Fuzzy BP neural network in radar intelligence quality evaluation

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Abstract. This paper presents a novel approach of radar station intelligence quality evaluation which based on fuzzy Backpropagation neural network (BPNN). Firstly, the index system of the radar station intelligence quality evaluation is established according to the analysis of the process, the characteristics, and the main influencing factors of the radar station intelligence production. And then the factor set, comment set and the membership matrix are structured, the fuzzy BPNN for evaluating the quality of the radar station intelligence is designed referring to the index system. Finally, the experiment shows that the accuracy and stability can be improved effectively by using fuzzy BPNN to evaluate the radar station intelligence quality

1. Introduction
The radar station intelligence quality evaluation is the process of analyzing and assessing information about position, velocity, course, quantity, threat level and track estimation of the target in the airspace detected by radars [1]. Its purpose is to discover the main factors that affect the quality of intelligence, and search the bottlenecks and shortcomings that restrict the intelligence support for the next technological innovation and improvement programs. So the research of the evaluation of the intelligence quality of the radar stations has become the important part of the equipment construction and development of the air defense and antimissile radar intelligence support[2,3]. There are three methods used in evaluating the radar intelligence quality at present, as following:

1) Expert evaluation. As in literature [4], the experts from different radar fields evaluate the radar intelligence quality and other performance by analyzing the data from radar intelligence support operation or simulation training.
2) Data analysis. As shown in literature [5] and [6], the evaluation index is described in different aspects respectively according to the intelligence data reported from the radar. Modeling and simulation are carried out to evaluate the radar intelligence support performance and the effectiveness.
3) Combination evaluation. The quality evaluation index is comb out from the radar intelligence production process, as shown in literature [7] and [8], and their value are taken from the measured data, the weight are distributed with AHP method, and then the nonlinear model is used to evaluate the radar intelligence quality.

Otherwise there are lots of research and exploration on the track quality evaluation and information fusion evaluation[9-11]. Nathan S. Dietrich proposed track quality evaluation indicators and calculation methods, and carried out modeling, simulation and analysis in literature [12]. Ali Naseri simulated and contrasted the information fusion algorithms of radar intelligence using mean method, Bayesian method and D-S evidence theory, et al in literature [13]. In literature [14], the evaluation index of
multi-sensor fusion information for netted radar is proposed and different models are made to simulate and analyze the performance of the radar net.

In the above-mentioned methods, qualitative and quantitative evaluation are effectively used. But the multi-factors, such as combatants, target environment, radar equipment status and integrated support that affect the comprehensive evaluation of intelligence quality are insufficient considered, and the practicability is limited. Otherwise, Quantitative evaluation pays more attention to the accuracy of evaluation, while intuition is more cared in qualitative evaluation. And comprehensive consideration them both is less.

Considering above, this paper proposes a radar station intelligence quality evaluation method based on fuzzy BPNN. Firstly, the index system of intelligence characteristics and quality evaluation are analyzed, and then the factor set, comment set and membership matrix are constructed. Finally, the method of combining multi-level fuzzy comprehensive evaluation with BPNN is carried out to estimate the intelligence quality of radar stations. The example shows that the combination of the two evaluation methods can perform better in terms of accuracy, timeliness and credibility.

2. Evaluation indexes system
The evaluation indexes system usually is constructed with its general steps, that is defining evaluation goals, extracting feature attribute, optimization and simplification, and distributing weight, et al[16]. Therefore, the evaluation index system of radar station intelligence quality is constructed according to its production process and main influencing factors. The production process of radar station intelligence is as following: Firstly, single radar searches and finds targets. Then the points data are measured and recorded, and the target tracks are generated referring to the relative condition. Finally, the radar intelligence is produced after the tracks fusion, target recognition, and threat estimating, and will be provided to users. The radar stations should adjust their tasks according to feedback from the users, and the information flow is updated iteratively to provide intelligence support for commanders and command agencies to make optimal decisions.

It can be proved that the main factors which affected the radar stations intelligence quality, usually include equipment's status, operator's skill, target's characteristics and environment, that are complex and interactional. As we know, the radar station intelligence mainly shows the range, orientation, and velocity of the target in the detected area, as well as the numbers, attributes and threat degree of the target identified, and all have measure data to compare with each other. Therefore, the evaluation index system of the intelligence quality is constructed based on the radar station intelligence data and analyzing the main factors. So the first-layer of the evaluation index is extracted according to the main characteristics of the radar station intelligence, such as timeliness, accuracy, integrity, objectivity, continuity and the wrong & missing situation. Furthermore, they can be refined as following:

The timeliness contains detection distance, processing speed and notification speed. The accuracy is determined by azimuth, distance, altitude and velocity error, as well as judgment and miss point rate. The continuity includes target track continuity and intelligence support continuity, expressed by notification density and track missed rate. The integrity mainly includes target integrity, track integrity and factor integrity. The target integrity means the rate of the mastered targets to all of the targets in each batch of intelligence. The track integrity is described as the radar track integrity rate of each target. The factor integrity refers to the elements integrity rate of each batch of reported information. The objectivity mainly inspects whether the radar station intelligence personnel in the process of processing each batch of information is strictly reported the actual data, such as elements, sources, and so on, as required. The wrong & missing situation refer to the statistics of the major errors, leaks, and delays intelligence which lead to bad result. As shown in Table 1.
Table 1 The evaluation indexes

| Objective | Factor sets | Factors | Objective | Factor sets | Factors |
|-----------|-------------|---------|-----------|-------------|---------|
| Timeliness | Radar discovery distance $F_{11}$ | | Continuity $F_3$ | Target track continuity $F_{31}$ |
|           | Processing velocity $F_{12}$ | Information velocity $F_{33}$ | | Information continuity $F_{32}$ |
|           | Information velocity $F_{33}$ | Azimuth error $F_{21}$ | Completeness $F_4$ | Target integrity $F_{41}$ |
|           | Distance error $F_{22}$ | Altitude error $F_{23}$ | | Track integrity $F_{42}$ |
|           | Velocity error $F_{24}$ | Missing track rate $F_{25}$ | | Element integrity $F_{43}$ |
|           | Missing track rate $F_{25}$ | Missing point rate $F_{26}$ | | Essential elements $F_{51}$ |
|           | | | | Sources $F_{52}$ |
|           | | | | The wrong & missing station $F_6$ |
| Quality of EWR | | Intelligence of EWR | | Wrong track rate $F_{61}$ |
| Accuracy $F_2$ | | | | Lost track rate $F_{62}$ |
| | | | | Delay intelligence $F_{63}$ |

3. The radar station intelligence quality evaluation based on BPNN

3.1. Factors set

All of the indicators are normalized to the cost-type and benefit-type. The cost-type indexes mean that the smaller the attribute values are hoped, such as azimuth error, distance error, altitude error, velocity error, missing track rate, missing point rate, wrong track rate, lost track rate delay intelligence, and other indicators. And the benefit-type indexes mean that the attribute values are hoped to be more greater, such as the radar discovery distance, processing velocity, information velocity, target track continuity, information continuity, target integrity, track integrity, elements integrity, objectivity of intelligence sources and elements, and so on. And usually, the cost-type indicators are normalized by formula (1) and the benefit-type indicators are normalized by formula (2).

\[
F_{ij} = \frac{f_{ij} - f_{ij}^{\min}}{f_{ij}^{\max} - f_{ij}^{\min}} \quad (i = 1, 2, \ldots, m)
\]

So the factors set can be constructed based on the above analysis as $F = (F_1, F_2, \ldots, F_m)$, and the factors are independent each other, that is $F_i \cap F_j = 0 (i \neq j)$. The factor subset should be described as $F_i = (F_{i1}, F_{i2}, \ldots)(i = 1, 2, \ldots, m)$, where the $F_i$ is the first layer factor, and the $F_{ij}$ is the second layer factor.

3.2. Comments set

For estimating the intelligence quality intuitively, the comments set is set up using empirical judgment terms, such as excellent, good, qualified, unqualified, general accident, and serious accident, which are expressed as $c_1$–$c_6$ respectively, and the formulas is as following:

\[
C = \{c_1, c_2, \ldots, c_6\}
\]
3.3. Membership Matrix
The membership matrix of evaluation indexes is mainly expressed with the membership degree of each index to the comments set. The membership degree is the support degree of each index to each evaluation result obtained through single evaluation to each index by the expert group. Their values are normalized in the interval of the real number (0,1), and the expression is as following:

\[
T = \begin{bmatrix}
t_{11} & t_{12} & \cdots & t_{1c} \\
t_{21} & t_{22} & \cdots & t_{2c} \\
\vdots & \vdots & \ddots & \vdots \\
t_{m1} & t_{m2} & \cdots & t_{mc}
\end{bmatrix} = (t_{ij})_{m \times c}
\]  

(4)

In Eq. (4), \( t_{ij} \) indicates the degree that factor \( i \) is subordinate to the \( j \) level comment.

3.4. Design BPNN structure
BPNN is one of the most widely used neural network models at present. They are usually composed of input layer, hidden layer and output layer. The hidden layer can be made up of multi-layers. It has been proved that increasing the hidden layers will improve the accuracy of the network, but will lead to the increasing complexity of the network at the same time. However, the accuracy can also be improved by increasing the number of hidden layer neurons. That's why there is only one hidden layer designed in neural network usually. The neurons number of the hidden layer is decided usually by testing different numbers on the premise of solving the problem more effective. The network structure is shown in Fig.1.

As shown in Fig.1, \( P_i \) is the input, and there are \( n \) input layer neurons, \( i \) hidden layer neurons, one output neuron, that is \( k \), and \( a \) is the output.

3.5. Comprehensive evaluation based on fuzzy BPNN
3.5.1. Fuzzy comprehensive evaluation
It's supposed that there are \( m \) batches of radar intelligence need to be evaluated. And the fuzzy comprehensive evaluation approach is usually carried out to evaluate them one by one. For example, when the \( i \)th batch intelligence needs to be evaluated, the weight of the first and second layer indexes are distributed by combining AHP with DELPHI method firstly, referring to the membership matrix. And then the weighted average operator is carried out to evaluate the intelligence quality, and the result should be obtained as following:

\[
B_i = W \begin{bmatrix}
W_{11}T_{11} \\
W_{12}T_{12} \\
\vdots \\
W_{1c}T_{1c}
\end{bmatrix} = (b_{i1}, b_{i2}, \cdots, b_{ic})
\]  

(5)
In Eq. (5), $T_i$ is the membership degree matrix of each index. $W = (\omega_j)$ and $W_j = (\omega_{kj})$ are the weights of the first and second layer indexes. $B_i$ denoted the fuzzy comprehensive evaluation vector.

The method of maximum membership degree can be used to judge the comment level of the radar station intelligence usually depending on the fuzzy comprehensive evaluation vector $B_i$. And the result will be used as the target output of BPNN weight and threshold optimization. While the maximum membership value of $B_i$ is close to sub-maximum value of it, and leads to hard judgement, the asymmetric proximity method can be used to further aggregate the evaluation results and make the results more credible and distinguishable[17].

3.5.2. Training BPNN

The target output of the training data of BPNN is the early radar station intelligence data of the pre-fuzzy comprehensive evaluation. The index value of the radar station intelligence evaluation is taken as the input of the network. The number of neurons in the hidden layer is set as the reference empirical formula, such as $d = \sqrt{n + i + c}$. In this formula, $n$ and $i$ are the numbers of neurons in the input and the output layer respectively, and $c$ is a constant within 0~9. Then the maximum training times, the learning rate, the expected error, the training algorithm, and so on, are set up according the requirement of the evaluation, and the BPNN can be trained. During the training, some parameters should be adjusted to achieve better convergence and smaller error. The trained network can be used to evaluate the later radar station intelligence.

4. Example and Discussion

4.1. Data preparation

As shown in Table 1, there are 19 secondary indicators should be taken as the input layer of the network, and the constant $c = 5$, then $d = 10$, according to empirical formulas. In this paper, the BPNN training and simulation are carried out in Window7 and Matlab20148.3.0. The BPNN toolbox is called, and the parameters are set as following: the training data are set to 50 groups and 500 groups respectively, and the maximum training times are 1000 and 4000. The learning rate is 0.01, the expected error is 0.001, the training algorithm is TRAINLM, and the transfer function is TANSIG. The training performance is shown in figure 2–5.

![Fig.2 Training convergence of 50 sets data](image1)
![Fig.3 Training convergence of 500 sets data](image2)
4.2. Discussion

There are 5 sets of data used to test the trained network, as shown in Table 2.

| Table 2 Comparison results of EWR intelligence quality evaluation |
|---------------------------------------------------------------|
| **Index** | NO.1 | NO.2 | NO.3 | NO.4 | NO.5 |
|---|---|---|---|---|---|
| F11 | 9  | 8  | 6  | 5  | 7  |
| F12 | 9  | 9  | 4  | 5  | 6  |
| F13 | 9  | 10 | 9  | 6  | 7  |
| F21 | 10 | 9  | 5  | 7  | 9  |
| F22 | 9  | 8  | 9  | 6  | 8  |
| F23 | 9  | 10 | 8  | 7  | 6  |
| F24 | 10 | 9  | 4  | 4  | 7  |
| F25 | 9  | 8  | 6  | 8  | 10 |
| F26 | 9  | 9  | 6  | 6  | 6  |
| F31 | 10 | 10 | 8  | 8  | 10 |
| F32 | 10 | 9  | 7  | 6  | 8  |
| F41 | 9  | 9  | 7  | 7  | 4  |
| F42 | 9  | 8  | 7  | 8  | 7  |
| F43 | 10 | 9  | 8  | 9  | 8  |
| F51 | 9  | 9  | 10 | 7  | 8  |
| F52 | 9  | 8  | 8  | 10 | 5  |
| F61 | 9  | 10 | 7  | 8  | 9  |
| F62 | 8  | 8  | 9  | 10 | 6  |
| F63 | 10 | 9  | 9  | 6  | 6  |
| EI  | 9.3062 | 8.8836 | 7.3594 | 6.9833 | 7.6119 |

| Simulation results of 50 sets data | 8.7259 | 8.5091 | 7.1038 | 7.1227 | 7.4522 |
|------------------------------------|--------|--------|--------|--------|--------|
| Simulation results of 500 sets data| 9.1075 | 8.8875 | 7.2573 | 6.9501 | 7.6122 |

1) The intelligence quality evaluation of the radar stations should solve the problems about the intelligence data quality, the effectiveness of intelligence operations and the accuracy of evaluation methods, and so on. However, it just evaluate one single batch of the intelligence quality by using formula (5) only, and it is difficult to form an overall evaluation because of the influence of subjectivity of weight setting and complexity of calculation in each evaluation. Therefore, it is necessary to adopt BPNN method to obtain more reliable and stable evaluation results.

2) It can be seen from fig. 2 and 3, that the results of the fuzzy comprehensive evaluation and the radar intelligence data accumulated earlier can be the training data of the evaluation BPNN. And the
BPNN will be more convergence as the increasing of the accumulated data. The comparison between Fig. 4 and Fig. 5 further illustrates that with the increase of training data and training times, although the training time is prolonged, the network performance is better. At the same time, the increased training time has less impact on the existing radar intelligence quality assessment targets.

3) It shows in Table 2 that the more errors exist in the network simulation results of 50 groups of data training than those of 500 groups. However, the ranking of intelligence quality of each batch of the radar station can be seen basically. It denotes that the BPNN can be used as ranking when the accumulated training data is less, although it has large errors. It also shows that the increasing number of data and training times will make the BPNN more accuracy and stability. It's more intuitive as shown in fig.6.

5. Conclusion

In this paper, a novel evaluation approach which based on the fuzzy BPNN for assessing radar station intelligence quality is proposed. Firstly, the index system of the radar station intelligence quality is constructed by combining with the production process of radar stations intelligence, analyzing the content of the intelligence, and the influencing factors and their mutual relations. They are timeliness, accuracy, continuity, integrity, objectivity, and their sub-indexes, and so on. Then, the weight set about the factors, comments set for ranking the radar station intelligence, and the membership degree matrix of the index to comment are constructed. Finally, the fuzzy BPNN is designed and trained referring to accumulated intelligence data from the radar stations, and the fuzzy BPNN is carried out to simulate and evaluate the intelligence quality of the radar station. The experiment shows that this method can continuously improve the accuracy and stability of radar station intelligence quality assessment. At the same time, the weight distribution of each factor set can be analyzed from the fuzzy BPNN, which can provide some reference for studying the bottleneck factors that restrict the intelligence quality of radar station and improving countermeasures.

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