The Design and Implementation of a Novel Distributed Multi-Sensor Information Fusion Simulation System

Yang Liu
School of Information Engineering, North China University of Water Resources and Electric Power, Zhengzhou, China
Email: liuyang_xueshu2009@163.com

Xin-qing Yan, Gui-ming Lu
School of Information Engineering, North China University of Water Resources and Electric Power, Zhengzhou, China
Email: 773531975@qq.com

***Abstract*—The large number of “false” targets, which are commonly faced by the aviators in real battlefields, will deteriorate the efficiency and initiative of the campaign. To detect and remove these “false” targets, a novel tracking simulation system is presented in this paper. As the key part of a multi-sensor information fusion simulation system, this tracking simulation sub-system consists of tracking pre-processing, tracking association, tracking fusion and tracking management modules. In the tracking association module, a multi-factors fuzzy synthetic evaluation (MFFSE) approach is adopted, and decision is made through common factors extraction, fuzzy synthetic function selection, fuzzy evaluation set construction and similarity construction. The architecture of the system, the process of information processing process, as well as design and implementation of algorithm are discussed in detail. Simulations are also performed, and it is verified that the multi-factors fuzzy synthetic evaluation based track-association method can remove the “false” targets effectively and improve the quality of object tracking significantly. Besides, the distributed multi-sensor information fusion simulation system presented here can act as a universal verification platform for different track association algorithm evaluation.**

***Index Terms*—track-association; track-fusion; multi-factor fuzzy synthetic evaluation; verification platform.**

I. Introduction

As the development of modern electronic information technology and adoption of intelligent weapon and equipment systems, more and more data can be collected in battlefield, and there is a urgent requirement to increase the quality of the information gathered by different sensors. But in practice, more and more aviators begin to reflect that many “false” or “illustrative” objects bring troubles to the rapid, clear and accurate judgment about the battlefield situation, and will deteriorate the efficiency and initiative of the campaign.

To remove these “false” targets, a new distributed simulation system for multi-sensors information fusion is designed and implemented. The track comprehensive processing simulation sub-system, as a main part of the system, consists of four modules: the track pre-processing, track association, track fusion and track management modules.

The rest of this paper is organized as follows. Section II introduces the hardware topology, software structure, interactions among the main components and the workflow of multi-sensors information fusion. Section III focuses on the track synthetic processing sub-system and presents the design of functional modules, track association algorithm and the realization of the system. Section IV presents the numeric simulation. Simulation result indicates that the multi-sensors information fusion distributed simulation system discussed in this paper is feasible in practice, the MFFSE based track association algorithm can remove the "false" targets effectively and improve the tracking quality of targets significantly. Besides, it can be seen that this system can be taken as a universal verification platform to examine different track processing algorithms. Finally in Section IV, we conclude this paper.

II. Design Of The Muti-Sensor Information Fusion Distributed Simulation System

A. The Hardware Topology and Software Structure of the System

The hardware topology of the multi-sensors information fusion distributed simulation system is depicted in Figure 1. The simulation system, connected by LAN, consists of one database platform and five sub-systems, which perform target production, sensors simulation, track processing, situation display and performance evaluation, respectively. These five software functional modules include the scenario simulation module, sensors simulation module, track processing module, situation display simulation module and performance evaluating module. Scenario simulation

by the Program for Science & Technology Innovation Talents in Universities of Henan Province under Grant No. 2011HASTIT020.National Natural Science Foundation of China (61240007).
Liu Yang(1979-) was born in Henan. Interests include: the theory and approach of maneuvering target tracking; multi-sensor information fusion. Yan Xin-qing(1967-) was born in Henan. Interests include: radio frequency identification, RFID; wireless sensor network

doi:10.4304/jsw.9.5.1081-1088

module produces battlefield targets and relevant environmental information. Sensors simulation module can get the original information belonging to targets and simulate the sensor data. Track processing module can process track pretreatment, track association, track fusion and the trajectory management. Situation display simulation module formulates the map based on the original information, sensor data and fusion data. Performance evaluation module can judge the accuracy and workability of algorithms and visualizes the evaluation results.

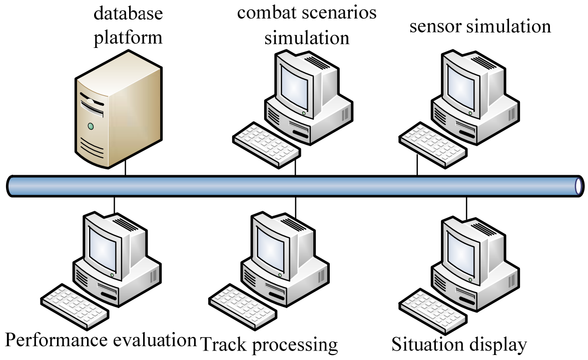

Figure 1 The hardware topology of distributed simulation system

B. *The Working Principle of Simulation System*

The information fusion system in this paper adopts distributed structure. The exchange and processing of data stream among the various functional modules in real time is showed in Figure 2.

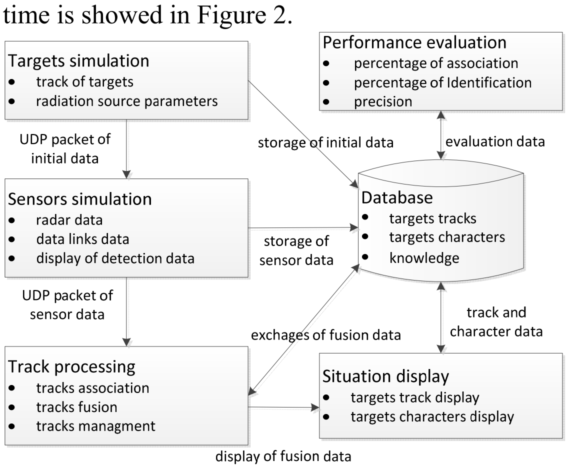

Figure 2 The working principle of distributed simulation system

III. Design And Realization Of The Track Synthetic Processing Simulation Subsystem

The comprehensive treatment of track system as a key part of the whole distributed simulation system decides the track processing quality of the total simulation system, at the same time, it can be replaced by other module. The so-called alternative means that the multi-sensors distributed simulation system provides a effective common platform. It is used to validate the track processing algorithms. Different algorithms of track processing which meet the requirements of data interface belonging to the simulation system can be embedded in the multi-sensor information fusion distributed simulation system for verification.

A. *The Procedure of Track Processing*

Comprehensive treatment of trajectory simulation sub-system processes track management command, firstly. In the process of operation, when the track management command arrived, it will be firstly responded by trajectory comprehensive processing sub-system. Otherwise, the trajectory comprehensive processing system will handle the track pre-treatment, track association, track fusion and the ambiguity processing by order. The figure 3 shows the workflow of track comprehensive processing simulation system.

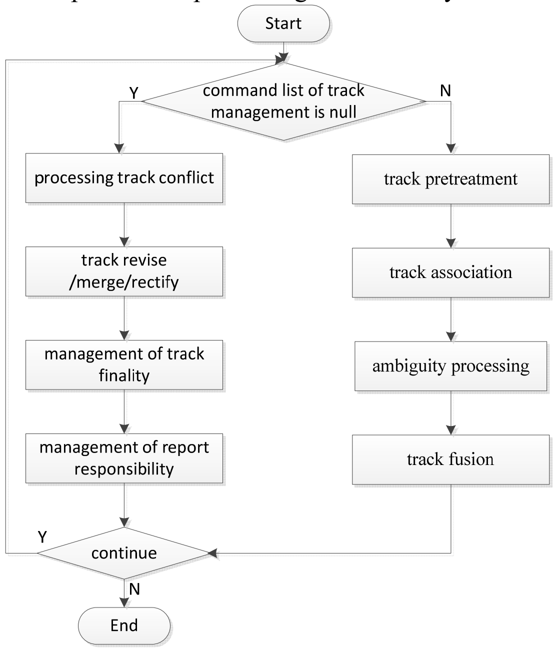

Figure 3 The workflow of track processing simulation system

B. *The Module of Track Association*

1) Algorithm structure

The track association algorithms usually have two kinds of processing structures: one is local tracks associate with system tracks, the other is local tracks associate with local tracks. Considering the requirement of real-time, we select the first structure. This structure defines that as long as the fusion center receives a group of local tracks, the algorithm will extrapolate the previous state to the current moment of the received local tracks. The fusion center will seek the local track data which is closed to this fusion node when the time arrives at the fusion node with fixed cycle time in the public time axis. Then the fusion center will fuse the data according to the certain criteria and get the best status estimation of the system track. At last, the fusion center can produce the new system track. Figure4 shows the structure of track association and fusion algorithm.

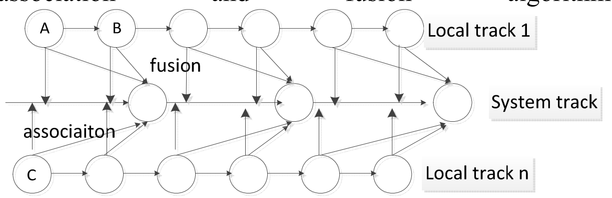

Figure 4 The structure of track association and fusion algorithm

In figure 4, the three local tracks data A, B, C will associate with all of the system tracks at their time, at the same time, the system tracks will associate and fuse with the local track which is closed to them. This structure can reduce the time complexity and space complexity of multi-sensor track association algorithm effectively and improves the system efficiency.

2) The module of track pre-treatment

The track pretreatment module should complete data acceptance, wild-value-eliminate, multi-dimensional state attribute decision, pre-filtering, dimension unity, space-time alignment, data format conversion and data assignment, etc. Firstly, the pre-treatment sub-system receives data from all the sensors correctly and detects error in real-time. Secondly, it will test whether these data participates in data fusion. Thirdly, the subsystem will sort and merge data according to observation time, at the same time, report position, sensor type and the attribute of information. Fourthly, the data will be converted to the same dimension when it is in different units of different precision. The workflow belonging to track pre-treatment is showed as figure 5

The main problem to be solved in the track pretreatment module is the time and space problems, and the correlation algorithm is described in detail in the literature [1]. Because of the limited space we will no longer descript in details.

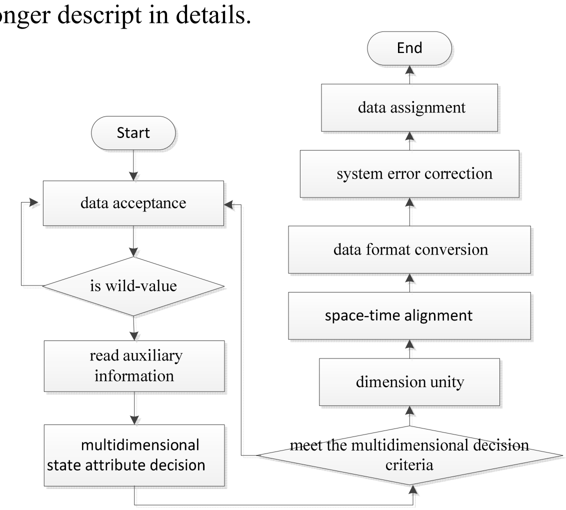

Figure 5 The track pretreatment workflow

3) The multi-factor fuzzy estimation algorithm

Fuzzy comprehensive evaluation and decision is a very effective method to the targets which are affected by many factors.

Usually fuzzy comprehensive evaluation method has four steps:

- Firstly, set up the factors set U={$u_1,u_2,\ldots,u_n$};
- Secondly, build the evaluation set V={$v_1,v_2,\ldots,v_n$};
- Thirdly, the single factor evaluation as following:

$$\underset{\sim}{f}:\mathbf{U}\rightarrow\Gamma(\mathbf{V}),u_i\rightarrow f(u_i)=(\omega_{i1},\omega_{i2},\omega_{i3},\ldots,\omega_{im}) \quad (1)$$

We know that fuzzy mapping can induce the fuzzy relation in the theory of fuzzy mathematics:

$$\underset{\sim}{\omega}\in\Gamma(\mathbf{U}\times\mathbf{V})=\underset{\sim}{f}(u_i)(v_j)=\omega_{ij} \quad (2)$$

Therefore, the single factor evaluation matrix $\omega\in u_{n\times m}$ can be expressed as following:

$$\omega=\begin{bmatrix}\omega_{11} & \omega_{12} & \cdots & \omega_{1m}\\ \omega_{21} & \omega_{22} & \cdots & \omega_{2m}\\ \cdots & \cdots & \cdots & \cdots\\ \omega_{n1} & \omega_{n2} & \cdots & \omega_{nm}\end{bmatrix} \quad (3)$$

- Fourthly, get the comprehensive evaluation.

Comprehensive evaluation adopts the synthetic operation to get the weight matrix A={$a_1,a_2,\ldots,a_n$}. In other words, comprehensive evaluation gets the synthetic evaluation C=A*W by getting $M(\wedge,\vee)$.

4) The track association based on the theory of multi-factor fuzzy synthetic evaluation

The principle of track association algorithm which based on the idea of multi-factors fuzzy synthetic evaluation is showed as figure 6. In this figure, firstly, we should obtain some common factors which are closely interrelated with the decision of the track association, at the same time, set up the fuzzy multi-factors set being the standard to make the decision of association. The number of factors should be small to ensure the efficiency of algorithm. Secondly, after we got the fuzzy multi-factors set **U**={$u_1,u_2,\ldots,u_n$}, we should choose a appropriate evaluation set and define single-factor membership function. We can classify the evaluation set into m grades according to the results of association. It will be labeled as **V**={$v_1,v_2,\ldots,v_n$},where v_k is the evaluation results of the *k*th grade. The evaluation results of track association at k moment is a subset of **V**. The fuzzy relation matrix between **U** and **V** is **R**=$(r_{kl})_{n*m}$, **R**={$r_{k1}, r_{k2},\ldots, r_{km}$} is the proximity of a local track and a system track *s* considering only one factor u_k, so that we call **R** is a single factor evaluation matrix. The synthesized relation evaluation between a local track and the system track is the composite working of fuzzy factor weight set **A** and the single factor evaluation matrix **R**. Then we can get a fuzzy set **B** to describe the similar level of a local track on the current time by the compositional operations of **A** and **R**, as formula (4):

$$\mathbf{B}=\mathbf{A}*\mathbf{R}=(b_1, b_2,\ldots b_m) \quad (4)$$

Where, "*"is compositional operations; b_k is the relative-membership grade of a local track belonging to the *k*th estimation scale. Now we will explain the main steps of track association algorithm in details.

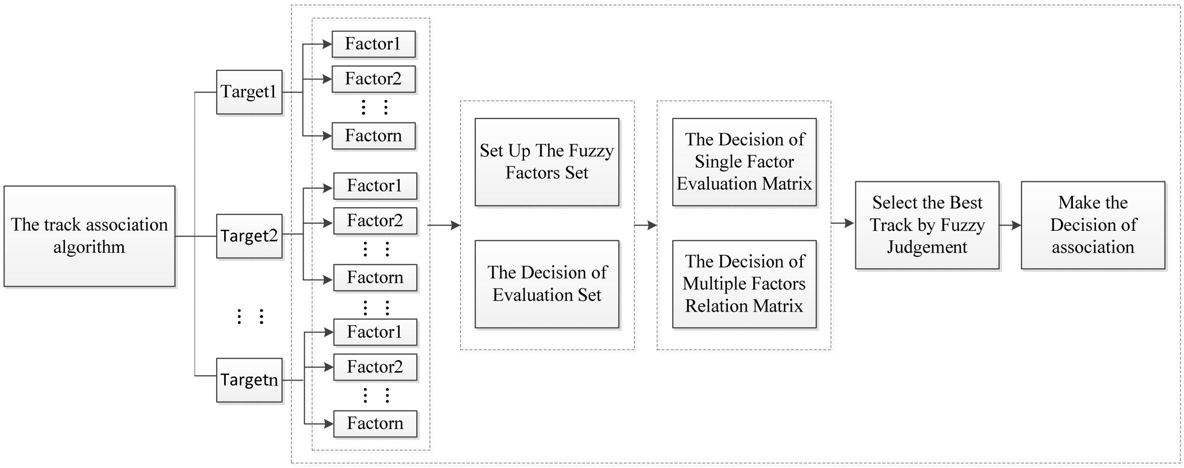

Figure 6 The work principle of track association algorithm

- Step one--The decision of fuzzy factor set

Now, we set up the fuzzy factor set **U**=$\{u_1,u_2,\ldots,u_n\}$ according to the state estimation results vector, where uk is the *k*th fuzzy factor which can be the judgment basis. The fuzzy factors that influence the decision of association in the algorithm include the Euclidean distance of position and velocity between the local track and the system track. The formula (5) tells us how to get the fuzzy factors set.

$$\begin{cases} u_1 = \| \mathrm{Pos}^i - \mathrm{Pos}^s \| \\ u_2 = \| \mathrm{Vel}^i - \mathrm{Vel}^s \| \end{cases} \quad (5)$$

- Step two--the decision of evaluation set

In the track association algorithm, we are interested in whether local track mi is closed to the system track s. So we select vector **V**=$\{v_1,v_2,\ldots,v_n\}$, m=2 to be the evaluation set of the track association algorithm, where v_1 indicates the local track is associate with system track and v_2 indicates the local track is not associate with system track, so V={association, not association}.Then we need to decide which function can be used as fuzzy membership function, here, it is defined as normal membership function. Formulation (6~7) calculate the relative-membership grade of the *k*th factor, where $r_{k1}+r_{k2}=1$:

$$r_{kl} = \exp\{-\tau_k (u_k^2 / \sigma_k^2)\}, k = 1,2,...n \quad (6)$$

$$r_{k2} = 1-\exp\{-\tau_k (u_k^2 / \sigma_k^2)\}, k = 1,2,...n \quad (7)$$

As results, the fuzzy evaluation matrix is defined as **R**=$(r_{ks})_{n*2}$.

- Step three--The decision of single factor evaluation matrix

We will distribute the weight to every factor after we have got the factor and the evaluation set. The weight set is A=$\{a_1,a_2,\ldots,a_n\}$, where a_k is the weight of the *k*th factor. Usually, we define that $\sum_{k=1}^{n} a_k = 1$, the results of a_k is decided by the importance of the *k*th factor. After getting the fuzzy evaluation matrix **R** and weight matrix **A**, we can calculate the similar level belonging to each local track. Here, compositional operation is defined as the matrix multiplication as (8):

$$b_l = \sum_{k=1}^{m} a_k r_{kl} \quad (8)$$

At last, we will calculate the similarity between the local track m_i and the system track s as formula (9).

$$g_{ij}(k) = \frac{b_{ij1}(k)}{b_{ij1}(k)+b_{ij2}(k)} \quad (9)$$

Where, the range of $g_{ij}(k)$ is [0,1]. The association probability will be higher when $g_{ij}(k)$ becomes one, on the contrary, The association probability will be lower when $g_{ij}(k)$ becomes zeros. We can select the system track whose association probability is highest with the specific local track.

- Step four--The workflow of Algorithm

At the beginning of the simulation, track association algorithm will traverse the local and system track library. If the system track library is empty we will construct the system track using this local track, then, we will test the correlation between this local track and all system tracks. The algorithm will produce a test association belonging to current local track, if the local track succeeds in association with the system track. At the same time, the algorithm will record the number of association and successful association. If current local track has built the test association, and it satisfies the condition n<=5 and s>=3, the algorithm will change the test association to the solid association. On the contrary, the algorithm will delete the test association and make this local track associate with all system tracks, again. If the current local track already has a solid association with system track, the algorithm will start the periodic test and judge whether the solid association is valid. If the solid association is valid, the algorithm will continue the system track directly, otherwise, the solid association will be deleted. The work flow of track association is

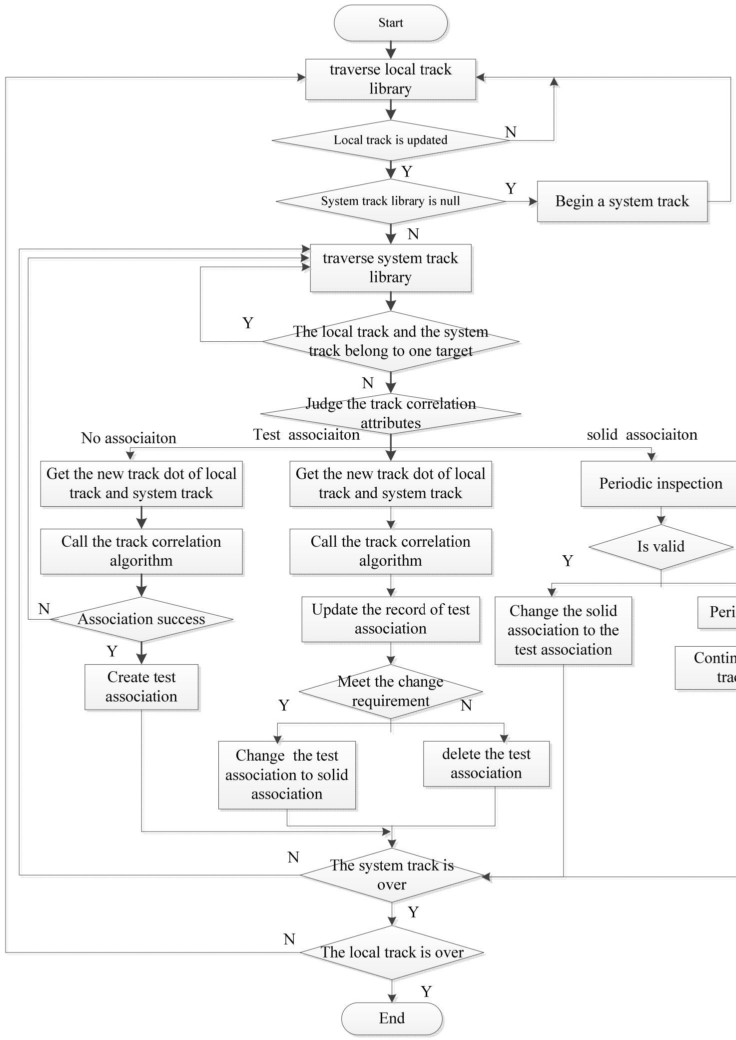

Figure7 The workflow of track association

showed in figure 7.

5) The module of track fusion

The track fusion algorithm can fuse the tracks which succeed in association to be one target basing on the track association and track management.

- Track fusion standard

The track fusion algorithm will not fuse the tracks when the track error is too big. The algorithm will adopt high precision track endurance to continue the system track.

The local tracks will not join in the track fusion if the time of the local track is different with the system track. The defaults value of the time is 3 second.

- Track fusion workflow

Track fusion module will traverse local tracks firstly. Each local track can succeeds in association with only one system track. On the contrary, each system track can succeed in association with several local tracks. If there is a local track which succeeds in association with several system tracks, the algorithm will do ambiguity processing to find out the system track which has the highest fuzzy degree with this local track. Then, the algorithm will traverse system tracks to select all local tracks which succeed in association with this system track and fuse these local tracks to produce a new system track dot. The figure 8 explains the workflow of track fusion in details.

- The module of track management

The module of track management will process the questions such as the temporary disappear of track and the track confliction. At the same time, it can produce track management commands to solve these conflictions.

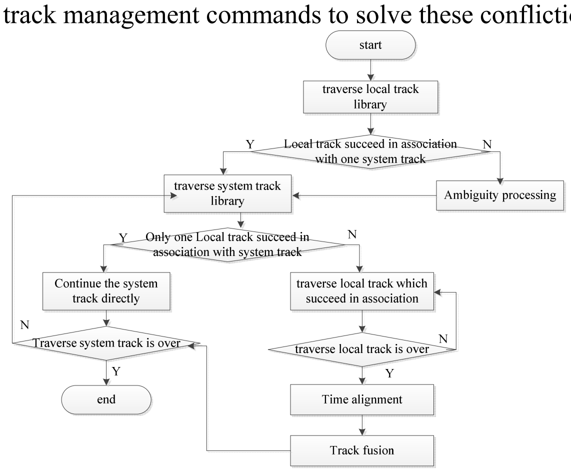

Figure 8 The workflow of track fusion

Usually, track management module works in automatic mode, but it can work in manual mode, too. Different projection has different track management rules. We will not introduce in details.

IV. THE REALIZATION OF MULTI-SENSOR INFORMATION FUSION DISTRIBUTED SIMULATION SYSTEM

A. *The Design of Simulation Scenario*

The scenario assumes that there are 5 blue targets and 1 red target. A radar is loaded on the red plane which can detect the information of blue planes in real time. The sampling time of radar is 0.02s, and the simulation will sustain 1000s. The measurement error obeys gauss distribution, the distance measurement error is 150m, azimuth measurement error is 1o. and pitch angle measurement error is 1o. The red plane can receive the information transmitted by two data links about the 5 blue planes and the sampling time of data link is 1s. The table I shows the initial position, destination and the inflection points in track belonging to the blue and red targets. Then, the table I designs the acceleration value between adjacent inflection points. The initial velocity of targets in [1500km/h, 2000km/h] and the weight vector in fuzzy track association is (a1=0.75, a2=0.25).

TABLE I
THE PARAMETERS OF BATTLE SCENARIO

	point of inflection1		point of inflection2		point of inflection3		point of inflection4		point of inflection5	
	longitude& latitude	acceleration	longitude& latitude	acceleration	longitude& latitude	acceleration	longitude& latitude	acceleration	Longitude& latitude	acceleration
blue	(25.12,122.82)	150	(25.52,121.50)	80	(24.90,120.41)	0	(24.18,118.96)	-40	(23.66,117.81)	-10
	(25.43,122.64)	150	(24.57,120.90)	60	(23.99,119.34)	10	(23.52,118.03)	-50	(23.20,117.01)	-16
	(25.59,122.32)	150	(24.86,121.65)	100	(24.13,120.09)	5	(23.34,118.20)	-70	(22.77,116.62)	-12
	(25.79,121.97)	150	(24.11,120.42)	20	(23.47,118.90)	3	(23.01,117.54)	-80	(22.71,116.29)	-18
	(25.85,121.67)	150	(24.25,121.06)	50	(23.56,119.06)	8	(23.12,117.67)	-40	(22.77,116.62)	-19
red	(23.40,177.09)	200	(23.53,117.86)	80	(23.98,119.13)	20	(24.56,120.64)	-80	(25.39,122.08)	-10

B. *The Analysis of Simulation Results*

The simulation results show that the system gets more accurate fusion tracks than all of the local tracks, at the same time, “illusive” targets are decreased effectively. Figure 8 shows five blue targets and one red target, each blue target has several mutual crossed tracks which are original track, several local tracks and a fusion track produced by track process subsystem. Here we consider two probabilities: one is the correct association probability E_c, the other is the error association probability E_e.

The table II shows the two probabilities and the cycle processing time of the algorithm. From the data in table II, we can conclude that the track association algorithm in this paper has good rate of track association. The table III statistics the mean error and the error standard deviation for position and velocity in the track association algorithm.

To make the results of tracks processing more clear, figure 9 amplifies one track of a blue target. In Figure 9, the blue track is the original track, the rose track and the orange track are two local tracks which are transmitted by two data links, the yellow one is a local track belonging to radar, and the white track is the fusion track processed by the information fusion system. From the result, we can see that the white fusion track is smoother, and it is more accurate than every local track. In a word, the system track fused by the track processing subsystem is closer to the original track.

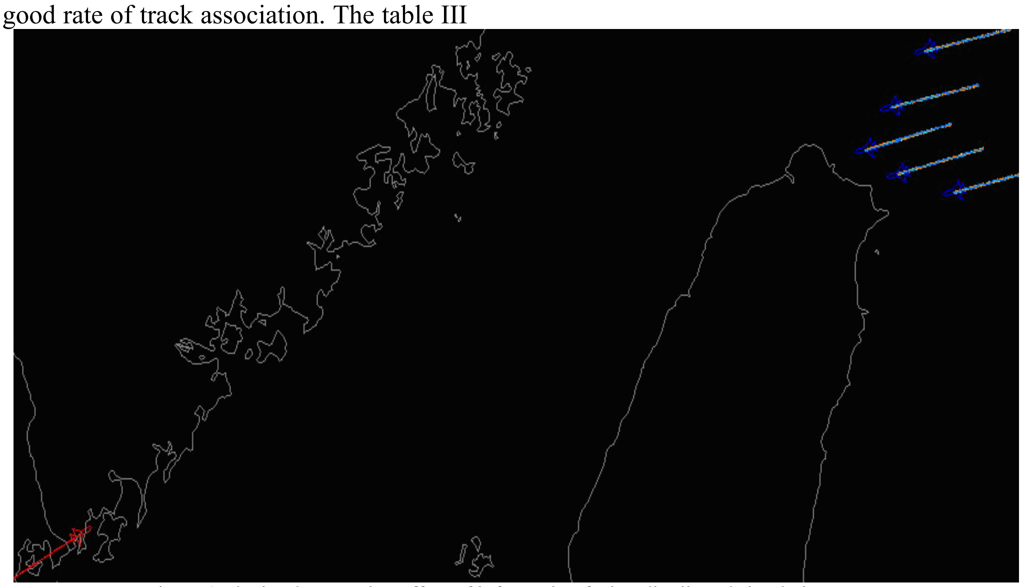

Figure 9 The implementation effect of information fusion distributed simulation system

TABLE II
THE PERFORMANCE PARAMETERS OF TRACK PROCESS ALGORITHM

correct probability(%)	false probability(%)	processing cycle(s)
97.424	2.576	0.0164247

Table III The error mean and standard deviation of algorithm

error mean of position(m)	error mean of velocity (m/s)	standard deviation of position (m)	standard deviation of velocity (m/s)
2.271	7.576	8.643	49.166

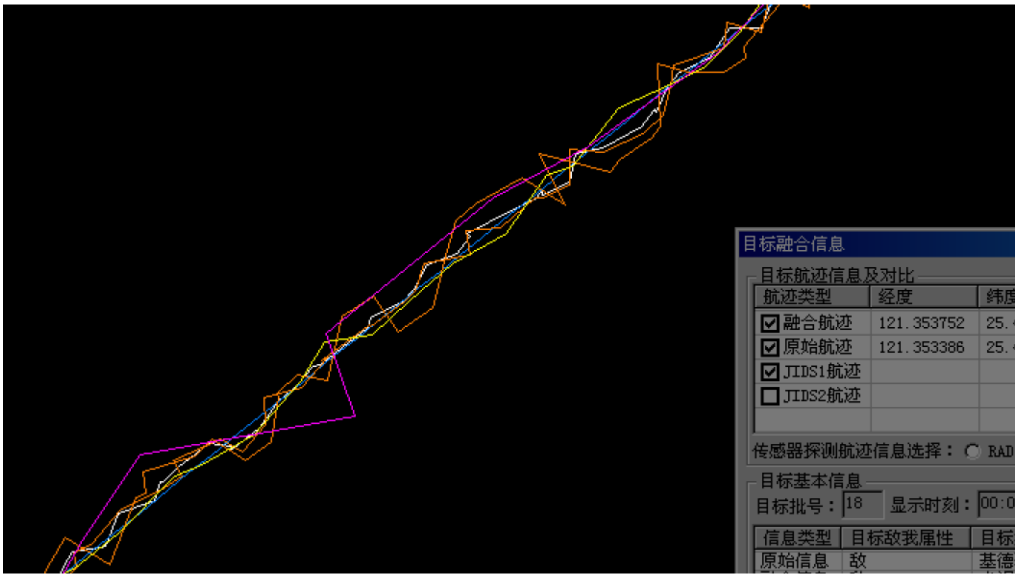

Figure10 The Amplification chart of one track

V. CONCLUSION

The design and implementation of a multi-sensor information fusion distributed simulation system is presented in this paper, which can provide a universal verification platform to examine various track processing algorithms. The main modules of this system are also described in detail.

In this system, the multi-factor fuzzy synthetic evaluation is introduced to the track association algorithm to remove the “false” targets, and the corresponding algorithm is designed and implemented. Simulations are performed to examine the algorithm in several typical scenarios, and simulation results indicate that this track association algorithm can remove the “false” targets effectively and improve the quality of data fusion significantly. Besides, simulations also verify that this multi-sensor information fusion distributed simulation system can be used to examine different track processing algorithms.

But there are still some works for future researches, for example, to examine the effect of the rack association algorithm and the simulation system in practice.

REFERENCES

[1] HE You, WANG Guo-hong. Multi-sensor Information Fusion With Application[M]. Beijing: Electronic Industry Press, 2000.

[2] HAN Ping, LI Fang-min, LUO Ting. Distributed Target Tracking Algorithm for Wireless Mobile Sensor Networks[J]. Journal of Beijing University of Posts and Telecommunications, 2009, 32(1): 90-94.

[3] TIAN Ming-hui, FANG Qing, REN Qing-an. Simulation of Track Fusion of Airborne ESM and Radar[J]. Radar Science and Technology,2012,10(1): 64-68.

[4] QI Chong-ying, WANG Yi, HAN Ying. Research on Common Framework and Key Technology of Data Fusion Simulation System[J]. Computer Engineering and Design, 2012, 33(2): 705-709.

[5] HU Juan. Fuzzy Optimization model of Oilfield Development Program and Its Application[D]. Southwest Petroleum University, 2013,1~142.

[6] HAO Qing-bo. Fuzzy Comprehensive Allocation and Prediction for NC Machine Tools Reliability and Maintainability[D]. Ji Lin University China, 2012, 1~147.

[7] HUANG Man-guo, FAN Shang-chun. Research progress of multi-sensor data fusion technology[J]. Transducer and microsystem trchnologies,2010, 29(3):5~8.

[8] Rong Hua-guo, Zheng Qin, Xiang Nan-li, Jun Liang-chen. Interacting Multiple Model Particle-type Filtering Approaches to Ground Target Tracking [J]. Journal of Computers, 2008, 7 (3): 23~30.

[9] LEI Xin, YAN Chu-ping, XU Hai-chuan. Research and simulation on data aggregation in wireless sensor network [J]. Computer Engineering and Design, 2008, 29(18):4669~4671.

[10] CHEN Wei, YUE Zeng-kun, CHEN Qi. Simulation testing and synthetic evaluation for data fusion performance [J]. Fire Control and Command Control, 2008, 33(6):106~110.

[11] Tsung-Ying Sun, Shang-Jeng Tsai, Chih-Li Huo. Intelligent Maneuvering Decision System for Computer Generated Forces Using Predictive Fuzzy Inference System. Journal of Computers, 2008, 3 (11):58~66.

[12] REN Qing-an, ZHAO Hong-li, LIU Jun-wei. Research on evaluation method of detection precision of airborne radar [J]. Radar Science and Technology, 2011, 9(1):29~33.

[13] Yang Liu, Ma Zhao, Qin-zhang Wu. A New Hybrid Grid Multiple Model Estimation Based on STF. Journal of Computers, 2012, 7(7): 1607-1614.
[14] Kun Yu, Guo-hua Xu, Xiong Shen. Position Location and Trajectory Tracking for MUWT Based Kinematics Approach, 2013,8 (4): 1020-1026.
[15] Xiao-ming Liu, Lian Pan. The Study of Target Tracking Based on ARM Embedded Platform, 2012, 7(8) , 2015-2023.

Yang Liu was born in Henan, China on April 21, 1979. She received the B.S. degree in computer theory from Shan'xi University, Taiyuan, China, in 2002, then, got the M.S. degree in computer theory from University of Electronic Science and Technology of China, Chengdu, China, in 2005. She got Ph.D. degrees in The Institute of Optics and Electronics, the Chinese Academy of Sciences, Chengdu, China in 2012. Interests include: the theory and approach of maneuvering target tracking, multi-sensor information fusion, and intelligent target tracking.

Xin-qing Yan was born in Henan, China, 1967. He is working in the school of information engineering, north china university of water resources and electric power in Zhengzhou. Interests include: RFID, wireless sensor net.