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Research on Warehouse Target Localization and Tracking Based on KF and WSN

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Abstract: This paper firstly established the model of warehouse targeting and tracking system based on Wireless Sensor Networks (WSN). The principle of Location and tracking is based on the maximum likelihood estimation method of multilateral measurement. According to monitoring motion trajectory of the same unknown target node within a continuous period of time, the motion equation can be established. It can achieve the effective tracking of warehouse target that KF algorithm is applied to carrying out the state estimation of warehouse target motion equation. Simulation results show that, while the warehouse target tracking system state equations are linear, using KF algorithm can obtain satisfactory tracking accuracy. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Warehouse, WSN, KF, Locating, Tracking.

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1. Introduction

As a platform acquiring brand-new information, wireless sensor networks can monitor and collect information of detection objects within the region of networks in real time. The information is sent to the gateway node, in order to realize monitoring and tracking the target within the network area. Warehouse target localization and tracking system consists of several wireless sensor nodes, those nodes include beacon nodes and unknown nodes. Beacon nodes can obtain their precise location by carrying GPS positioning equipment or other means. Beacon nodes are the reference point of unknown node location [1].

While unknown nodes can be the active ones of support personnel, vehicles, machinery and other warehouse targets. By communicating with nearby beacon nodes or the unknown nodes which have acquired their own position information, the unknown nodes can calculate their own position according to a certain location algorithm. Warehouse targeting and tracking system should be equipped with multiple sensors to achieve redundancy. These sensors may be different in types, and the placement and measurement principles are also different. This paper firstly established the model of warehouse targeting and tracking system based on wireless sensor networks. The principle of locating and tracking is based on the maximum likelihood estimation method of multilateral measurement. According to monitoring motion trajectory of the same unknown target node within a continuous period of time, the motion equation can be established. It can achieve the effective tracking of warehouse target that KF algorithm is applied to carrying out the state estimation of warehouse target motion equation [2].

2. Establishment of the Model of Warehouse Target Localization and Tracking System

Warehouse target localization and tracking system is composed of several wireless sensor nodes. These nodes contain beacon nodes and unknown nodes. The proportion of beacon nodes in the network is small. Beacon nodes can get their own precise location by some means such as carrying GPS positioning equipments. Beacon nodes are the reference points of unknown nodes location. And beacon nodes are arranged inside and outside the warehouse evenly. The unknown nodes can be active nodes of personnel, vehicles and warehouse equipments. By communicating with nearby beacon nodes or the unknown nodes which have acquired their own position information, the unknown nodes can calculate their own position according to a certain location algorithm (Fig. 1 [5]).

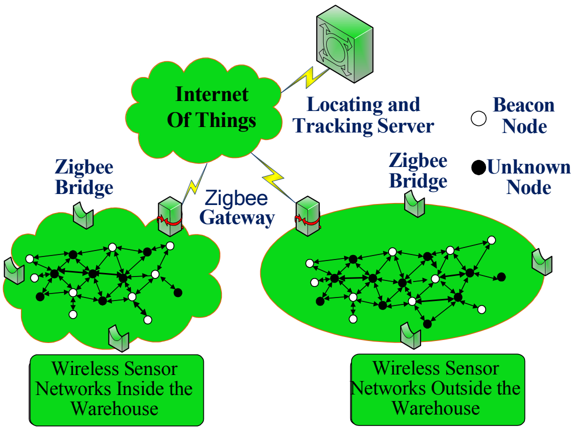

Fig. 1. Schematic diagram of warehouse target localization and tracking system.

The positioning principle of warehouse target localization and tracking system is to calculate the coordinates of the unknown nodes with node position calculation method. Wireless sensor networks have a lot of localization algorithms. These algorithms can be basically divided into two broad categories: positioning algorithm based on ranging and the one dispense with ranging. The maximum likelihood estimation method of the multilateral measurement is used to calculate the coordinates of the unknown nodes [3].

The multilateral measurement method is often used in solving the coordinates of the unknown nodes. As shown in Fig. 2, there are n reference nodes $P_1(x_1,y_1)$, $P_2(x_2,y_2)$, …, $P_n(x_n,y_n)$, and their distance to unknown node Q respectively is $R_1(t)$, $R_2(t)$,…, $R_n(t)$. We set the coordinates of Q as (x (t), y (t)). Then the coordinates satisfy Eq. (1) [8].

Eq. (2) can be acquired by the maximum likelihood estimation method.

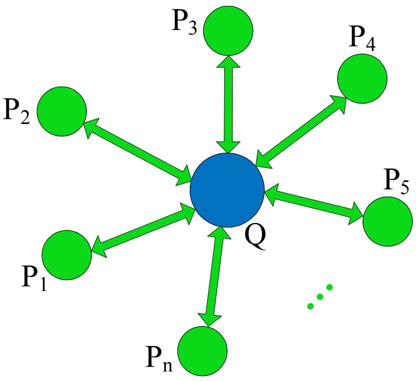

Fig. 2. Schematic diagram of maximum likelihood estimation of multilateral measurement method.

$$\begin{cases} (x(t)-x_1)^2+(y(t)-y_1)^2=R_1{}^2(t) \\ \quad\cdots\cdots \\ (x(t)-x_n)^2+(y(t)-y_n)^2=R_n{}^2(t) \end{cases} \tag{1}$$

$$\begin{cases} x_1^2-x_n^2-2(x_1-x_n)x+y_1^2-y_n^2 \\ -2(y_1-y_n)y=R_1{}^2(t)-R_n{}^2(t) \\ \quad\cdots\cdots \\ x_{n-1}^2-x_n^2-2(x_{n-1}-x_n)x+y_{n-1}^2-y_n^2 \\ -2(y_{n-1}-y_n)y=R_{n-1}{}^2(t)-R_n{}^2(t) \end{cases} \tag{2}$$

Using system of linear equations, it can be expressed as follows

$$AX(t)=B(t)\,, \tag{3}$$

where

$$A=\begin{bmatrix} 2(x_1-x_n) & 2(y_1-y_n) \\ \vdots & \vdots \\ 2(x_{n-1}-x_n) & 2(y_{n-1}-y_n) \end{bmatrix} \tag{4}$$

$$B(t)=\begin{bmatrix} x_1^2-x_n^2+y_1^2-y_n^2+R_1^2(t)-R_n^2(t) \\ \vdots \\ x_{n-1}^2-x_n^2+y_{n-1}^2-y_n^2+R_{n-1}^2(t)-R_n^2(t) \end{bmatrix} \tag{5}$$

$$X(t)=\begin{bmatrix} x(t) \\ y(t) \end{bmatrix}, \tag{6}$$

where x(t) represents coordinates of unknown node Q on x direction at time t, y(t) represents coordinates of unknown node Q on y direction at time t, $R_n(t)$ represents the distance from reference node P_n to unknown node Q at time t.

The coordinates of the node Q can be acquired by standard minimum mean variance estimation method.

The coordinates is

$$\hat{X}(t)=(A^TA)^{-1}A^TB(t)\,, \tag{1}$$

Warehouse target tracking based on wireless sensor networks is applying wireless sensor network to monitor, identify and track moving warehouse target within the monitoring area. Warehouse target tracking system can monitor motion characteristics information of warehouse target and warehouse target attribute information in real time. From the acquiring process of position and velocity of the mobile targets, it must be that multiple sensor nodes work together to complete the target tracking [9].

In order to improve the accuracy of tracking, the optimal tracking program is the one that all sensor nodes participated in the target tracking as the fastest sampling frequency, but the actual implementation of such programs is difficult. Since the warehouse target nodes are constantly moving, and the speed and direction are uncertain, so the tracking system should be very real-time. As time goes on, the sensor nodes may appear unstable, sometimes even damaged, it requires that the system should have strong robustness [1].

The process of warehouse target tracking based on WSN can be divided basically into four basic stages: monitoring, locating, establishing the equations of motion, predicting target movement trends and noticing [4].

1) Monitoring: The main task of the monitoring stage is to find targets. The nodes of WSN periodically monitor whether the target appeared by the sensor module. If the target indeed reaches the monitoring area of this node, the node calculates its distance to the target firstly, then broadcasts the target detection information to the whole network. The message contains basic information, such as ID of the node, the location of the node itself and the distance to the tracking target, etc. After receiving the signal of target detecting, the neighbor node save the content in the local information table with timestamp. The local information table is maintained dynamically by the node, it will be deleted if the information is not updated in the scheduled time.

2) Locating: In accordance with the principle of localization in WSN, the location of an unknown target node is calculated by applying maximum likelihood estimation of multilateral measurement method which is introduced in this section, the system records the position coordinates of unknown target node within the monitoring area at the different time.

3) Establishing the equations of motion: According to monitoring motion trajectory of the same unknown target node within a continuous period of time, the motion equation can be established. The motion equation can be linear or nonlinear.

4) Predicting target movement trends: The system predicts the following motion state of the unknown target nodes. The more records tracking the unknown target nodes motion, the more accurate the prediction for its velocity and trajectory of the movement, while the computational cost and the communication cost will be correspondingly greater [7].

5) Noticing: When the target trajectory has been calculated, wireless sensor networks need to activate the nodes nearby the trajectory and make them to join in tracking process. After locating the target, the node of WSN broadcasts a notification message containing the target motion parameters and the location of the sender. The node receiving information calculates its distance to the target, if the distance exceeds a certain threshold value, the sensor node remains dormant. If the distance is within the threshold, the node will be activated and join the list of target tracking nodes [11].

Warehouse target tracking is essentially a problem of estimating the hybrid system, namely applying discrete sensor measurements to estimate the target's continuous state, the principle is shown in Fig. 3. The difference between the value measured by the sensor and the value of state prediction forms residual vector. The system can automatically detect or flexibly recognize the target according to the change of residual vector, and identify motion characteristics of the target in accordance with certain formula or logic in real time, then obtain the target state estimation and prediction value by applying filtering algorithm. Therefore, the key elements of warehouse target tracking consist of warehouse target motion model modeling, target locating, target recognition and filtering algorithms [6].

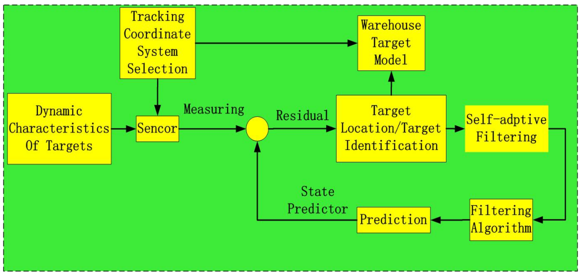

Fig. 3. Schematic diagram of warehouse target tracking principle.

3. The Model of Warehouse Target Localization and Tracking Based on Kalman Filter

3.1. Kalman Filter (KF) Model

1) The mathematical description of the Kalman filtering

In the Kalman filter, the mathematical description of the system state equation and measurement equation is as follows:

$$\begin{cases} x_{t+1} = A_t x_t + B_t u_t + W \\ y_t = C_t x_t + V \end{cases}, \quad (8)$$

where x is the state vector, u is the control vector, y is the observation vector, W is the process noise vector, V is the observation noise vector.

Here we define $\hat{x}_t^-$ as x_t priori state estimate, $\hat{x}_t$ as x_t posteriori state estimate value, $\hat{y}_t^-$ as y_t priori state estimate value.

While priori estimate of the current value of a random variable is based on previous moment and earlier historical observation information, posterior estimate is based on the present moment and earlier historical observation information.

We can get the priori estimate value of x_t by the posterior estimated value of previous time and the input information. A priori estimates of y_t also could be obtained by priori estimate prediction of x_t.

$$\begin{cases} \hat{x}_t^- = A_t\hat{x}_{t-1} + B_t u_{t-1} \\ \hat{y}_t^- = C_t\hat{x}_t^- \end{cases}, \tag{9}$$

Difference between the actual measured value and predicted value of y_t is called the residual of the filtering process.

$$\text{Residual} = y_t - \hat{y}_t^- = y_t - C_t\hat{x}_t^- \tag{10}$$

Residual reflects the difference between the forecast value and the actual value. If residual is zero, its estimated value and actual value were perfect. If the residual is small, estimate is very good. If not, it is not good. Kalman filter can use the remnants information to improve estimates of x_t and give a posteriori estimation:

$$\hat{\text{x}}_\text{t} = \hat{x}_t^- + \text{kResidual} = (1 - kC_t)\hat{x}_t^- + ky_t \tag{11}$$

Here the k is called Kalman gain.

Now the rest of the problem is how to find a suitable k, to make estimation the best. This need to define a priori error e_t^- and posterior error e_t :

$$e_t^- = x_t - \hat{x}_t^- \quad e_t = x_t - \hat{x}_t \tag{12}$$

Their variance is the priori mean variance p_t^- and the posterior mean variance p_t

$$p_t^- = \text{var}(e_t^-) = \left\langle (e_t^-)^2 \right\rangle \tag{13}$$

$$p_t = \text{var}(e_t) = \left\langle (e_t)^2 \right\rangle \tag{14}$$

The best k value is the value which can make posterior mean variance to be minimum that is making $\frac{\partial p_t}{\partial k_t}$ to be zero. Here k value is changing along with time, so k is replaced by k_t.

According to the formula, you can calculate a priori mean variance and a posteriori mean variance:

$$p_t^- = A_t^2 p_{t-1} + \left\langle W_{t-1}^2 \right\rangle \tag{15}$$

$$p_t = (1 - C_t k_t) p_t^- \tag{16}$$

where

$$k_t = C_t p_t^- / [C_t^2 p_t^- + \left\langle V_{t-1}^2 \right\rangle] \tag{17}$$

2) The steps of Kalman filter algorithm

Kalman filter algorithm is divided into two iterative steps: time update and measurement update. This can be summed up as shown in Fig. 4.

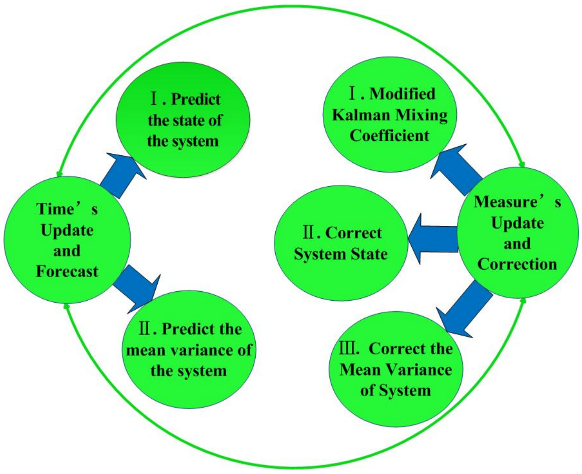

Fig. 4. Diagram of algorithm steps of Kalman filter.

Time's update and forecast

I. Predict the state of the system

$$\hat{x}_t^- = A_t\hat{x}_{t-1} + B_t u_{t-1} \tag{18}$$

II. Predict the mean variance of the system

$$p_t^- = A_t^2 p_{t-1} + \left\langle W_{t-1}^2 \right\rangle \tag{19}$$

Measurement update correction

I. Correction of Kalman mixed coefficient

$$k_t = C_t p_t^- / [C_t^2 p_t^- + \left\langle V_{t-1}^2 \right\rangle] \tag{20}$$

II. Correct system state

$$\hat{\text{x}}_\text{t} = (1 - kC_t)\hat{x}_t^- + ky_t \tag{21}$$

III. Correct the mean variance of system

$$p_t = (1 - C_t k_t) p_t^- \tag{22}$$

3.2. Building a Warehouse Target Tracking Model Based on KF

We make the following assumptions: Within the monitoring area of WSN , there is one mobile target node , the location coordinate of the target node is (x(t), y(t))(unit: m),the speed coordinate of the target node generated by the process noise is (v_x(t), v_y(t)) (unit: m/s).We assume the system process noise U(t) distribution follow Gaussian noise distribution which the mean is zero and the variance is σ_1^2 , the acceleration coordinate of the target node generated by the measurement noise is (a_x(t), a_y(t))(unit: m/s^2). The interval between the time t and the time (t-1) is T (unit: s) [10].

$$\begin{cases} x(t) = x(t-1) + Tv_x(t-1) + \frac{1}{2}a_x(t-1)T^2 \\ v_x(t) = v_x(t-1) + Ta_x(t-1) \\ y(t) = y(t-1) + Tv_y(t-1) + \frac{1}{2}a_y(k-1)T^2 \\ v_y(t) = v_y(t-1) + Ta_y(t-1) \end{cases} \tag{23}$$

Eq. (23) can be written as the matrix equation

$$\begin{bmatrix} x(t) \\ v_x(t) \\ y(t) \\ v_y(t) \end{bmatrix} = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x(t-1) \\ v_x(t-1) \\ y(t-1) \\ v_y(t-1) \end{bmatrix}, + \begin{bmatrix} T^2/2 & 0 \\ T & 0 \\ 0 & T^2/2 \\ 0 & T \end{bmatrix} \begin{bmatrix} a_x(t-1) \\ a_y(t-1) \end{bmatrix} \tag{24}$$

State equation of the target is as follows

$$\mathbf{x}(t) = \mathbf{A}(t,t-1)\mathbf{x}(t-1) + \mathbf{B}\mathbf{U}(t-1), \tag{25}$$

where

$$\mathbf{x}(t) = [x(t) \quad v_x(t) \quad y(t) \quad v_y(t)]^T \tag{26}$$

$$\mathbf{A}(t,t-1) = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{27}$$

$$\mathbf{B} = \begin{bmatrix} T^2/2 & 0 \\ T & 0 \\ 0 & T^2/2 \\ 0 & T \end{bmatrix} \tag{28}$$

$$\mathbf{U}(t-1) = \begin{bmatrix} a_x(t-1) \\ a_y(t-1) \end{bmatrix} \tag{29}$$

About the measurement equation, we set the coordinates of the target measured at time t as (x_z(t), y_z(t)).The measurement process noise distribution follows Gaussian noise distribution which the mean is zero and the variance is σ_1^2 . The two orthogonal components resulting from the influence of noise on the target are respectively w_x(t) and w_y(t) on the x-axis and y-axis.

At time t measurement coordinate of the target is

$$\begin{cases} x_z(t) = x(t) + w_x(t) \\ y_z(t) = y(t) + w_y(t) \end{cases} \tag{30}$$

Eq.(30) can be written as matrix equation:

$$\begin{bmatrix} x_z(t) \\ y_z(t) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x(t) \\ v_x(t) \\ y(t) \\ v_y(t) \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} w_x(t) \\ w_y(t) \end{bmatrix} \tag{31}$$

The target measurement equation can be written as follows:

$$\mathbf{Z}(t) = \mathbf{C}(t)\mathbf{x}(t) + \mathbf{D}\mathbf{W}(t), \tag{32}$$

where

$$\mathbf{Z}(t) = [x_z(t) \quad y_z(t)]^T \tag{33}$$

$$\mathbf{C}(t) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{34}$$

$$\mathbf{x}(t) = [x(t) \quad v_x(t) \quad y(t) \quad v_y(t)]^T \tag{35}$$

$$\mathbf{D} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \ \mathbf{W}(t) = \begin{bmatrix} w_x(t) \\ w_y(t) \end{bmatrix} \tag{36}$$

So the state equations and the measurement equations of the model are as follows:

$$\mathbf{x}(t) = \mathbf{A}(t,t-1)\mathbf{x}(t-1) + \mathbf{B}\mathbf{U}(t-1) \tag{37}$$

$$\mathbf{Z}(t) = \mathbf{C}(t)\mathbf{x}(t) + \mathbf{D}\mathbf{W}(t) \tag{38}$$

After establishing the above state equation and measurement equation, according to the Kalman filtering algorithm steps we can constantly update measurement and time, until the Kalman gain tend to be a specific value, it make $\hat{x}(t)$ optimum.

4. Simulation Results and Analysis

We make the following assumptions: The initial location coordinate of the target node is (4 m, 6 m), the initial velocity coordinate of the target node is (2 m/s, 2 m/s), the initial acceleration coordinate of the target node generated by the system process noise is (0.2 m/s^2, 0.2 m/s^2), the coordinate of two orthogonal amplitude components resulting from the system measurement noise is (3 m,3 m), sensor sampling period is 0.5 s, sample number is 400 times.

By the above conditions is given, combining with the state equations and the measurement equations which are created in the paper, we simulated the movement trajectory of the target node. Fig. 5 describes the simulation diagram consists of the real trajectory of the target node, the measurement trajectory and the tracking trajectory based on KF algorithm. Fig. 6 describes the measurement error diagram of wireless sensor. Fig. 7 describes the simulation diagram of KF estimation error. From the above simulation diagram, we can see that the error between the true value of the target movement and the estimate value based on KF algorithm is very small, KF algorithm can basically meet the need of target trajectory tracking.

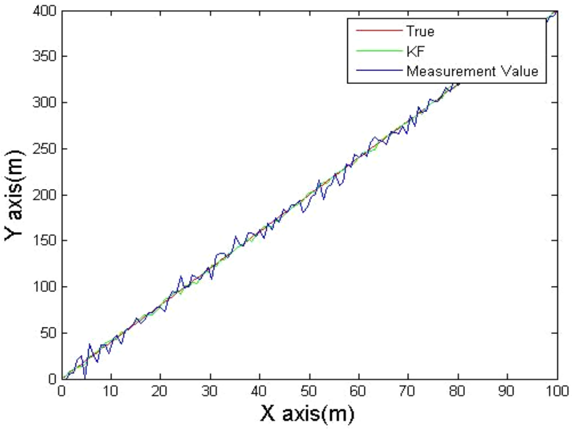

Fig. 5. Simulation diagram of target tracking trajectory based on KF.

5. Conclusions and Suggestions

Applying maximum likelihood estimation algorithm of multilateral measurement method, the paper firstly established the model of warehouse target localization and tracking system based on WSN. When the state equation of the warehouse target tracking system is linear, applying the basic KF algorithm can acquire a satisfying tracking precision. While the state equation of the warehouse target tracking system is nonlinear, it is very difficult to apply basic KF algorithm to solving nonlinear system posterior distribution (mean and covariance), so it cannot be realized. Here we should consider applying other filtering algorithm to solve it.

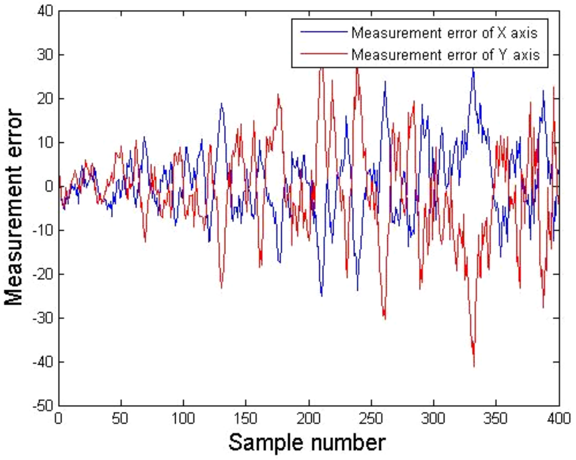

Fig. 6. Measurement error diagram of wireless sensor.

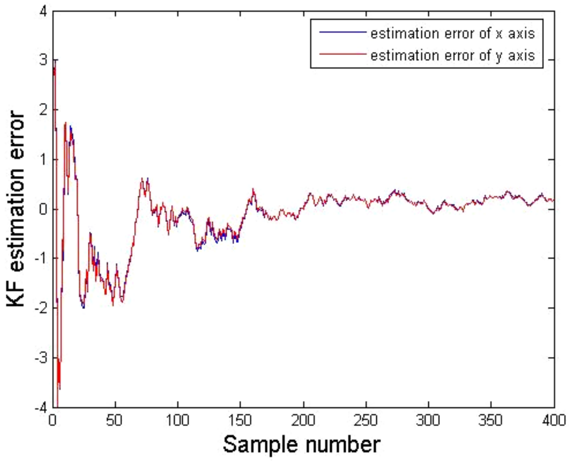

Fig. 7. Simulation diagram of KF estimation error.

References

[1]. Wang Ruchuan, Sun Lijuan, Wireless sensor network technology and its applications, *People's Posts and Telecommunications Press*, 2011.

[2]. Juan Chóliz, Ángela Hernández, Antonio Valdovinos, A framework for UWB-based communication and location tracking systems for wireless sensor networks, *Sensors*, Vol. 11, Issue 9, 2011, pp. 9045-9068.

[3]. Matthias R. Brust, Mustafa Ilhan Akbas, Damla Turgut, Multi-hop localization system for environmental monitoring in wireless sensor and actor networks, *Concurrency and Computation: Practice and Experience*, Vol. 25, Issue 5, 2013, pp. 701-717.

[4]. Min-Xiou Chen, Yin-Din Wang, An efficient location tracking structure for wireless sensor networks, *Computer Communications*, Vol. 32, Issue 8, 2009, pp. 1495-1504.

[5]. Bian Guangrong, Li Hongsheng, He Ninghui, Multi-sensor data processing and fusing based on Kalman filtering, *TELKOMNIKA*, Vol. 11, Issue 3, 2013, pp. 1266-1277.

[6]. Francesca Cuomo, Anna Abbagnale, Emanuele Cipollone, Cross-layer network formation for energy-

efficient IEEE 802.15.4/ZigBee wireless sensor networks, *Ad Hoc Networks*, Vol. 11, Issue 2, 2013, pp. 672-686.

[7]. Mohsen Javadi, Samad Sheikhaei, Aazar Saadaat Kashi, et al., Design of a direct conversion ultra low power ZigBee receiver RF front-end for wireless sensor networks, *Microelectronics Journal*, Vol. 44, Issue 4, 2013, pp. 347-353.

[8]. Kuang-Yow Lian, Sung-Jung Hsiao, Wen-Tsai Sung, Intelligent multi-sensor control system based on innovative technology integration via ZigBee and Wi-Fi networks, *Journal of Network and Computer Applications*, Vol. 36, issue, 2013, pp. 756-767.

[9]. Wang Xiaonan, Qian Huanyan, Research on all-IP communication between wireless sensor networks and IPv6 networks, *Computer Standards & Interfaces*, Vol. 35, Issue 4, 2013, pp. 403-414.

[10]. Min-Xiou Chen, Yin-Din Wang, An efficient location tracking structure for wireless sensor networks, *Computer Communications*, Vol. 32, issue, 2009, pp. 1495-1504.

[11]. Hui Xia, Zhiping Jia, Lei Ju, et al., Impact of trust model on on-demand multi-path routing in mobile ad hoc networks, *Computer Communications*, Vol. 36, Issue 9, 2013, pp. 1078-1093.

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ADVANCES IN SENSORS: REVIEWS 1

Modern Sensors, Transducers and Sensor Networks

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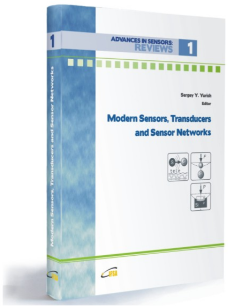

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