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Research and Implementation of a Testing Method in Target Tracking Based on Multi-Radar Information Fusion

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Abstract. According to the target characteristics in multi-Rader information fusion systems, an index-based testing method in target tracking has been proposed. In addition, a testing prototype system has been designed and a testing simulation model has been established. The index data were extracted from a multi-Radar information system in antiaircraft battlefield, and have been evaluated in our testing prototype system. Experimental results indicate the feasibility and rationality of our testing method.

Keywords: multi-Rader information fusion, target tracking precision, tracking efficiency, evaluation index

1. Introduction

It is obvious that research on multi-Radar information fusion (IF) technology has achieved great improvement in recent years, which has been wildly applied in varied fields, e.g. in the command and control field. But how to evaluate the performance of these IF systems and how to test the capabilities of these systems remains one of the issues that hasn't been well solved.

Within the last few years, research efforts were mainly concentrated on the IF technology system evaluating methods, with several performance evaluation systems proposed. Experts in institutions from the US, Australia and Canada have been studying the evaluation technology of Radar-IF systems since 1995, who have built the evaluation system based on track quality [1]. In addition, Bowman and Steinberg, the famous Swedish experts in IF field, have proposed performance evaluation methodology for distributed multi-sensor fusion systems [2]. But application of these theories was not quite satisfactory because no comprehensive index system has been established [3], [4], [5].

According to the target characteristics in multi-Rader IF systems, the paper proposes the target tracking precision index and the continuous tracking efficiency index, which are the two important indexes in IF systems[6]-[8]. Our simulation lab was used to design a prototype system for test and to establish a T&E (Testing & Evaluation) system. Experimental results indicate the feasibility and rationality of the proposed T&E method.

2. Principles and Architecture Design of Testing & Evaluation system

Multi-Radar IF technology is an intelligence fusion process which gathering information provided by varied Radar sources [9]-[13]. The objective of this process is to build a fresh and correct situation view from all available information, which is proved to be more adequate than from just one single information source [14], [15]. As can be seen, the goal of the proposed T&E system is to compare the performance of the every

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single source on track detection and performance of the fusion system on track processing, to test which track is closer to the true value of targets.

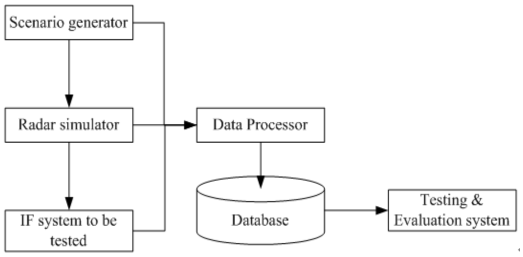

Fig. 1. A schematic diagram of the testing & evaluation system

Fig.1 shows the schematic diagram of our simulation evaluation system. It is proved in experiments that the proposed T&E system is feasible according to this architecture.

T&E system is consisted of five portions: the scenario generator, the Radar simulator, the data processor, the database and the T&E system. The IF system is to be tested using the proposed T&E system.

The main function of the scenario generator is to generate testing scenarios. In this software, we could set Radar detection models, track paths, target models, and so on. It is aimed at simulating the situation according to the scenario file, generating simulation targets which are considered as criterion (true value). The generated true value data are packed and transmitted to the Radar simulators and the data processor through the network transmission software.

The general workflow of the Radar simulator is to receive the true value data generated by the scenario generator, detect targets by the Radar detection model, and add measurement error set by the scenario generator on the true value of the target. Subsequently, the detection data are sent to the IF system to be tested and the data processor.

Data processor receives three sources of data: the true value generated by the scenario generator, the detection data sent from the Radar simulator and the target intelligence data reported by the IF system to be tested. These data are then classified into the database.

Above data are stored in the database, along with the evaluation results based on our testing index.

The proposed T&E system extracts the testing data based on the appointed indexes from the database, makes evaluation results according to the algorithms of the indexes. Then the evaluation results are stored into the database for check and algorithm comparison when needed.

According to the principles of T&E system, we put the whole testing process into three phases: the phase of testing preparation, the phase of data acquisition & process and the phase of index calculation & evaluation. The software design flow chart of the proposed T&E system is shown in Fig. 2.

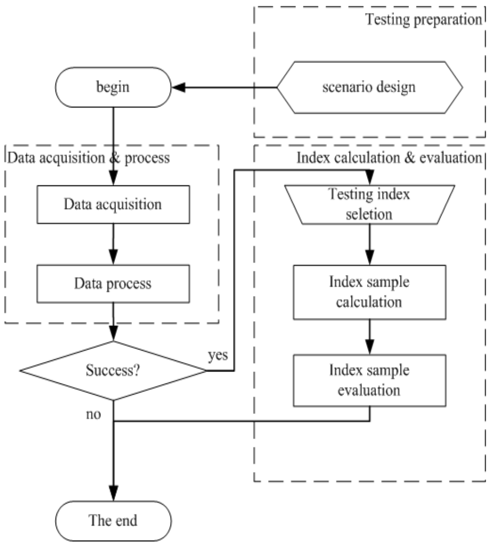

Fig. 2. Software design flow chart of the T&E system

3. Definition & algorithm of testing indexes

In this paper, target characteristics in multi-Rader IF systems are studied. The target tracking precision and the continuous tracking efficiency are proposed as two important aspects to evaluate IF systems, along with the following testing indexes.

3.1. Lateral deviation of target localization and tracking

Definition: The lateral deviation of position of every single track of every entity to be tested. This index is used to measure the smooth characteristic of target tracking, which is an index on track quality evaluation. Obviously, the smaller the discrete value of the lateral deviation is, the smoother the track is.

The calculation algorithm is as following:

$$dx_{ji} = x_{ji} - \overline{x_{ji}}, dy_{ji} = y_{ji} - \overline{y_{ji}} \tag{1}$$

$$d_{ji} = dx_{ji} \times \cos \overline{k_j} - dy_{ji} \times \sin \overline{k_j} \tag{2}$$

$$s_{ji} = d_{ji} \times d_{ji}, \overline{s_j} = \frac{1}{m}\sum_{i=1}^{m} s_{ji} \tag{3}$$

$$\bar{s} = \frac{1}{n}\sum_{j=1}^{n} \overline{s_j}, \sigma = \sqrt{\bar{s}} \tag{4}$$

where x_{ji}, y_{ji} indicate coordinates of the i th point of the j th track, $\overline{k_j}$ indicates the course of the j th criterion track with $j = 1,...n$, $\overline{x_{ji}}, \overline{y_{ji}}$ are the coordinates extrapolated from the associated criterion track to the j th track, d_{ji} is the lateral deviation of the i th point of the j th track, $\overline{s_j}$ is the mean square error (MSE)of all points of the j th track, m is the sum of points of the j th track, n is the sum of track reported from a Radar simulator, $\bar{s}$ is the MSE of lateral deviation of all track reported from a Radar simulator, σ indicates the root mean square error (RMSE) of lateral deviation of all targets reported from a Radar simulator.

3.2. Efficiency index on continuous target tracking

3.2.1. Mean time of a target tracking

The definition of this index is the mean value of all targets' tracking time, which is used to scale the tracking capability of an IF system. Obviously, the longer the tracking time is, the better the target tracking performance of a system is.

We can define

$$\Delta T_j = \frac{1}{m}\sum_{i=1}^{m}\left(T_{eji} - T_{bji}\right) \tag{5}$$

where ΔT_j is the tracking time of the j th track, m represents the sum of tracking segments, T_{eji}, T_{bji} is the end time and begin time of a target tracking, and then the mean time of a target tracking is

$$\frac{1}{n}\sum_{j=1}^{n}\Delta T_j \tag{6}$$

where n is the sum of all targets with $j = 1,...,n$.

3.2.2. Mean time of a target interrupted-tracking

Definition: The mean value of all targets' interrupted-tracking time, which is used to measure the tracking interruptions of an IF system. Obviously, the shorter the interrupted-tracking time is, the better the target tracking performance of a system is.

Define:

$$DT_j = \frac{1}{m}\sum_{i=1}^{m}\left(T_{bji+1} - T_{eji}\right) \tag{7}$$

where DT_j is the interrupted-tracking time of the j th track with $j=1,...,m$, m represents the sum of interrupted-tracking segments, T_{eji} is the end tracking time of the j th track and T_{bji+1} is the next started tracking time of the j th track, and then the mean time of a target interrupted-tracking is

$$T=\frac{1}{n}\sum_{j=1}^{n}DT_j \tag{8}$$

where n is the sum of all targets with $j=1,...,n$.

3.2.3. The efficiency of target continuous tracking

Definition: The time proportion of all targets tracked by a system, which is to measure the efficiency of a system's tracking performance. Obviously, the larger the value is, the higher the efficiency of the system tracking performance is.

Given this description, this index is defined as:

$$\eta=\frac{T_1}{T_1+T_2} \tag{9}$$

where T_1 represents the sum of all target tracking time, T_2 is the sum of all target interrupted-tracking time.

4. Experimental results

According to the proposed principle and design process, a T&E prototype system has been built to evaluate the target tracking performance of a typical IF system in antiaircraft battlefield. In this experiment, the plat was consisted of a scenario generator, four Radar simulators covering different areas with different kinds of models and an IF system for test, whose information were all sent to the proposed T&E system by network. 100 batches of targets were designed in the experimental scenario file, the velocity of which was 900 km/h, 1100 km/h, 1200 km/h and 1500 km/h, respectively. The whole run time of the experiment was 710 seconds. In addition, the random distance errors of the four Radar simulators were 0.8km, 1 km, 1.2 km, 1.4 km, respectively, and the random course errors were 0.08 °, 0.1 °, 0.12 °, 0.14 °.

Some experimental results are presented as follows.

4.1. Target tracking precision

The testing results are listed in Table 1, including the mean value of lateral deviations, the RMSE of lateral deviations and so on. As can be seen, the IF system has higher scores than the Radar simulators, so the fusion tracking performance is better than the sensors. Fig. 3 shows the mean value and the Gaussian curve of lateral deviations of the entities. As can be seen, the value of the IF system to be tested (Station No.888) is better than most of the Radar simulators, and the tracks of No.888 are smoother. Notice that Radar 103 has the least mean error, while this does not mean the highest score, because mean error is the summarization of both positive and negative values. Comparatively, mean square error is a more convictive evaluation index.

Table 1. Tracking Precision

Entity to be tested	Station No.	Mean value of lateral deviations(m)	RMSE of lateral deviations (m)	The sum of target batches	The sum of target points
IF system	888	2.135378	188.265524	100	7019
Radar station 1	101	-13.353029	1024.47646	85	5853
Radar station 2	102	-14.505835	1239.049823	93	6338
Radar station 3	103	1.860121	1443.812949	72	5009
Radar station 4	104	-9.122358	820.827869	88	6134

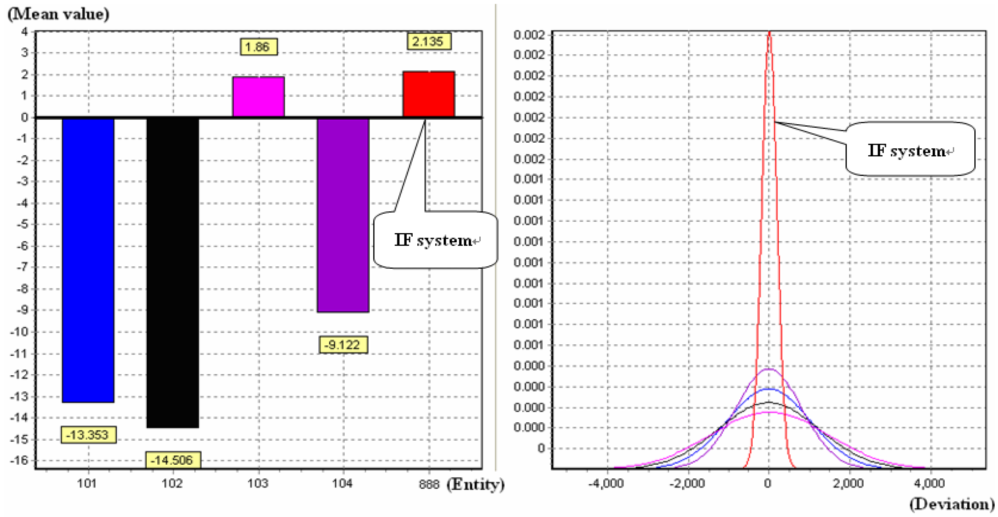

Fig. 3. The mean value and the Gaussian curve of lateral deviations of the entities

4.2. Target continuous tracking index

The experimental results on the target continuous tracking index are shown in Fig.4, including the mean tracking time, the mean interrupted-tracking time and the tracking efficiency. As can be seen, the results of the IF system to be tested are better than the Radar simulators, which presents higher efficiency of tracking performance.

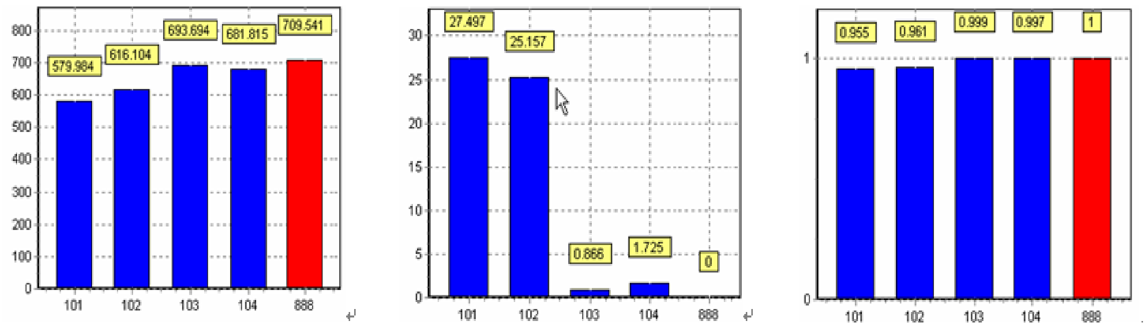

Fig. 4. Testing results of target continuous tracking

5. Conclusion

The purpose of this paper was to propose an index-based testing method in target tracking. A testing prototype system was designed and two indexes on testing the target tracking performance were presented, to evaluate whether an IF system reaches the performance quality requirement. Our discussion was started from a principle and architecture design of our testing & evaluation system. Then the definition & algorithm of testing indexes were proposed. In addition, experimental results were presented, which indicated the feasibility and rationality of our testing method.

Future research will be focused on identifying the measurement indexes that can be used to verify the capability and performance of the proposed T&E system. Meanwhile, lots of other testing indexes would be discussed in order to evaluate other fields of performance in IF systems, such as association accuracy, processing capacity and so on.

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