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MODELLING AND STIMULATION OF TARGET TRACKING AND LOCALIZATION IN WIRELESS SENSOR NETWORK

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Original scientific paper
Localization and tracking of moving target is one of the research focuses of wireless sensor network applications. It has great value in military field. Researchers have proposed many algorithms to complete target localization precisely. Tri-cyclic mutual crosses method based on *received signal strength indicator* can skip the estimation of transmitting attenuation consumption to locate the target accurately. For the great error happening when the target turns its direction, this paper proposes an algorithm to predict the turning point of its motion path. This method can improve the approximation between depicted and real trajectory, and promote the localization and tracking accuracy of whole system.

Keywords: *Wireless Sensor Network, Received Signal Strength Indicator, target localization, trajectory estimation, turning point estimate*

Modeliranje i stimulacija lociranja i praćenja mete u mreži bežičnog senzora

Izvorni znanstveni članak
Lociranje i praćenje pomične mete je jedno od glavnih ciljeva u istraživanju aplikacija mreže bežičnog senzora. Od velike je važnosti na vojnom planu. Istraživači su predložili mnoge algoritme za precizno lokaliziranje mete. Trociklična metoda uzajamnih presijecanja zasnovana na *indikatoru jačine primljenog signala* može preskočiti procjenu potrošnje oslabljene prijenosne snage za točno lociranje mete. Kako bi se izbjegla velika greška koja se događa kada meta promijeni pravac kretanja, ovaj rad predlaže algoritam kojim se predviđa točka u kojoj će ona promijeniti putanju. Tom se metodom može poboljšati aproksimacija između izabrane i stvarne putanje te povećati točnost lokaliziranja i praćenja cijelog sustava.

Ključne riječi: *mreža bežičnog senzora, indikator jačine primljenog signala, lokaliziranje mete, procjena putanje, predviđanje prekretnice*

1 Introduction

Wireless Sensor Network (WSN) is emerging as a key tool for various applications including search and rescue, disaster relief, target tracking, and smart environments due to its reliability, accuracy, cost effectiveness, and ease of deployment [1]. A WSN is a collection of small, cheap, and low-powered sensors which can dynamically form a network without any underlying infrastructure support [2]. The responsibilities of sensors are to sense data from the environment (e. g., temperature, light, etc), process the data, and finally transmit the data to the base station (or sink) directly or in multi-hop fashion.

The conventional wireless sensor network architecture, as described in the majority of the literature, assumes the existence of a large number of miniature battery-powered sensor devices scattered over an area of interest and organized in an ad-hoc communication manner. The primary goal of wireless sensors is to gather relevant data from the environment and, subsequently, to route the gathered data to a central processing node, commonly referred to as sink. Since sensors are typically battery-powered, they possess limited processing and memory resources. In contrast, the sink node has greater energy resources (larger battery or main power support). Therefore, besides collecting data samples from sensors, the sink node can assume greater number of tasks in the network. Some of the responsibilities of the sink node may include: initiating the network formation, route management, address assignment, fusing data collected by sensor nodes and serving as a gateway node between the outside users of the system and the network.

Mobile target localization and tracking is one of the research focuses of WSN, and it is also an important function of WSN development [1]. Adopting WSN has many advantages: (1) More precise: The sensors which are deployed densely can track the target location precisely and reveal the motion details of the target. (2) More reliable: WSN is a self-organizing network. It can complete error correction and tolerance automatically. Therefore, the system could have better reliability, fault tolerance and robustness. (3) Real-time: Many kinds of sensors work together. It can not only make the target be found rapidly, but also make the distributed data processing and corporation among the nodes easier to be completed. (4) More concealed: The sensors are small and their communication power is low, so it is hard for the enemy to find the network. (5) Low cost. (6) Low power consumption.

There are many localization and tracking algorithms. Some are range based, such as trilateration localization, triangulation localization and maximum likelihood estimation localization. Some are range free, such as centroid algorithm, DV-HOP and so on. This paper proposes an algorithm connecting both the range based and range free ones: Tri-cyclic mutual crosses localization algorithm based on RSSI (Received Signal Strength Indication). It solves the electromagnetic wave transmission consumption during the estimation and improves the accuracy of the measurement. Based on it, the algorithm solves the problem which happens when the target turns its direction and improves the approximation between depicted and real trajectory [2÷5].

2 The localization based on range based and range free technology in WSN

According to the specific mechanism, the localization and tracking algorithms of WSN can be classified into two types: range based and range free method. Range based method needs to measure distance and angle information between beacon and target, and then computes the location of the target with trilateration measurement, triangulation measurement or maximum likelihood estimation. Range free method does not need the information or have to get them directly. It just uses the connectedness of the network to complete localization [6, 7].

Range free method has advantages on the facets of cost and energy saving. However its accuracy is worse than range based method. Therefore it fits the project which does not demand high accuracy, such as district localization. For example, the biggest advantages of centroid algorithm are simplicity and low computation. It just relies on the connectedness of network, but more beacon nodes are needed. DV-HOP algorithm is similar to range based method. It needs to know the distance between the unknown target and beacon, whereas DV-HOP gets the data by computing the topology information of the network, not measuring the radio wave signal. In the range based method, unknown nodes just know their distance to the beacon which is within their radiofrequency coverage [8]. However DV-HOP can get the distance data between unknown node and the beacon beyond its radiofrequency range, so it can get more useful data to improve accuracy.

The drawback of range based algorithm is that it makes the production cost of sensors increase, and consumes more energy of the battery. Besides, the accuracy and complexity of different algorithms differ a lot from each other, but the range based one has better accuracy and more mature technology [9, 10]. Therefore it is more commonly used between depicted and real trajectory [2÷5].

3 Localization and tracking for mobile target

3.1 Sensor nodes distance measurement based on RSSI

During the movement, the mobile target keeps sending power signal. Once it enters the WSN, sensor nodes can receive the target signal, and get the received power according to the power model in the receiver. The unit is W. Use RSSI to estimate the distance between mobile target and receiver node.

Radio wave has attenuation during its transmission in the air:

$$P_{ri} = P_{r0} - 10k \cdot \lg\left(\frac{d_i}{d_0}\right) + X_i. \qquad (1)$$

In the Eq. (1), P_{ri} is the power of transmitter, P_{r0} is the power of receiver, $d_i = \| \rho - r_i \|$, d_0 is the distance between receiver node and target, k is attenuation factor, X_i is Gaussian variable.

Since the energy of sensor node is limited, it cannot do complicated computation. Moreover, there are too many factors affecting the communication circumstances, and it is hard to determine the channel, thus neglecting transmission attenuation when the sensor nodes estimate the distance through received power. Radio wave transmits in spherical way, so the relationship between distance and power is:

$$R = \sqrt{\frac{P}{4\pi \cdot I}}. \qquad (2)$$

In the Eq. (2), P is the transmission power of mobile target, I is the received power of sensor nodes. Because the transmission attenuation is neglected, we need to use improved range based localization and tracking algorithm.

3.2 Tri-cyclic mutual crosses localization and tracking algorithm for mobile target

According to the received power, sensor node uses Eq. (2) to compute its distance from the target. However, the received power has attenuated, so the practical received power is lower than the ideal one. So the computed result is larger than practical distance. To solve this problem, this paper proposes the tri-cyclic mutual crosses localization and tracking algorithm based on RSSI.

Once the target enters the range of WSN, the sensors nearby will detect it and estimate the distance from it with the received power. When the cluster head gets the data from three nodes, it stops to run the algorithm.

Let three nodes be the centers of three circles. Then use their distance from the target as radius to draw three circles. Because the transmission attenuation is neglected, the radius is larger than the real distance and the target will be within the range of the circle. As shown in Fig. 1, three circles intersect each other. The algorithm can be simplified as calculating the intersection coordinates of two circles.

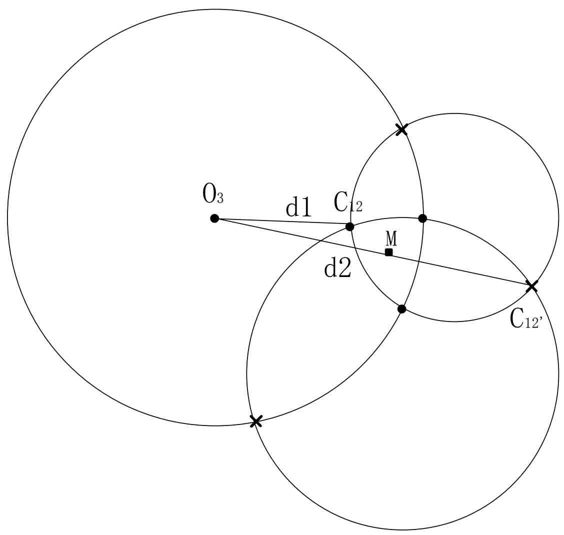

Figure 1 Tri-cyclic mutual crosses localization and tracking algorithm

Use the parametric equation of circle to simplify programming. Three centers of circle are (x_1, y_1), (x_2, y_2) and (x_3, y_3). The intersection coordinate is (x_{ij}, y_{ij}).

$$\begin{cases} x_{12} = R_1\cos\theta + x_1 \\ y_{12} = R_1\sin\theta + y_1 \end{cases}. \qquad (3)$$

Use substitution to solve the equation and obtain the value of $\cos\theta, \sin\theta$. Then judge if Eq. (4) establishes.

$$(R_1\cos\theta + x_1 - x_2)^2 + (R_1\sin\theta + y_1 - y_2)^2 = R_2^2. \qquad (4)$$

Substitute the two groups of cos θ and sin θ into Eq. (3) to get the coordinates of two intersections.

Compute the distance between the two coordinates and the center of the third circle. Then keep the smaller one and abandon the further one.

$$d=\sqrt{(x-x_3)^2+(y-y_3)^2}. \tag{5}$$

Repeat the steps above to obtain all the intersection coordinates, as shown in Fig. 2. Then use centroid algorithm (Eq. (6)) to compute the target coordinate (x, y).

$$\begin{cases} x=\dfrac{x_{12}+x_{13}+x_{23}}{3} \\ y=\dfrac{y_{12}+y_{13}+y_{23}}{3} \end{cases}. \tag{6}$$

Adopt five points centroid algorithm and tri-cyclic mutual crosses localization and tracking algorithm to stimulate and compare, as shown in Fig. 2. Fig. 3 shows the contrast detail of the two algorithms. Error contrast is shown in Fig. 4.

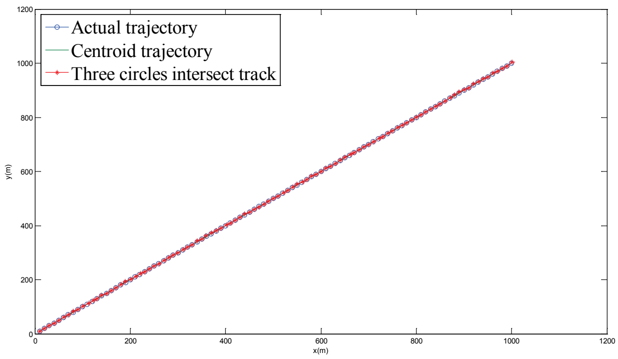

Figure 2 Contrast of stimulation result

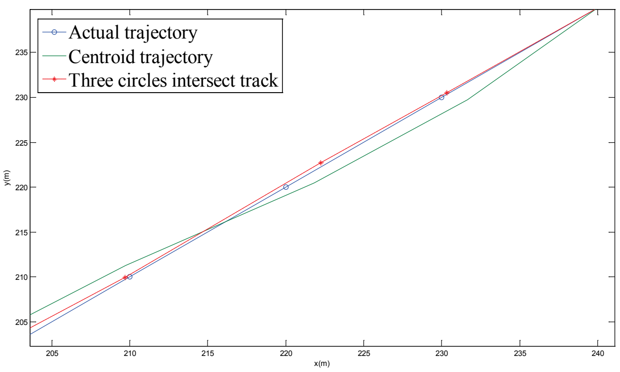

Figure 3 Contrast of stimulation result (Detail)

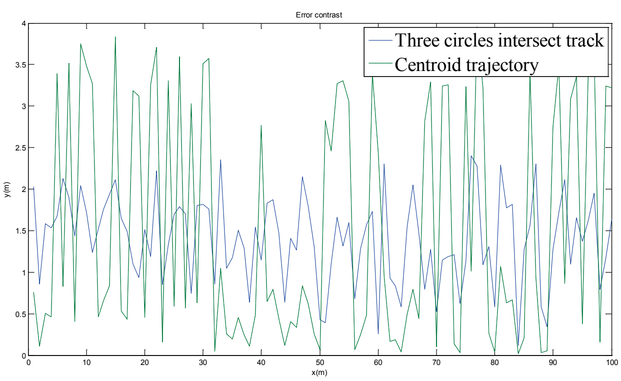

Figure 4 Error contrast

3.3 Path nodes prediction

The energy of wireless sensor nodes is limited. It is not necessary to let all sensors wake to work when target enters the network. Hence the movement trend of the target should be analyzed and computed to predict the position where the target may locate at the next moment. Only the sensor nodes nearby are waked to start working. It is significant to reduce the energy consumption and predict the turning point of the target.

Predicting the target movement trajectory is a procedure of analyzing historical and measured data. When three nodes obtain the measured data, it starts computing to predict the location of target. Let all movements be composed by myriad linear motion, and decompose them into two vectors on the direction of x and y.

For example, in the x direction:

$$\begin{cases} a_n=\dfrac{\overline{v_{n-1}}-\overline{v_{n-2}}}{t} \\ \overline{v_{n-1}}=\dfrac{x_{n-1}-x_{n-2}}{t} \\ \overline{v_{n-2}}=\dfrac{x_{n-2}-x_{n-3}}{t} \\ \overline{v_{n0}}=\overline{v_{n-1}} \end{cases}. \tag{7}$$

According to Eq. (7), we can obtain:

$$\begin{cases} a_n=\dfrac{x_{n-1}+x_{n-3}-2x_{n-2}}{t^2} \\ x_n'=2{,}5x_{n-1}-2x_{n-2}+0{,}5x_{n-3} \end{cases}. \tag{8}$$

Similarly, we can get the acceleration and coordinate in the y direction.

$$\begin{cases} a_n=\dfrac{y_{n-1}+y_{n-3}-2y_{n-2}}{t^2} \\ y_n'=2{,}5y_{n-1}-2y_{n-2}+0{,}5y_{n-3} \end{cases}. \tag{9}$$

During the computation, we use average speed to substitute the practical speed. Therefore the acceleration we obtain is average value. If the target moves uniformly, there will be no error of the prediction. If it is uniformly accelerated motion, there will be error. Take x direction as an example. If the acceleration a is 2 m/s^2, the error in the direction is 1 m. If the acceleration is not uniform, it is hard to make error analysis. If acceleration increases rapidly at a moment, large error of prediction would happen.

3.4 Turning judgment and prediction

If the turning angle of mobile target is big within the interval of two measurements, large error will happen because the point where the target turns is unknown. As shown in Fig. 5, sensor nodes get the coordinate P3 through measurement. Before they execute the next localization P4, the target turns a lot. The turning point is unknown, and the predicted coordinate S2 is completely out of the target motion trajectory. Then wrong prediction happens. If only the two measured points P3 and P4 are connected, we can get trajectory d2. If predicted point is added, we obtain trajectory d1. They all deviate a lot from the practical trajectory.

To make the result more similar to the practical trajectory, one should deal with the problem of missing turning point. The nodes should firstly judge if the target has turned. This needs the predicted point mentioned in previous section. After measuring the three points, prediction begins. By comparing it with the measured coordinate, we find that if the distance between them is out of range or cannot establish the motion trajectory Eq. (10), we know the target has turned.

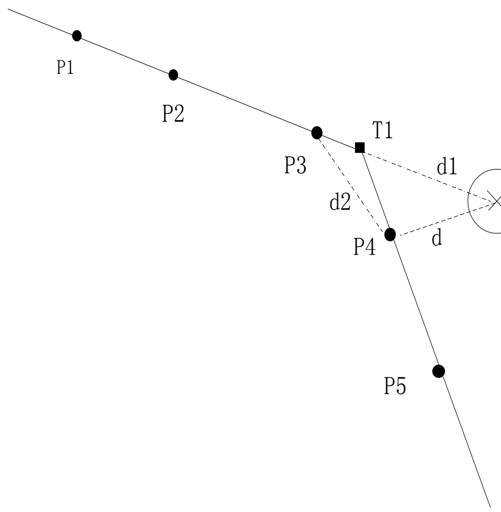

Figure 5 Turning point prediction of mobile target

$$\frac{y-y_{n-1}}{x-x_{n-1}}=\frac{y_{n-1}-y_{n-2}}{x_{n-1}-x_{n-2}}. \tag{10}$$

Here, we should consider the influence on range caused by errors. First error is from tri-cyclic mutual crosses localization and tracking algorithm. According to the simulation in Section 3.2, if the target moves linearly, the error is within 2,5 m. The second error is caused by acceleration. If the target moves uniformly, this error does not exist. If the target moves with uniform acceleration a, during prediction it will lead to the error of $a/2$. Analyze the two errors and make the predicted point the center of the circle. Let 2,5a be the radius of the circle. If the distance between the two points is shorter than the radius, we consider the target does not turn, otherwise it has turned.

If the target has turned, break the previous location prediction and use the new measured point to start recording. Then start prediction point judgment after completing the measurement of three points. This paper proposes an algorithm to estimate the coordinate of turning point. When it is certain that the target has turned and got the coordinates of the two measured points (x_n, y_n), (x_{n+1}, y_{n+1}), execute the algorithm and obtain the motion Eq. (11) after the target turns.

$$\frac{y-y_{n+1}}{x-x_{n+1}}=\frac{y_{n+1}-y_n}{x_{n+1}-x_n}. \tag{11}$$

Combine Eqs. (10) and (11):

$$\begin{cases}\dfrac{y-y_{n-1}}{x-x_{n-1}}=\dfrac{y_{n-1}-y_{n-2}}{x_{n-1}-x_{n-2}}=k_1\\ \dfrac{y-y_{n+1}}{x-x_{n+1}}=\dfrac{y_{n+1}-y_n}{x_{n+1}-x_n}=k_2\end{cases}. \tag{12}$$

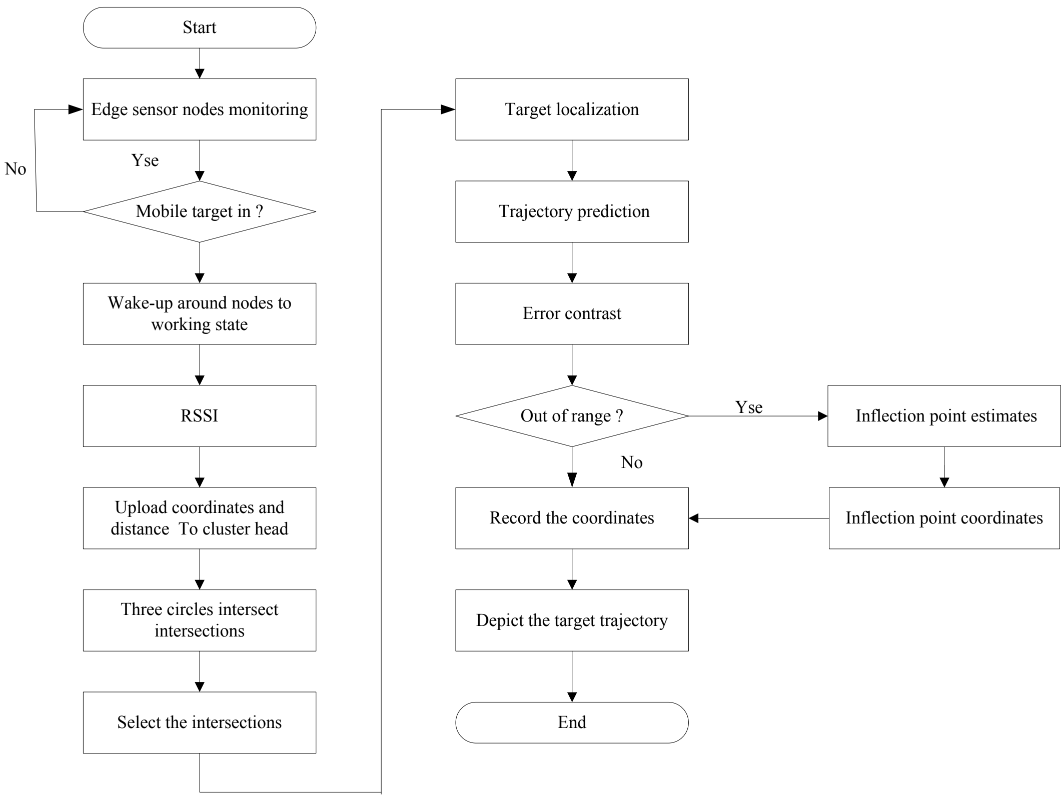

Figure 6 Flow chart of the algorithm

Get:

$$\begin{cases} x = \dfrac{k_1 x_{n-1} - k_2 x_{n+1} + y_{n+1} - y_{n-1}}{k_1 - k_2} \\ y = k_2 \dfrac{k_1 (x_{n-1} - x_{n+1}) + y_{n+1} - y_{n-1}}{k_1 - k_2} + y_{n+1} \end{cases} . \quad (13)$$

Compute and store the coordinate of turning point (x, y). Then put it between the two measured points and draw the trajectory. The flow chart is shown in Fig. 6.

4 Stimulation

The localization and tracking procedures include three phases: (1) **Monitoring phase**. The sensors detect if there is any object entering the network periodically. If the target moves into the node network the nodes nearby broadcast the information. The adjacent nodes save it and add the timestamp. (2) **Localization phase**. The nodes nearby use the previous information and the algorithm to compute target coordinate and predict the motion trajectory and wake the nodes near the path. (3) Informing phase. Estimate the target coordinate and broadcast the information to inform the nodes nearby to complete localization and tracking.

The wireless sensor network model in this paper is constructed of physical layer, MAC layer, network layer, energy module, topology control layer and application layer. This paper focuses on the localization and tracking algorithm of network layer. Therefore we do not describe the details of WSN protocol stacks modelling and so on.

Table 1 The protocol and algorithm in different layers and models

Stimulation component	Protocol and algorithm
Application layer	Localization and tracking for mobile target
Network layer	DD route protocol
MAC layer	IEEE802.11MAC protocol
Physical layer	OPNET built-in wireless pipeline mechanism
Topology control	Simplified LEACH
Energy model	RM battery model

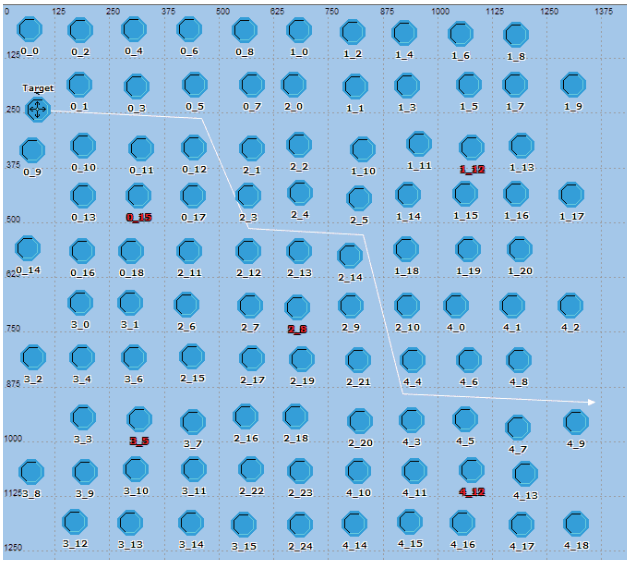

Figure 7 WSN Stimulation Model

Deploy 100 sensor nodes in the range of 1200 × 1000 m to establish the WSN model. Mark the nodes with M_N (M means the cluster head ID, N is the node ID). Coordinates of all nodes are known. To make the model more practical, we deploy the sensors randomly, not precisely uniformly, as shown in Fig. 7. The network is divided into 5 clusters. Each cluster includes a cluster head and many member nodes.

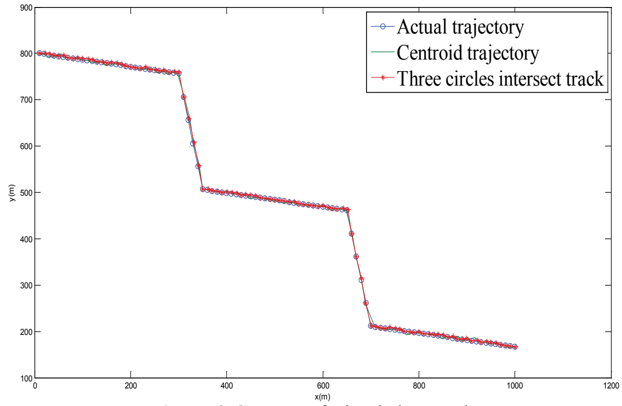

Figure 8 Contrast of stimulation result

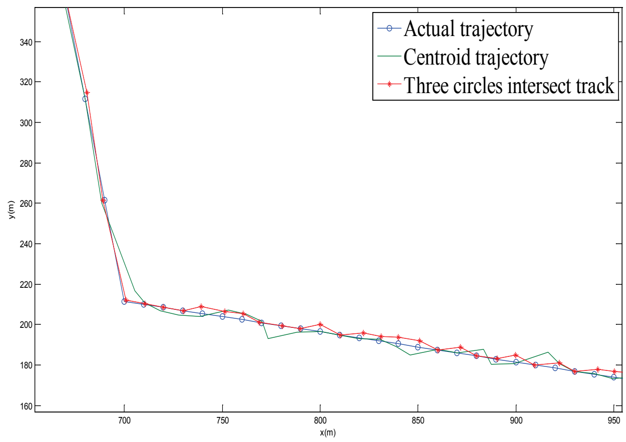

Figure 9 Contrast of stimulation result (Detail)

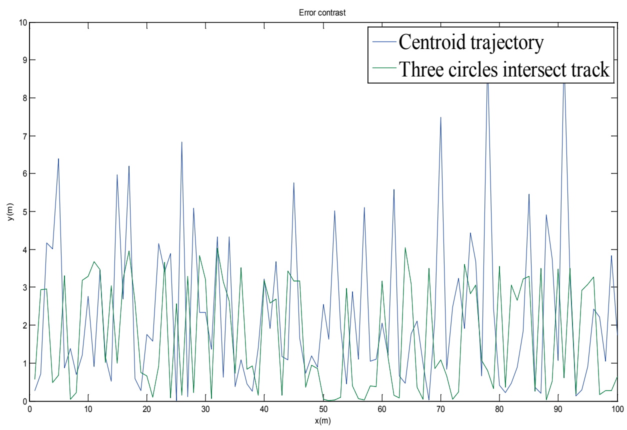

Figure 10 Error Contrast

The target moves on the trajectory set before. Every cluster determines its state according to the awakening and dormancy mechanism. The active cluster keeps monitoring the target motion trajectory periodically. When sensor nodes detect the target, the nodes spread information through DD route protocol. Cluster heads take the responsibility of data fusion, coordinate computation, trajectory prediction and turning point estimation, and then draw the motion trajectory.

Compare with the 5 points centroid algorithm, the stimulation result is shown below.

5 Conclusions

This paper proposes a tri-cyclic mutual crosses localization and tracking algorithm based on RSSI for the mobile target localization and tracking of WSN. This algorithm can avoid the energy consumption of the transmission attenuation estimation. Furthermore trajectory prediction and turning point estimation are introduced to improve the algorithm. The simulation proves that the algorithm proposed is better than centroid algorithm. The result is more similar to the practical trajectory.

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