coverage holes recovery algorithm aiming at the coverage holes in wireless sensor network is designed in literature[18]. The nodes movement is divided into several processes, in each movement process according to the balance distance and location relations move nodes to separate the aggregate nodes and achieve the maximum coverage of the monitoring area. In a given sensing range, the video sensor can get some information of the target, but because of the distance from the target to the sensor, the pixel resolution of video and so on, it can not monitor the specific appearance of the target. That is to say, video sensor nodes can determinately sense the target points within a given range, and with the increase of distance, the perceptive ability of sensor nodes to the target point will have a certain decline. The
current study of video sensor network mostly adopts deterministic perception model, which is not in accordance with the actual situation, so the paper uses probabilistic sensing model to explore the deployment of video sensor network.

In this paper, the probabilistic sensing model and virtual force algorithm are adopted to control the video nodes within the network. The detecting probability and sensing effect of video nodes to the path of targets entering into the monitoring area are enhanced by the fusion of the sensing probability of the node and its neighbor node to the target trajectory points. The simulation results indicate that the algorithm makes the network realizing the fully efficient coverage to target moving path, and making full use of sensor probabilistic sensing area to achieve detection and monitoring of the target.

II. SENSING MODEL

2.1 Directional sensor model

Fig. 1 shows the model of probabilistic sensing of directional sensor sector. In order to denote the probabilistic sensing range of directional sensor, a new probabilistic range parameter \( d \) is added into the information of sensor nodes. Therefore, the node information can be represented by \(< S, R_s, \vec{V}(t), \theta_f, d >\), where \( s \) is the position coordinate, represented by \((x_s, y_s)\); \( R_s \) is the effective sensing radius; \( \vec{V}(t) = (V_x(t), V_y(t)) \) is the sensing direction at time instant \( t \); \( \theta_d (0 \leq \theta_d \leq 360) \) in Fig. 1 is the angle value between node sensing direction
and horizontal direction at time instant $t$; $2\theta_f$ is the effective sensing angle, called viewing domain of directional sensor, represented by $\text{fov}$; $d$ is the probabilistic sensing range and its value is related with power and hardware design of nodes.

Define a set $S = \{s_1, s_2, \ldots, s_i, \ldots, s_n\}$ to denote $n$ nodes in directional sensor network, $1 \leq i \leq n$. $p$ is the target point in the monitoring area, located by the coordinate $(x_p, y_p)$; $s_i$ is the $i^{th}$ node in the video sensor network, located by the coordinate $(x_{s_i}, y_{s_i})$; $P_{st}(s_i, p)$ is the sensing probability that target $p$ is sensed by video sensor node $s_i$; $d(s_i, p)$ is the Euclidean distance between target point $p$ and node $s_i$.

When $d(s_i, p) \leq R_s$, $P_{st}(s_i, p) = 1$; $d(s_i, p) = R_s + d$, $P_{st}(s_i, p) = 0$; and $R_s \leq d(s_i, p) \leq R_s + d$, the probability is expressed as

$$P_{st}(s_i, p) = -\frac{d(s_i, p)^2 - R_{far}^2}{d^2 + 2R_d d} \quad (2)$$

Therefore, sensing model of directional sensor can be described mathematically as

$$P_{st}(s_i, p) = \begin{cases} 
1 & d(s_i, p) \leq R_s \quad \text{and} \quad \theta_d - \theta_f \leq \theta_{max} \leq \theta_d + \theta_f \\
-\frac{d(s_i, p)^2 - R_{far}^2}{d^2 + 2R_d d} & R_s < d(s_i, p) \leq R_{far} \quad \text{and} \quad \theta_d - \theta_f \leq \theta_{far} \leq \theta_d + \theta_f \\
0 & \text{other}
\end{cases} \quad (3)$$

Fig. 2 shows probability sensing diagram of target $p$ sensed by video sensor node $s_i$.
2.2 Equivalent centroid calculation

We adopt two ways to control and adjust the deployment of the network in order to get better coverage to monitoring area and guarantee the quality of services of network. One way is to increase the scale of node deployment, which can make up for the deficiencies of quality of network services. Another way is to adjust the position of sensor nodes based on the existing network. The movement of the traditional sensor network is only aiming at the node itself, and when the node is moved by the action of the external force, the sensing range is moved. Due to the characteristics of irregular and incomplete symmetry, the movement of directional sensor network is special. In order to study the mobile characteristics, the method of equivalent centroid\[12,19\] of directional sensor, which is put forward according to the previous literatures that research on wireless sensor, is used widely.

Point C in Fig. 3 is the centroid of probabilistic sensing model of video sensor. The position of centroid varies with the different value of probabilistic sensing range parameter \(d\), but it must be located in the angle bisector of viewing angle of the video sensor.

![Fig. 3 Centroid of probabilistic sensing model of video sensor](image)

In order to calculate the centroid of the directional sensor based on the probabilistic sensing model, assume that the probability of sensed any point by the sensor is the density function in the sector area. Since the probability that sensed by the node within the sensing area is nonuniform; that is, the quality of the sensing sector area is nonuniform, we find the position of centroid in the symmetry axis of the directional sensor, and the distance from the vertex is \(d_{cen}\):
\begin{align*}
\mathbf{d}_{\text{cen}} &= \frac{\iint_{D} xP_{st})d\sigma}{M} = \frac{\iint_{D} xP_{st})d\sigma}{\iint_{D} P_{st})d\sigma} \\
&= \int_{-\theta_{f}}^{\theta_{f}} \cos\theta d\theta \int_{0}^{R_{s}} \rho^{2} d\rho + \int_{-\theta_{f}}^{\theta_{f}} \cos\theta d\theta \int_{R_{k}}^{R_{\text{far}}} -\frac{\rho^{2} - R_{\text{far}}^{2}}{d^{2} + 2R_{s}d} \rho^{2} d\rho \\
&= \int_{-\theta_{f}}^{\theta_{f}} d\theta \int_{0}^{R_{s}} \rho d\rho + \int_{-\theta_{f}}^{\theta_{f}} d\theta \int_{R_{k}}^{R_{\text{far}}} (-\frac{\rho^{2} - R_{\text{far}}^{2}}{d^{2} + 2R_{s}d}) \rho d\rho \\
&= \frac{2\theta_{f} \rho d - \rho d \theta}{\theta_{f} \rho d - \rho d \theta} \\
\end{align*}

where \( \rho = d(s_{i}, p) \), \( p \) is the point located within the sector sensing range of \( s_{i} \), and \( d(s_{i}, p) \) is the distance between \( p \) and \( s_{i} \).

Equation 4 indicates that when the probability of all the points monitored in the sector area is 1, the probabilistic sensing model is equivalent to the deterministic sensing model. The centroid is located in the symmetry axis and the distance from the circle center is \( 2(R + d) \sin \theta_{f} / 3\theta_{f} = 2R_{\text{far}} \sin \theta_{f} / 3\theta_{f} \).

2.3 Target trajectory

The red dotted line in Fig. 4 is the target moving trajectory from left to right, which is denoted by \( L \).

**Definition 1** sample the trajectory \( L \) with interval \( \Delta l \) uniformly and each sampling point is called a trajectory point[11] of the target. \( m \) is the total number of trajectory points, so trajectory points of the target can be represented as a set \( T = \{ t_{1}, t_{2}, t_{3}, ..., t_{m} \} \), \( i = 1, 2, 3, ..., m \) and the value of \( m \) can be calculated by the expression 5 (just take the integer part).

\[ m \approx \frac{L}{\Delta} \quad (5) \]

**Definition 2** the region, whose distance from target moving trajectory is less than or equal to \( R_{\text{far}} \), the farthest perception distance of the video sensor trajectory, is called as trajectory
belt[11]. Black solid lines represents the trajectory belt of the deterministic sensing model, while the black dotted line denotes the trajectory belt of probabilistic sensing model adopted in this paper; that is, the area between the black solid line and dotted line is the monitoring area which is expanded based on the improved algorithm in this paper .

**Definition 3** The video nodes within the trajectory belt are called tracking nodes, represented by the set \( S_k = \{s_1, s_2, \ldots, s_i, \ldots, s_k\} \), \( i = 1, 2, \ldots, k \), \( k \leq n \) and \( S_k \in S \).

![Fig. 4 The target moving path and the node distribution map in the monitoring region](image)

### 2.4 Coverage model

The target appears and passes through in the monitoring area and the trajectory is formed. The points on the trajectory are selected uniformly, represented by a set \( T = \{t_1, t_2, t_3, \ldots, t_i, \ldots, t_m\} \), \( i = 1, 2, 3, \ldots, m \). \( t_j \) is the \( j \)th target trajectory point and \( s_i \) is the \( i \)th directional node. We definite \( P(s_i, t_j) \) to denote the perceived probability of \( s_i \) sensing \( t_j \) and \( P_n(t_j) \) to denote the perceived probability of sensor network sensing \( t_j \) such that we get the joint perceived probability[20] that all the sensor nodes \( S = \{s_1, s_2, \ldots, s_i, \ldots, s_n\} \) of the network sense each target trajectory point in the monitoring area:

\[
P_{st}(t_j) = 1 - \prod_{i=1}^{n}[1 - P(s_i, t_j)] \quad i = 1, 2, 3 \quad n
\] (6)
Let the threshold of sensing probability be $P_{th}$. If $P_{st}(t_j) \geq P_{th}$, the trajectory point is judged to be sensed, namely, the trajectory point $t_j$ is covered by the network; Otherwise, the trajectory point is judged not to be covered. $P_{c}(t_j)$ denotes the perceived probability of sensor network sensing the trajectory point $t_j$, expressed as follow:

$$P_{c}(t_j) = \begin{cases} 
0 & \text{if } P_{st}(t_j) < P_{th} \\
1 & \text{if } P_{st}(t_j) \geq P_{th}
\end{cases} \quad (7)$$

$\eta_{cov}$ represents the coverage ratio that the target trajectory point is covered by sensor network, and its value is the ratio of the number of trajectory points sensed and the total number of target trajectory points, expressed as follow:

$$\eta_{cov} = \frac{t_{dis}}{m} = \frac{\sum_{j=1}^{m} P_{c}(t_j)}{m} \quad (8)$$

Where $t_{dis}$ is the number of trajectory points which are judged to be sensed by network, and $t_{dis} = \sum_{j=1}^{m} P_{c}(t_j)$. The value of $\eta_{cov}$ is related with $t_{dis}$ and $m$ which is the trajectory points number obtained by sampling the target trajectory.

Thus, by calculating the number of all the target trajectory points sensed by sensor network, we can get the situation of the detected target when moving in the monitoring area.

III. PATH COVERAGE ENHANCEMENT ALGORITHM FOR VIDEO SENSOR NETWORK BASED ON PROBABILISTIC SENSING MODEL

3.1 Algorithm assumption

To simplify the simulation, some assumptions are given:

(1) All the nodes have the same sensing radius $R_s$ and the same communication radius $R_c$ ($R_c = 2R_{far}$). In additional, the probabilistic sensing range of video sensor nodes is the same;

(2) The video sensor is deployed randomly. The nodes go to sleep when not working, which is
controlled by the network;
(3) After random deployment, the video sensor node knows the coordinate of itself, sensing
direction of itself and the location information of all the neighbor nodes;
(4) The position of the video sensor nodes cannot be moved, but its sensing direction can do a
circumferential movement around the node;
(5) The communication of video sensor nodes is omnidirectional. Set any two points in the
network as \( s_i \) and \( s_j \), and \( s_j \) is not in the current sensing direction of \( s_i \). The distance
between the two nodes is \( d(s_i, s_j) \). If \( 0 \leq d(s_i, s_j) \leq 2R_{\text{far}} \), the two nodes can communicate
with each other.

3.2 Virtual force analysis

(1) Attractive force between the target point \( t_j \) and the tracking node \( s_i \)

As shown in Fig.5, \( d(s_i, t_j) \) denotes the Euclidean distance between \( t_j \) and \( s_i \). If and only if
\( d(s_i, t_j) \leq R_s + d \), the attractive force between \( t_j \) and \( s_i \) is \( F(s_i, t_j) \).

Based on the probabilistic sensing model, the attractive force model can be described as:

\[
F(s_i, t_j) = \begin{cases} 
  \frac{k_a}{d(c_i, t_j)^a \sqrt{P_{st}(s_i, t_j)}} \cdot a_{ij} & \text{if } d(s_i, T_j) \leq R_{\text{far}} \\
  0 & \text{otherwise}
\end{cases}
\]  

\( 9 \)

Fig.5 the attractive force between the trajectory of target and the node
where $k_a, a$ is gain coefficient, $d(c_i, T_j)$ is Euclidean distance between centroid $c_i$ of node $s_i$ and trajectory point $c_i$ and $\overrightarrow{a_{ij}}$ is unit vector. Attractive force $\overrightarrow{F(s_i, T_j)}$ is inversely proportional to the probability that trajectory point sensed in equation 9, that is, the greater the sensing probability is, the smaller the attractive force is. $F_\perp(s_i, t_j)$ and $F_\parallel(s_i, t_j)$ is the components of attractive force $\overrightarrow{F(s_i, T_j)}$. $F_\perp(s_i, t_j)$ is the component force pointing to the node, while $F_\parallel(s_i, t_j)$ is the component force along the tangential direction. Since the node does not move, only $F_\parallel(s_i, t_j)$ makes the node rotating.

![Diagram](image)

**Fig. 6** The repulsion between centroid points of node $s_i$ and $s_j$

(2) Repulsive force between tracking nodes $s_i$ and $s_j$

$d(s_i, s_j)$ represents the distance between $s_i$ and $s_j$. When $d(s_i, s_j) \leq 2R_{far}$, repulsive force exists between $s_j$ and $s_i$, which acts on the centroid of tracking node $s_i$, as shown in Fig.6. $\overrightarrow{F(s_i, s_j)}$ is used to denote repulsive force between nodes, so repulsive force model is described as

$$
\overrightarrow{F(s_i, s_j)} = \begin{cases} 
  k_b \frac{1}{d^*(s_i, s_j)^b} \cdot \overrightarrow{a_{ij}} & d(s_i, s_j) \leq 2R_{far} \\
  0 & otherwise
\end{cases}
$$

(10)
Where $d^*(s_i, s_j)$ is Euclidean distance between centroid $C_i$ of $s_i$ and centroid $C_j$ of $s_j$, $k_a$ and $b$ is gain coefficient, $k_b \leq k_a$, $a_{ij}$ is unit vector pointing from $C_j$ to $C_i$. If and only if $d(s_i, s_j) \leq 2R_{fa}$, that is, they are neighbors, virtual repulsive force exists between $C_i$ and $C_j$. The repulsive force makes nodes move towards the direction in which the overlapped area is decreased. $F(s_i, s_j)$ is inversely proportional to Euclidean distance $d^*(s_i, s_j)$ and the repulsive force on centroids is inversely proportional to the distance between $C_i$ and $C_j$ in equation 9. $F_{\perp}(s_i, s_j)$ and $F_{\parallel}(s_i, s_j)$ is the components of repulsive force $F(s_i, s_j)$, $F_{\perp}(s_i, s_j)$ is the component force pointing to the node, while $F_{\parallel}(s_i, s_j)$ is the component force along the tangential direction. Similarly, only $F_{\parallel}(s_i, s_j)$ makes the node rotating.

(3) Resultant force acting on the centroid of node $s_i$

Repulsive force and attractive force jointly act on node $s_i$, and $\overline{F}_i$ represents resultant force on the centroid, expressed as follow:

$$\overline{F}_i = F(s_i, t_j) + F(s_i, s_j)$$

(11)

$\overline{F}_i$ can be divided into two components, $\overline{F}_{i\perp}$ and $\overline{F}_{i\parallel}$, and the node rotates on the action of component $\overline{F}_{i\parallel}$.

(4) Moving rules

If the perceived probability, tracking node sensing trajectory point $t_j$, $P_{fa}(s_i, t_j) \geq P_{th}$, namely $P_{fa}(t_j) \geq P_{th}$, the node cannot move anymore; If $P_{fa}(s_i, t_j) < P_{th}$, calculate the force acted on the node.

If the virtual force, with the value $F$, along the tangent direction, makes the node rotating a angle $\Delta \theta$, given the value of $F_{i\parallel}$, we get the expression as follow:

$$\theta_{mov} = \frac{F_{i\parallel}}{F} \times \Delta \theta$$

(12)
Before rotating, it is necessary to calculate the new perceived probability $P_{st}(t_j)$ of the sensor network to target trajectory point $t_j$ according to formula (6). If $P_{st}(t_j) \geq P_{th}$, the node moves; If not, the node stays in its original place.

3.3 Algorithm description

The situation of part of the monitoring region is shown in Fig.7. Before deployment, roughly estimate the number of nodes required for network deployment, as a basis for deployment in the monitoring area.

Step1: After all the video sensor nodes are deployed, initialize parameters of nodes and the nodes exchange information to confirm the location of itself and the neighbor node, then go to Step2;

Step2: calculate the coverage ratio $\eta_{cov}$ of all the nodes in the set $S$ to the monitoring area. Marked the working state of all the nodes 0 and Let $n_{work} = 0$, go to Step3;

Step3: Define $L$ to represent a route randomly selected through the monitoring area. Choose target trajectory points with interval $\Delta l$ randomly and uniformly, and the number of target trajectory points can be calculated according to expression (5). Find out all the nodes with vertical linear distance to route $L$ less than $R_{far}$, give each node a number, and save the nodes as a set $S_k$, then go to Step4;

Step4: The centroid position of tracking node is calculated by formula (4), then go to Step5;

Step5: from formula (6), calculate the joint perceived probability of trajectory point $t_j$ sensed by all the nodes which can track $t_j$. According to the movement rule, if the trajectory point don’t need to rotate, let $n_{work} = n_{work} + 1$; repeat the same work to next trajectory point $t_{j+1}$; if the trajectory point need to rotate, calculate the repulsive force between the centroid of this node and that of its neighbor node, the attractive force of the centroid of the node and the trajectory point, and the rotation angle. Go to Step6;
Step6: assuming the positive direction is clockwise, sensor $s_i$ turn the corresponding angle with the action of $\vec{F}_i$ which is the component force of $\vec{F}$ along the tangential direction on centroid $c_i$, such that the node can reach the corresponding position. Go to Step7;

Step7: execute Step5 and Step6 circularly until all the trajectory points of the target set $T = \{t_1, t_2, t_3, \ldots, t_m\}$ are adjusted and then go to Step8 (distributed greedy strategy);

Step8: calculate the number of working nodes $n_{\text{work}}$, coverage ratio $\eta_{\text{cov}}$ of all the nodes in set $S$ to the monitoring area and the coverage rate $\eta_{\text{cov}}$ of tracking nodes in set $S_k$ to all the trajectory points in set $T = \{t_1, t_2, t_3, \ldots, t_m\}$.

Note:
(1) Due to deterministic sensing model adopted in the literature[13], if the distance between node $s_i$ and trajectory point $t_j$ is less than the sensing radius of the sensor, after node $s_i$ adjusting the angle of view, $s_i$ can cover point trajectory $t_j$ definitely with the action of virtual force. While probabilistic sensing model adopted in this paper, so after the node rotates, the sensing probability of the node to the target is uncertain. Therefore, it is necessary to calculate the sensing probability firstly and then carry out the adjustment to reduce the times of rotating viewing angle and to achieve the purpose of energy saving;

![Fig. 7 The situation of part of the monitoring region](image)
(2) The tracking nodes involved by adjacent trajectory points \( t_j \) and \( t_{j+1} \) need adjust the angle of view multiple times.

(3) The tracking node makes the adjustment of rotation with the moving of the target point so as to guarantee that the sensing probability of network to trajectory points is greater than \( P_{th} \). But after rotation adjustment, the total coverage ratio of nodes to the monitoring area may be decreased.

IV. SIMULATION ANALYSIS

This paper simulates the algorithm in MATLAB platform, and the simulation parameters are set as follows: monitoring area \( S_{area} \) is 500m \( \times \) 500m, sensing radius \( R_s \) of the sensor nodes is 40m, sensing angle of view \( \text{fov} \) is \( 2\theta_{\text{fov}} = \pi / 2 \), probabilistic sensing range \( d \) of sensor nodes is 10m, \( R_{far} = R_s + d = 50m \), \( k_a=3 \), \( k_b=1 \), the number of nodes deployed is 80, threshold \( P_{th} \) of sensing probability is 0.85, rotation angle \( \Delta \theta = 5^\circ \), sampling interval \( \Delta l = 10m \), and trajectory points coverage ratio \( \eta_{req} \) is greater than or equal to 90%. The simulation results are compared with those of PFPCE algorithm.

Adopting probabilistic sensing model, the number of nodes used can be significantly reduced. After the deployment of the same number of nodes, the initial coverage ratio of nodes is significantly greater than that of deterministic sensing model. The same as algorithm PFPCE, there are two main parameters affecting the performance of the improved algorithm, and they are initial coverage ratio of network \( \eta_{cov} \) and the discrete degree of trajectory points of the target, which is related with sampling interval \( \Delta l \).

Fig.8 indicates that the relation between the number of nodes and coverage ratio in the same monitoring area, adopting PFPCE algorithm and the algorithm used in this paper respectively. As shown in the diagram, with the increase of working nodes number, the coverage ratio of the two algorithms are raising, but the raising speed using the algorithm in this paper is faster, and when \( n \geq 300 \), the raising speed becomes slow and tends to be stable.
Fig. 9 shows that the effect of the number of nodes on coverage ratio $\eta_{cov}$ in PFPCE and this algorithm respectively. With the increase of the number of nodes, they move in the coverage area, without running the algorithm, namely without rotation adjustment of nodes, we can see the advantage of using a probabilistic sensing model, in which average 40 nodes per increase, the coverage ratio of nodes using probabilistic sensing model is 3% greater than that without using it. When the number of nodes is about 300, coverage ratio based on the model of this paper is $\eta_{cov} \approx 94\%$ and that based on PFPCE is stable at 90%. The coverage ratio of target tracking point tends to be stable with continuing to increase the number of nodes.

**Fig. 8** the effect of the number of nodes to regional coverage in PFPCE and this algorithm

**Fig. 9** the effect of the number of nodes to $\eta_{cov}$ in PFPCE and this algorithm
Fig. 10 shows the relation between the number of nodes and coverage ratio of trajectory points after running PFPCE and the algorithm adopted in this paper respectively. Deploying the nodes of 80, after running the algorithms, PFPCE enhance by 38.24%, while the algorithm in this paper increases by 31%. But finally the coverage ratio to the trajectory point got by the algorithm in this paper is 87.52%, which is higher than that of PFPCE algorithm with 85.71%. With the increasing of the number of the nodes, when the number of nodes reaches 300, the coverage ratio based on the algorithm used in this paper can reach about 95%, while that based on PFPCE is about 91%. If the number of nodes is kept on increasing, the coverage ratio tends to be stable. The reason is that when the number of nodes is larger, the target can always be detected whenever it enters into the monitoring area.

From Fig.8, Fig.9 and Fig.10, it can be concluded that: initial coverage ratio of the area $\eta_{cov}$ increases; the improved degree of coverage ratio to the target trajectory points decreases with the increase of $\eta_{cov}$; if the value of $\eta_{cov}$ is less, namely less nodes, the coverage hole is more, and if the moving distance of target trajectory points $\Delta l$ is larger, the probability of blind zone coverage is relatively large along the path. After running the two algorithms, they all improve coverage ratio of the trajectory point, and the final area coverage ratio is stable with the increase of $\eta_{cov}$. If nodes are deployed more so that the monitoring area is fully covered, there is not so much improvement after running the two algorithm when targets pass though the monitoring the area.

![Fig. 10](image.png)

Fig. 10 the effect to the $\eta_{cov}$ of trajectory after running PFPCE and this algorithm
Fig. 11 The relationship between sampling interval $\Delta l$ and trajectory coverage rate $\eta_{\text{cov}}$.

Fig. 11 shows the relationship between sampling interval $\Delta l$ and trajectory coverage ratio $\eta_{\text{cov}}$. When the node number is less, the smaller the sampling interval $\Delta l$ is, the smaller the detected probability of target points is. Because fewer nodes are deployed randomly, the nodes fail to maintain good coverage. When sampling interval $\Delta l$ is increased, the coverage ratio of the tracking nodes is increased, and the algorithm in this paper is better than the PFPCE algorithm. When the nodes are gradually increasing, with the same sampling interval $\Delta l$, the detected probability of the target detected by the nodes within the trajectory belt is gradually increased. The algorithm in this paper has a larger coverage ratio, and with the continuous increase of nodes, the growth of trajectory coverage ratio is gradually decreased, and ultimately achieves 93%.

V. CONCLUSIONS

Based on the probabilistic sensing model in this paper, the algorithm of path coverage in video sensor network is proposed. By processing the taget information obtained by the node and its neighbour node, making full use of redundancy of sensor network and adopting target sensing joint probability to integrating data, when a large number of nodes available in the monitoring area, namely very high initial coverage ratio, the high detected probability can be guaranteed. Compared with the PFPCE algorithm, the algorithm in this paper saves the energy of nodes, extends the lifetime of network, enhances the target sensing probability.
simulation results show that The improved algorithm uses fewer sensor nodes, and can get more efficient coverage of video sensor network.

REFERENCES


