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Research on Target Tracking Based on Unscented Kalman Filter

Xing Liu, Shoushan Jiang
School of Mechanical Engineering, Northwestern Polytechnical University,
Xi'an, 710072, Shaanxi, China
E-mail: hgyao1996@163.com

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Abstract: Aiming at the multi-source heterogeneous of target tracking system information. On the basis of "current" statistical model, this paper researches the unscented Kalman filter information fusion method and analyzes its mathematical model. According to the mathematic model researching of optimal estimation real time tracking algorithm, it be able to describe and process the sensor information of uncertainty characteristics by using fuzzy theory, making an adaptive adjustment of the measurement parameters of the Kalman filter, so as to achieve the system error calibration and measurement error adaptive function. In line with the model of functional parameters, carrying on the simulation of the single sensor filtering error and multiple sensor filter error, by comparing the trajectory and actual motion analysis shows, this method can effectively improve tracking precision and stability. It can avoid external interference; accelerate the convergence speed of response and adapting active period of target tracking measurement requirements. *Copyright © 2013 IFSA.*

Keywords: Multi-source information fusion, Unscented Kalman filter, Fuzzy theory, Target tracking.

1. Introduction

Multi-sensor data fusion is the common functions for a human being. People are very natural to use the ability from the body sensors (eye, ear, nose, legs) information (sights, sounds, smells and touch), and use of prior knowledge to estimate and understand the surrounding environment. Multi-source information fusion features can be summarized as: expand the search range of space and time; improve the detect ability; improve the target detection performance; improve the resolution of time or space, reduce the uncertainty of information, improve information in confidence; Enhance the fault-tolerant ability and adaptive ability of system; etc. [1-2]. Thus make the whole system performance is greatly increased. Fundamentally speaking, the result is from the information redundancy and complementarily. Therefore, multiple sensor information fusion can often get the results that single sensor is difficult to obtain. Its performance will often have a qualitative leap. In principle, these ideas can be further performed to equipment and system integration [3-7].

Applications of wireless sensor network make target tracking and recognition from one single trace model into multiple tracking models. The operation mode of the wireless sensor network has the characteristics of simple, convenient and low cost than any other communication mode, and so it has extensive engineering application. For a multi-sources target tracking system, how to make full and effective use of information that acquired and how to realize accurate measurement of target is a very meaningful research content. Among all of methods, the information fusion is an effective way to solve this problem.

Kalman filter theory is a filter method that based on Bayesian filter theory with a state equation and a measurement equation to describe the linear system. Kalman filtering is actually a set of real-time

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recursion method implemented by computer. Extended Kalman filter is put forward by the people to solve the problem of nonlinear system estimation. The traditional solution is to use Taylor series expansion. Without tracking Kalman filter match the statistical properties of a random variable is through a set of Sigma points that precise selected. This is a way that easy to implement.

Multi-source heterogeneous information fusion is a very strong comprehensive interdisciplinary, it involves a wide range of knowledge, methods and techniques of different fusion processes used are different. A variety of information and data obtained by the multi-sensor information acquisition, after preprocessing and feature extraction, and finally through the different fusion algorithm to obtain the fusion result, the multi-source heterogeneous information fusion technology has outstanding advantages compared with the traditional information processing technology. It can increase the reliability of the system and information, reduce the data ambiguity, and improve the ability of the system's anti-interference and the data accuracy. In terms of the target tracking and measuring system, according to the equipment size, distribution, communication ability and the mission requirements, the choice of information fusion structure is not the same [8]. Multi-source heterogeneous information fusion technology was first used in the field of military, the basic model of information fusion in the literature has been given, but for target tracking the research of multi-source heterogeneous data integration is much less, there is no comprehensive integration and analysis of relevant data in tracking. Therefore, in this paper, on the basis of target tracking principle and method, using the adaptive unscented Kalman filter information fusion method to process the multi-source heterogeneous tracking data of the target [9].

2. The Analysis of Real-time Target Tracking Fusion Model

2.1. Multi-source Information Fusion Model Analyses

Multi-source heterogeneous information fusion technology was first used in military field. The basic information fusion model is shown in Fig. 1. The target tracking system of this article is composed by multiple sensors. Because each sensor's coverage is different, and each sensor have different observation period, target tracking data is obtained by real-time fusion processing model. The model in diagram mainly includes the multi-source data fusion, data calibration and association, etc. After the data fusion of multi-source information and real-time filtering processing, it can be get a relatively accurate target trajectory measurement [10-12].

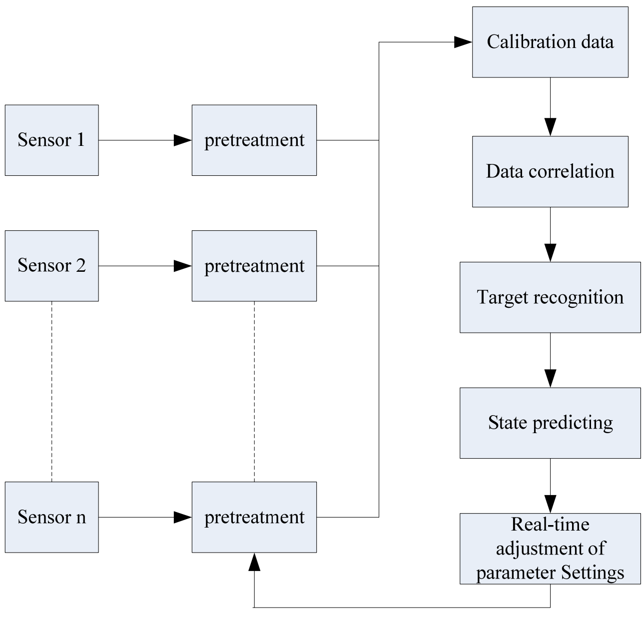


Fig. 1. Multi-source target tracking system block diagram.

We can see from Fig. 1. Multi-source detecting system work process is described as below. First of all, because the difference of multi-source heterogeneous sensors that worked independently, the system must take unified parameters preprocessing. Pretreatment can correct the data error. This ensures the quality of subsequent processing. At the same time, the main task of the preprocessing is reducing all kinds of uncertain factors that affect the performance of target recognition. These factors include noise, clutter, active or passive interference. Second, the detection system disorders can cause nonlinear and inconsistency of the equipment. This makes detection data have system error, and it can influence the target parameter. In order to ensure the high quality of the data, it needs to store a batch of calibration compensation data advanced in the computer. When detection system worked, it can be calibration and compensation the data according to the measurements or the system state. Thus can eliminate or reduce the system error data. Third, it needs to analyze the correlation of multi-source heterogeneous sensor data, and get useful information as possible. So, it can improve the detection performance of the system. Fourth, target recognition task is drawn one or more characteristics that directly related to target properties from the target echo as the sources of information for target identify [13]. Target identification needs to extract target logo and stable characteristics from echo information and determine its properties, which echo signal amplitude, phase, frequency, etc all can be used. Through obtain the goal of information for computer processing, and compared with known characteristics of the target, it can achieve the purpose of target of automatic identification. Fifth, through the analysis of the information processing, the system can estimate of target state, and get the overall trend prediction. At the same time, the system parameters can adjust in real time [14-16].

2.2. Target Tracking Model Analysis

The real-time target tracking fusion model is shown in Fig. 2, the model adopts the measurement fusion algorithm, without the need of each sensor of a UKF filter, so as to reduce the computational burden, is conducive to improve the real-time system. The main components of the model are the "current" statistical model of state equation, measuring equation, unlock anomaly inspection, Kalman filter and fuzzy processing module. The operating principle of the fusion model is as follow, with the use of the "current" statistical model to construct the state equation, after the real-time filtering of the Kalman filter to obtain fusion data, at the same time, in the light of the fused target information, real-time tracking and revising the structure parameters of the filter to improve the accuracy of data processing by the fuzzy theory algorithm. At the same time, according to the measurement values and prediction equations to judge and test the unlock anomaly of the filter [17].

"Current" statistical model belongs to the type of maneuvering motion model, it can better approach to the target maneuver period movement features. This article chooses zero mean time correlation models, using Rayleigh distribution to describe maneuvering acceleration. Discrete state equations for this model is

$$X(k+1) = F(k)X(k) + G(k)\bar{a} + W(k).$$

$$F(k) = \begin{bmatrix} 1 & T & (\alpha T - 1 + e^{-\alpha T})/\alpha^2 \\ 0 & 1 & (1 - e^{-\alpha T})/\alpha \\ 0 & 0 & e^{-\alpha T} \end{bmatrix}$$

$$G(k) = \begin{bmatrix} -\left(T + \alpha T^2/2 + (1 - e^{-\alpha T})/\alpha\right)/\alpha \\ T - (1 - e^{-\alpha T})/\alpha \\ 1 - e^{-\alpha T} \end{bmatrix}$$

$F(k)$ is the state transition matrix and $G(k)$ is the input control matrix, $W(k)$ is the error term. The prediction equation of the model is $\hat{X}(k+1/k) = F(k+1)\hat{X}(k/k) + G(k+1)\bar{a}$, it can be concluded that

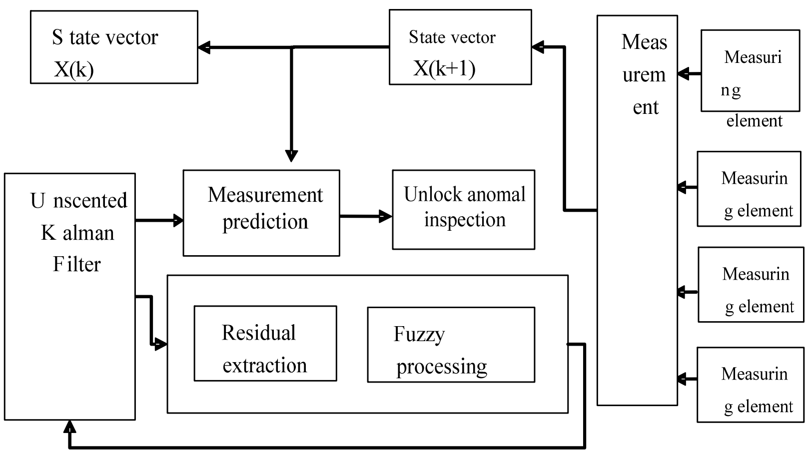


Fig. 2. Real-time target tracking fusion model diagram.

$$\hat{X}(k+1/k) = F_1(k+1)\hat{X}(k/k).$$

$$F_1(k+1) = \begin{bmatrix} 1 & T & T^2/2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}$$

The equation described a uniformly accelerated rectilinear motion, suitable for tracking uniform acceleration target.

2.3. Loss of Lock Judge and Outliers Test

When detection system in observation tracking, not all the device worked in the observation interval. Devices need to be unlocked test. Assumes that only i stage within the scope of the observation, the system measurement equation is $Y = [y^1 ... y^i ... y^N]^T$.
Outliers are usually divided into isolated outliers and spot outliers. These values will affect the filtering characteristic of tracking system. In order to guarantee the stability of the system, this paper use the predictive value that produced a moment ago to recognize and process. This unlock judge and outlier test method as shown in Fig. 3.

3. The Processing Algorithm of Unscented Kalman Filter in Target Tracking

Kalman filter is a minimum variance estimation algorithm for dynamic system. It through the state equation and the prediction equations describing dynamic system. Kalman algorithm has the characteristics of small amount of calculation and real-time computation, so it is widely used in target tracking and measuring system. At the same time, the fuzzy theory is based on the uncertainty of detection information, and it is according to certain decision-value making common information flexible, so as to improve the accuracy and credibility of information.

The essence of Kalman filter is the state vector reconstruction of the system from the measured value. It is via the order of "prediction - measured - revision" recursively, using the measured value to eliminate the random error and reappear the system state. The state equation of traditional Kalman filtering equation is too complex, and the real-time effect is relatively poor, so this paper uses the unscented Kalman filter [18]. The unscented Kalman filter is on the foundation of Kalman filter, the Kalman equation is described by using the probability density distribution, which uses sigma point to measure sample mean and covariance. On the basis of guaranteeing the measurement precision, making the amount of calculation reduced significantly, and has high anti-interference ability.
The noise interference state is a random variable, can not be accurately measured, but can conduct a series of observations. According to a set of observations, Kalman proposed a recursive optimal estimation theory, using the state space description method, and the algorithm adopts recursive form. Aiming at the target movement model, established the signal’s nonlinear state equation:

$$X(k+1/k) = f[X(k/k), U(k), k] + W(k) \qquad (1)$$

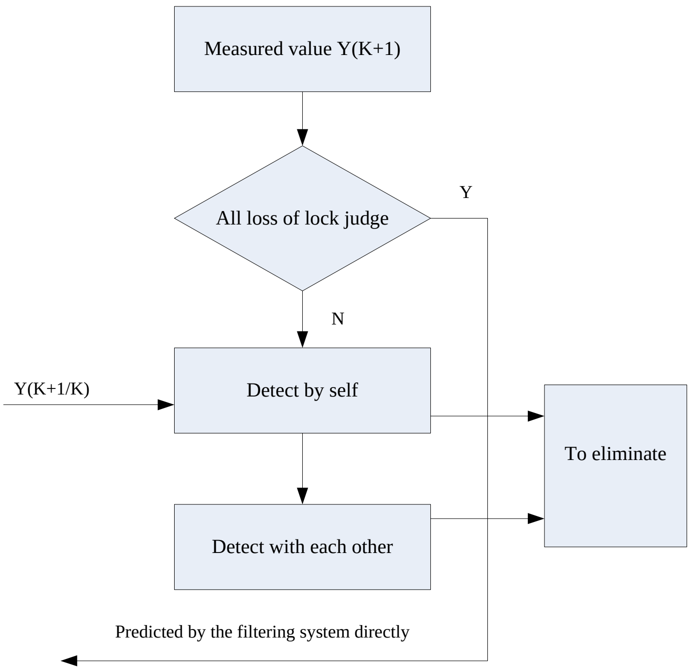


Fig. 3. Unlock judge and outlier test method diagram.

The measurement equation:

$$Y(k) = h[X(k/k), k] + V(k) \tag{2}$$

Among them, the state parameter $X \in R^L$, input $U \in R^n$, the state noise $W \in (0, P_k)$, measurement noise $V \in (0, Q_k)$. The average initialization parameter $X^a = [x^T, v^T, n^T]^T$, $\overline{X}_0 = E(\overline{X}_0)$ and the covariance p_0 is

$$P_0 = E[(X_0 - \overline{X}_0)(X_0 - \overline{X}_0)^T] \tag{3}$$

If we add noise during initialization, then

$$\overline{X}_0^a = E[\overline{X}_0^T \quad 0 \quad 0], P_0^a = \begin{bmatrix} P_0 & 0 & 0 \\ 0 & Q & 0 \\ 0 & 0 & R \end{bmatrix}$$

$$\overline{X_0^a} = E[\overline{X_0^T} \quad 0 \quad 0] \tag{4}$$

One of the important factors to influence the unscented Kalman filtering effect is the sampling method of the point sigma. Set up $X_i = \overline{X} \pm \sqrt{(n_x + \lambda)P_x}$, let the sampling weights be $W_i^m = W_i^c = 1/\{2(n_x + \lambda)\}$, λ is the scale parameter, adjusting the distance between the sigma point and the mean point. The set of sigma points is obtained by the nonlinear transformation criterion:

$$X_i^a(k/k) = g(x_i), i = 0,...,2n_x .$$

Weighted processing the transformed sigma point set, calculating the Sigma sampling prediction mean, the weight is W_i. It can express by formula (5).

$$\overline{X}_i^x[(k+1)/k] = \sum_0^{2n_x} W_i^m X_i^x[(k+1)/k], i = 0,...,2n_x \tag{5}$$

The state parameter $X \in R^L$ contains the target coordinates, speed and other information. Weighted processing can be adjusted according to the actual situation, to meet the different requirements of measurement system. But at any time the measurements of target position, velocity and acceleration are often have noise [19]. The Kalman filter using the target's dynamic information, trying to get rid of the influence of the noise and to get a good estimation about the target position. Sigma sampling point prediction covariance is calculated by formula (6).

$$P(k+1/k) = \sum_0^{2n_x} W_i^c [X_i^x[(k+1)/k] - \overline{X}_i^x[(k+1/k)]]$$

$$[X_i^x[(k+1)/k] - \overline{X}_i^x[(k+1)/k]]^T + P_k, \quad i = 0,...,2n_x \tag{6}$$

The noise interference state is a random variable, can not be accurately measured, but can conduct a series of observations. According to a set of observations, Kalman proposed a recursive optimal estimation theory, using the state space description method, and the algorithm adopts recursive form. According to the predicted measurement sampling equation

$$Z_i(k+1/k) = h[X_i^x(k/k), U(k), X_i^w(k+1)] \tag{7}$$

And the prediction measurement mean and the covariance.

$$\overline{Z}_i[(k+1)/k] = \sum_0^{2n_x} W_i^m Z_i[(k+1)/k], i = 0,...,2n_x \tag{8}$$

$$\begin{aligned} P_{zz}(k+1/k) = \sum_0^{2n_x} W_i^c [Z_i[(k+1)/k] - \overline{Z}_i[(k+1/k)]] \\ - \overline{Z}_i[(k+1/k)]][Z_i[(k+1)/k] \\ - \overline{Z}_i[(k+1)/k]]^T + \mu Q_k, \\ i = 0,...,2n_x \end{aligned} \tag{9}$$

$$\begin{aligned} P_{xz}(k+1/k) = \sum_0^{2n_x} W_i^c [X_i^x[(k+1)/k] \\ - \overline{X}_i^x[(k+1/k)]][Z_i[(k+1)/k] \\ - \overline{Z}_i[(k+1)/k]]^T \\ i = 0,...,2n_x \end{aligned} \tag{10}$$

State estimation is an important part of the Kalman filter. In accordance with the multi-source observed data to deduce random quantity quantitatively, which is the estimation problem, especially for dynamic target state estimation, it can realize the real-time running state estimation and prediction. State estimation is of great significance for the understanding and control of a target system. The Kalman gain, the updated mean and variance can be calculated.

$$W(k+1/k) = P_{xz}(k+1/k) P_{zz}^{-1}(k+1/k) \tag{11}$$

$$\begin{aligned} \overline{X}(k+1/k+1) = \overline{X}(k+1/k) \\ + W(k+1)(Z(k+1) \\ - \overline{Z}(k+1/k)) \end{aligned} \tag{12}$$

$$\begin{aligned} P(k+1/k+1) = P(k+1/k) \\ - W(k+1) P_{zz}(k+ \\ 1/k) W^T(k+1) \end{aligned} \tag{13}$$

Diagram of processing algorithm flow chart of unscented Kalman filtering in target tracking as Fig. 4.

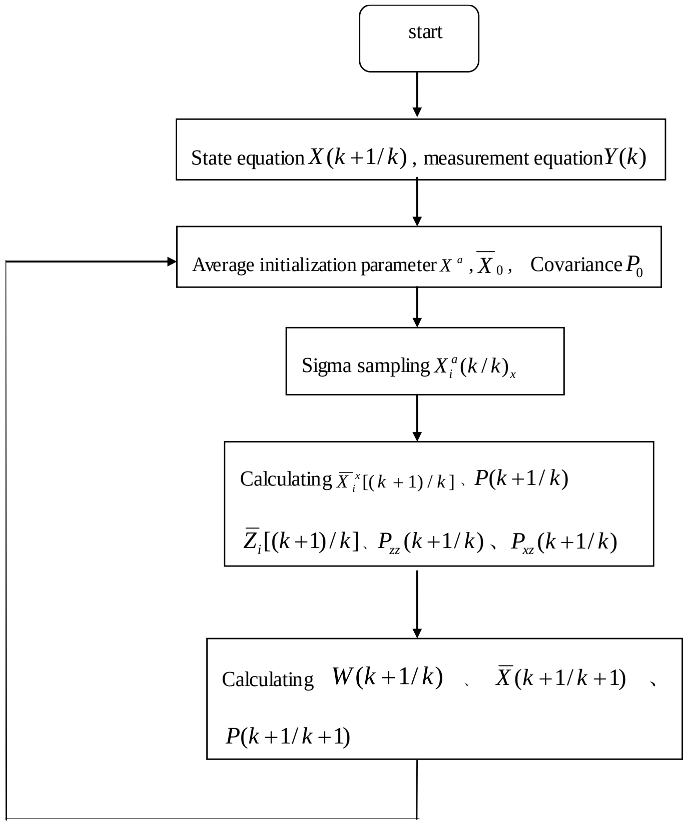


Fig. 4. Processing algorithm flow chart of unscented Kalman filtering in target tracking.

With the establishment of the unscented Kalman filtering algorithm, it can be seen that the algorithm does not need the system equation and the prediction system function which the ordinary Kalman algorithm needs. It greatly reduce the amount of calculation, and the covariance of the algorithm has higher degree of freedom, can reduce the system error effectively [20]. According to the algorithm above, we can use the following flowchart for processing.

4. Fuzzy Inference in the Application of the Unscented Kalman Filtering Process

Fuzzy reasoning fusion process can be carried on the statistical analysis on the innovation sequence in the unscented Kalman filtering process, estimating the system error and measurement error, and revising accordingly [21]. In the fuzzy inference process, by dynamic real-time adjusting the weigh of measurement noise covariance matrix, making the actual value of the adjusted covariance value approximately equal to the residual theoretical value. In order to extract the effective acceleration information, selecting the appropriate data to extract the appropriate characteristic values as input of the fuzzy inference system [22], the fuzzy processing steps are as follows:

(a) Using the unscented Kalman filter algorithm, accumulating the information sequence whose length is N, defined as:

$$V_k = y(k+1) - y(k+1/k) \tag{14}$$

The actual value of residual covariance at time t_k is

$$\delta^2 = \sum_{i=1}^{N} V_i^2 / N, i = 1,2,\ldots,l \tag{15}$$

The theory residual value of the system is P_{zz}.

(b) Defining the ratio of residual value

$$k = tr(\delta^2) / tr(P_{zz}).$$

(c) In order to make the value k maintained at around 1, it needs to real-time adjust the theory residual value P_{zz}, by adjusting the value μ from formula (5) to maintain the stability of the value k. "*a*" characterized for the fuzzy set of "Small", "*b*" for the fuzzy set "1", and "*c*" for the fuzzy set "Big", the fuzzy criterion is:

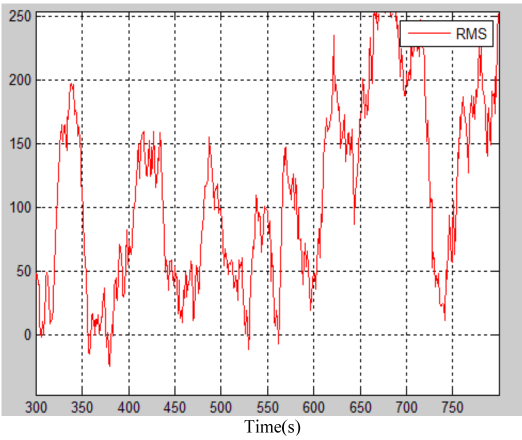
$$\begin{aligned} k \in a &\rightarrow \mu \in a \\ k \in b &\rightarrow \mu \in b \\ k \in c &\rightarrow \mu \in c \end{aligned} \tag{16}$$

5. Simulation and Verification

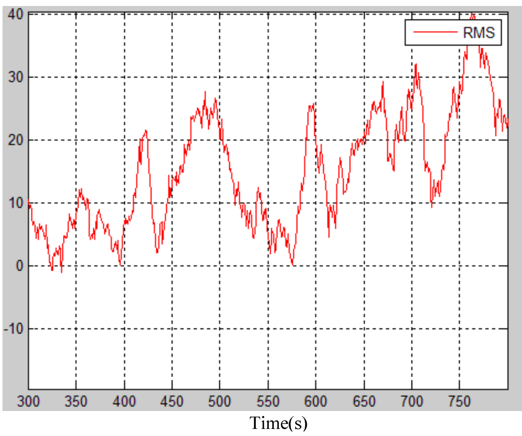
To assess the effect on fusion algorithm in tracking measurement technique, this paper using the MATLAB simulation software to make simulation experiment, adopting the Monte Carlo method, and carry on the experiment many times to get the average value, generally for 50 times.

Firstly, the simulation is initialized, the simulation time is set to 1000 s, establishing the standard system initial value: stator (0) and measurement initial value, and generate a trajectory generator. In order to promote the authenticity of the simulation, the actual moving trajectory should have certain randomness and motor section, as shown in Fig. 3; select the actual movement trajectory in 200 s.

Secondly, using Kalman filter simulation experiment of single sensor data and a plurality of sensor data, and display the tracking path obtained by single sensor and multi-sensor tracking path after treated. The simulation results are as follows. Fig. 5 shows the output error's mean square value of the system for target tracking in the [300, 800 s] time interval.



(a)



(b)

Fig. 5. Error comparison of the sensor and multiple sensors.

Fig. 5 (a) is a test of the single sensor data. It can be seen from the Fig. 5 (a), the part of measurement error increased dramatically should be the target maneuvering time interval, the error in the 340 s and 675 s all reached and surpassed 200. Fig. 5 (b) is the test of multi-sensor data. In Fig. 3 (b), the measurement error in the 480 s and 760 s respectively achieve maximum, but never reach 40. Contrast Fig. 5 (a) and (b), when the system is using a single sensor measurement, the error of the mean square value can reach more than 200, and when the system uses multiple sensors measurement, the error of the mean square value is about 30. It is obviously that the multiple sensor fusion can effectively reduce the motor segment error and achieve the goal of fast convergence.

Fig. 6 (a) shows the actual trajectory of the target in 0 ~ 250 s, it can be seen that there is a target maneuver near 50 s. Target trajectory is smooth.

Fig. 6 (b) is the test of the single sensor's data retrieval of target motion trajectory, it can be seen that the target system of trajectory reconstruction in the former 50s is relatively smooth, when the target is in the vicinity of maneuvering around 50 s, the system output volatility, error and output error is difficult to convergence, at the same time, the system becomes unstable. Fig. 6 (c) is the multiple sensors' target motion trajectory of the test data reproducing, it can be seen that the multi-sensor's output target trajectory is much smoother than single sensor through the unscented Kalman filter. Especially when the target motorized, it also does not appear large measurement fluctuations.

Synthesis the simulation results of Fig. 6 (a), (b), (c). The target motion trajectory measured by the single sensor has larger jitter. Especially when the target maneuver accelerated, the measurement error of the single sensor becomes larger, the ability of anti-noise is not enough. From the multi-sensor data fusion map, the real-time tracking data with high precision, and the tracking ability is very strong, especially the mobile target tracking can still be effective. In the case of big maneuvering acceleration, the speed of convergence is fast, thereby reducing the maneuvering phase measurement error.

Information fusion research extremely rich content, and that involving the basis of the theory is also very extensive. The information fusion method is the core technology of information fusion research. Current fusion method can be roughly divided into two categories: probability statistics method and artificial intelligence. The probability statistics methods mainly include Kalman filtering, hypothesis test, the Bayesian method, statistical decision theory, and other deformation method. Artificial intelligence methods including D - S evidence reasoning, fuzzy logic and god through network, expert system, etc. In practice, there is no a completely correct algorithm for one detecting system. So, when choosing information fusion algorithm, it will be decided according to the actual situation.

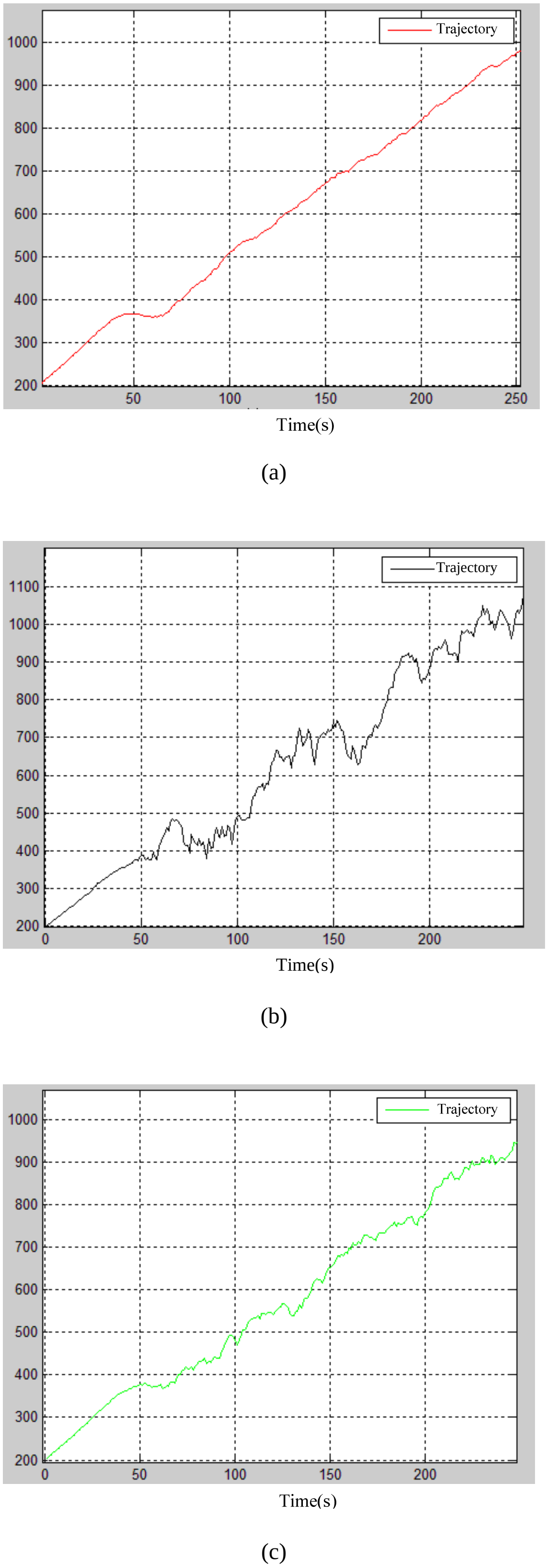


Fig. 6. Comparison of the measurement and actual trajectory between the single sensor and multi-sensor.

It should be based on the prior data available to analyze and select the appropriate algorithm. A large number of prior data and system simulation is very important to select the appropriate algorithm. For the problem of prior data is insufficient in the practical application, it should be undertake system simulation as much as possible, and choose the decision by comparing the algorithm. For the real time ability of algorithm, computation in the practical application and speed requirements are not the same. For example, the ground system and the airborne system are characteristic of higher real-time demand. At the same time, the algorithm's robustness and accuracy of the system have the contradictions. It should be according to the practical problems to choose the reasonable accuracy and robustness of the algorithm, and this is an important criterion of algorithm selection.

6. Conclusion

This paper uses multi-source information fusion theory, the structure is simple. The small amount of calculation of fuzzy adaptive unscented Kalman filter algorithm for real-time target tracking is analyzed and simulated, it can be seen from the simulation results, using the method of multi-source information fusion in the measurement of real-time target tracking can reduce the error greatly and accelerate the dynamic convergence speed. The method is suitable for tracking and measuring high speed maneuvering targets, it has a good application in engineering. At the same time, using fuzzy reasoning fusion process to statistical analyze the innovation sequence in unscented Kalman filtering process, estimate the system error and measurement error, and revised relevantly, also improve the accuracy of the algorithm. There are many kinds of information fusion algorithm; the algorithm and application of multi-source heterogeneous information fusion are closely linked. For the practical information fusion problems, it should be designed the suitable algorithm according to the concrete problem, in order to achieve the best performance.

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