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An Improved D-S Evidence Theory Method based on Evidence Influence Weight

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Abstract

The D-S evidence theory in Multi-information fusion has been widely used in many fields, there always been controversial in the problem of evidence conflict. Aiming at this problem, this paper proposes an improved D-S evidence theory method based on the weight of evidence influence. First, the influence weight of evidence is calculated by neural network to obtain the internal correlation and influence between evidences; Then import the evidence into the improved DS synthesis rule to obtain the synthesis result; Finally, design simulation experiments to analyze the performance of the method in terms of the number of evidence and conflict problems, and compare it with existing methods. The simulation results show that the improved method has excellent convergence speed when the number of evidences is greater than 4, the trust degree of a single focus element is 0.9359, the degree of concentration of focus element trust is high, and it is less affected by a single high conflict evidence; when the number of evidence is 7, a single focus element has a trust degree of over 0.99, the performance is stable and the robustness is good; The results are greatly improved compared with other methods, which can prove the advancement and effectiveness of this improved method.

Keywords

D-S Evidence Theory; Evidence; Conflict; Weight; Neural Network.

1. Introduction

In military, engineering, mechanical systems and other fields, the identification, judgment and diagnosis of a target often need to use multiple information from the same category or different categories. The process of comprehensive processing and final synthesis of these information is often called information fusion. As an information fusion method, D-S evidence theory is widely used because of its extensive advantages in dealing with defects, anomalies and uncertain information.

The name of D-S evidence theory is dempester Shafer theory, which was produced in the United States in the 1960s. It was proposed by dempester [1] and then perfected by its student Shafer to form a complete theory [2]. Its method of using the upper and lower limits of probability to solve uncertainty is widely used in military [3-4] and engineering [5-6]. Classical D-S evidence theory often produces unrealistic results when dealing with the conflict of multiple information. Therefore, scholars at home and abroad have made a lot of improvements on D-S evidence theory to make it more suitable for all fields of application. The improvements to the problem can be divided into two categories: the first is to improve the D-S synthesis rules; The second is to improve the evidence itself. The first kind of improvement methods mainly include: Yager et al redistribute the evidence, which greatly reduces the possibility of evidence conflict [7]; Sun Quan et al. Improved the synthesis rules on the basis of Yager, and greatly improved the accuracy in the case of multiple evidences [8]; Bao Tiantian and others use the correction of evidence distance to improve the synthesis rules and reduce the degree of conflict between evidences [9]. The second kind of improvement methods mainly include: Deng Yong et al. Put forward the concept of evidence distance according to the internal relationship of evidence and substituted it into D-S synthesis rules for improvement, which completely avoids the occurrence of conflict problems, but the amount of computation is too large and the convergence speed is reduced [10]; Murphy proposed an improved method of average synthesis, which is simple and easy to operate, reduces the conflict between evidences, but destroys the relevance of evidence ontology [11]; Ke Xiaodao et al. Put forward the processing method of relevant evidence based on Zhongxin function and explored the effective acquisition of evidence source information [12]; Duan Wanchun and others solved the problem of expert evaluation conflict by using probabilistic language preference, and put forward specific conflict evidence adjustment methods [13]; Zhang Huan et al. Corrected the evidence in combination with Pearson correlation coefficient, which greatly improved the convergence speed and higher the reliability of the results.

However, the existing improved methods for D-S evidence theory are based on the traditional mathematical model to optimize the algorithm. By changing the synthesis rules or modifying the evidence, it affects the generation of results, reduces or even avoids the occurrence of conflicts, and makes the application of D-S evidence theory more reasonable. With the continuous updating of technology and the vigorous development of computer technology, intelligent algorithms, which are more accurate than traditional mathematical model calculation and more complex depending on powerful computing power, have sprung up. In various industries and technical fields of society, intelligent algorithms have shown great advantages, progressiveness and intelligence. In the past, the evidence of D-S evidence theory basically comes from a priori knowledge and depends on expert experience. Too many human factors and contingency have brought inevitable problems. Using neural network + D-S evidence theory, starting with D-S synthesis rules, the problem is avoided at a certain level on the evidence level, and the whole calculation model is more intelligent and accurate.

This paper mainly aims to improve the relationship between evidences. By analyzing the problems existing in the principle of D-S evidence, this paper puts forward the correction of the influence weight of evidence. The weight relationship between the input and output of neural network is used to obtain the correlation relationship between the evidences, so as to obtain the influence weight of a single evidence, and then the influence weight is introduced into the D-S synthesis rule to fully reflect the correlation between the evidences in the synthesis process. Then the evidence is introduced into the improved synthesis rule, and all the evidences are fused and calculated. Finally, the simulation analysis experiment verifies that the improved method is based on the number of evidences Conflict problems and other aspects of performance.

2. Theoretical Knowledge

2.1 D-S Evidence Theory

D-S evidence theory is a common mathematical method of information fusion. It has extensive advantages in dealing with defects, anomalies and uncertain information. It divides the research of a complete proposition into the research of several sub propositions, sets rules for synthesis and decision-making, and has been widely used in the field of multi-attribute fusion evaluation. Compared with probability theory and Bayesian method, D-S evidence theory can solve the problems of "uncertainty" and "ignorance". It is expressed directly by using the basic probability function without giving a complete a priori probability and conditional probability, and all evidence can be given confidence, which is similar to the process of human collecting evidence.

The advantages of D-S evidence theory mainly include the following aspects:

(1) The constraints are relatively loose compared with Bayes theory, and there is no need to describe the process of obtaining probability.

(2) It has the advantage and ability to directly describe "uncertainty" and "don't know".

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(3) Evidence from different levels can be fused and synthesized continuously, so as to reduce the hypothesis set.

(4) It can be well combined with other methods, such as rough set theory, neural network, support vector machine, Bayesian method and so on.

D-S evidence theory solves the result trust distribution to the target through the basic probability assignment function from different references. The main concepts and function expressions are as follows.

In D-S evidence theory, the recognition framework "Θ" is used to represent the proposition set of the selected target. The finite problems contained in the target are solved as the propositions of the recognition framework, and they are incompatible and independent of each other. Therefore, they can be defined $m:2^{\Theta}\rightarrow[0,1]$,and satisfied:

$$\begin{cases} m(\varnothing)=0 \\ \sum\limits_{A\subset\Theta} m(A)=1 \\ m(A)\geq 0 \end{cases} \tag{1}$$

Then the function m is called the basic probability assignment function on the power 2^{Θ} set,which A is called the basic probability assignment function on $m(A)$. The value of $m(A)$ reflects the degree of trust in A .Equation (1.1) shows that in the recognition framework, the basic reliability of empty set is 0;The sum of the credibility of all propositions is 1;The subset A is consistent $m(A)\geq 0$ and A is called the focal element of the function m .

For the recognition framework "Θ", where A is a subset of Θ, meet $A\subseteq\Theta$, $m:2^{\Theta}\rightarrow[0,1]$. For $\forall A\in 2^{\Theta}$, comply with:

$$Bel(A)=\sum_{B\subseteq A} m(B) \tag{2}$$

It is called $Bel:2^{\Theta}\rightarrow[0,1]$ the reliability function on the recognition framework Θ, which B represents the sum of the basic probability values of all subsets in the A. It is also defined Bel as the lower bound function, indicating complete trust in A.

For the recognition framework Θ, where A is a subset of Θ, meet $A\subseteq\Theta$, $m:2^{\Theta}\rightarrow[0,1]$. For $\forall A\in 2^{\Theta}$, comply with:

$$Pl(A)=1-Bel(\overline{A}) \tag{3}$$

It is called $Pl:2^{\Theta}\rightarrow[0,1]$ the likelihood function on the recognition framework Θ, that is A, the likelihood of, indicating that the sum of the probability of A not rejecting the proposition , Pl is also defined as the upper bound function.

As shown in Figure 1, the uncertainty of focal element A can be expressed by reliability function and likelihood function, and the uncertainty interval of A can be expressed as $[Bel(A),Pl(A)]$,that the value in this interval indicates that focal element is neither supported nor rejected A, which is an uncertainty interval; The interval of $[0,Bel(A))$ represents the complete trust focal element A, which is the trust interval; The interval of $(Pl(A),1]$ indicates that the focal element A is completely rejected, which is the rejection interval.

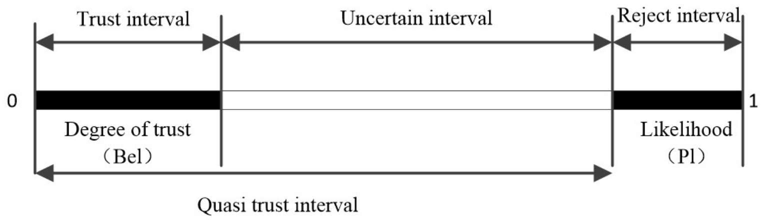

Figure 1. Trust interval division

In practical problem application, the basic assignment function obtained for the target may come from multiple references. In order to make the reasoning and calculation more accurate, the basic probability assignment functions of different reference systems under the same recognition framework will be combined. This method is called orthogonal sum operation, also known as Dempster Shafer synthesis rule, that is, D-S synthesis rule.

Let m_i ($m_i = 1, 2, ...n$) be the basic probability assignment function of the i group of evidence under the recognition framework Θ. When only two groups of evidence are synthesized, the synthesis rule is:

$$m(A) = m_1(A) \oplus m_2(A) = \frac{\sum_{A_i \cap B_j = A} m_1(A_i) m_2(B_j)}{K} \tag{4}$$

$$K = 1 - \sum_{A_i \cap B_j = \varnothing} m_1(A_i) m_2(B_j) \tag{5}$$

Where is the K conflict coefficient between the two groups of evidence, representing the degree of $m_1(A)$ conflict with the evidence $m_2(A)$; At that time $K \neq 0$, there was an orthogonal sum between the two sets of evidence; When $K = 0$, it shows that the two sets of evidence are contradictory and there is no orthogonal sum.

When the number of synthetic evidence is greater than 2, the synthesis rule is:

$$m(A) = m_1(A) \oplus m_2(A) \oplus ... m_n(A) = \frac{\sum_{\cap A_i = A} \prod_{i=1}^{n} m_i(A_i)}{K} \tag{6}$$

$$K = 1 - \sum_{\cap A_i = \varnothing} \prod_{i=1}^{n} m_i(A_i) = \sum_{\cap A_i \neq \varnothing} \prod_{i=1}^{n} m_i(A_i) \tag{7}$$

2.2 The Problem

D-S evidence theory can express uncertainty. When the probability of proposition cannot be determined and specific and clear probability cannot be obtained through prior knowledge, D-S evidence theory is undoubtedly an effective solution, but its trust in a focal element in the evidence source set conflicts with conventional cognition. It is mainly manifested in the problems of "complete conflict" and "consistency of evidence".

There is a sample space $\Omega = \{A, B, C\}$. The existence m_1, m_2, m_3 and m_4,four groups of evidence of the sample space are as follows:

$$m_1 : m_1(A) = 0.5 \quad m_1(B) = 0.3 \quad m_1(C) = 0.2$$

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$$m_2 : m_2(A) = 0.6 \quad m_2(B) = 0.2 \quad m_2(C) = 0.2$$
$$m_3 : m_3(A) = 0 \quad m_3(B) = 0 \quad m_3(C) = 1$$
$$m_4 : m_4(A) = 0 \quad m_4(B) = 0.5 \quad m_4(C) = 0.5$$

By substituting m_1 and m_2 into equations (6) and (7), we can obtain $K=0.4$, $m(A)=0.75$, $m(B)=0.15$, $m(C)=0.1$, and then synthesize m_3 with the result, we can find $K=0.1$, $m(A)=m(B)=0$, $m(C)=1$, which shows that the "complete trust" in the focal element in the evidence m_3 makes the synthesis result also fully trust the focal element C. From the analysis of the synthesis m_1, m_2 and m_4 .result is $K=0.125$, $m(A)=0$, $m(B)=0.6$, $m(C)=0.4$,although the proposition is supported as a whole, the result is completely negative, which is caused by the evidence m_4's "0 complete negation" of A. In the conflict problem, when the support of a focal element in the evidence is 0 or 1, no matter how supported by other evidence, the evidence has the phenomenon of "one vote veto" or "one vote support", that is, this group of evidence is completely contradictory to other evidence, making the final result directly become 0 or 1.

At the same time, in the process of multi group evidence synthesis, there will be the same basic assignment function of two or more evidences to the focal element. In the process of synthesis, the evidence is "consistent in size" and there is no distinction, which is inconsistent with the actual situation, that is, the unreasonable situation that D-S evidence cannot distinguish the size of the same evidence.

The main reasons for the above problems can be summarized as follows:

(1) Uncertainty of information source data. D-S evidence theory has the ability to deal with uncertain problems, but the uncertain factors may be environmental factors or human factors, which is often the source of evidence conflict.

(2) Identify the cognitive limitations of the framework. The determination of target recognition framework is a mutually exclusive event that people confirm and divide based on common sense. Its uncertain probability is all attributed to the complete set, which is also one of the factors causing the conflict.

(3) The inaccuracy of the mathematical model of the basic trust function. In practical application, there are too many uncertainties in confirming the trust function of the target through different evidence, which can not be converted into an accurate, reasonable and reliable function, resulting in conflict in the synthesis of evidence, resulting in deviation or even contradiction between the result and the actual situation.

D-S evidence theory is not wrong as a mathematical formula, but there will be various situations described above in its application. Therefore, it is necessary to optimize the evidence and make the result more accurate on the premise of overcoming special situations.

3. Improved D-S Evidence Theory

According to the above discussion, the uncertainty of evidence source is the main reason for the abnormal synthesis results. An improved D-S evidence theory method based on the influence weight of evidence is proposed to change the problems of conflict and abnormality through the correction of evidence. The method of determining the influence weight of evidence by neural network is used to explore the correlation between evidences, and then the influence weight is combined with D-S synthesis rules. When the evidence is synthesized, it is calculated according to its influence weight coefficient to obtain the improved results.

Neural network algorithm is a network composed of a large number of neurons by simulating the principle of human neural transmission. It mainly realizes the processing and storage of complex information. As shown in Figure 2, the neuron A_j receives the input information from the upper layer $X_1 \ldots X_i \ldots X_n$, takes the weight w as the connection coefficient, and then A_j continues to

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transmit the result O_j until it converges to the result. The figure T_j shows the threshold of neurons A_j, f is the neuron transfer function.

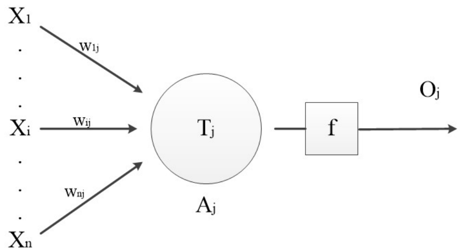

Figure 2. Neuron diagram

Connecting neurons is to form a multilayer neural network, which is generally divided into input layer, hidden layer and output layer. Set the input layer as $X = [x_1, x_2 ... x_i ... x_n]^T$, the hidden layer as $Y = [y_1, y_2 ... y_i ... y_n]^T$, and the output layer as $Z = [z_1, z_2 ... z_i ... z_n]^T$.

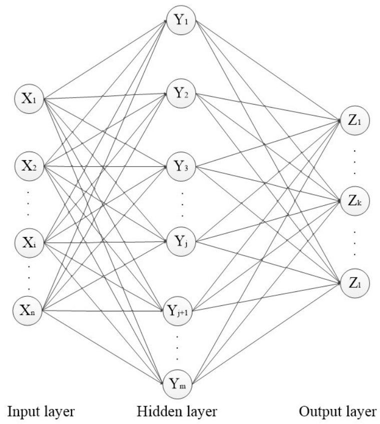

Figure 3. Neural network diagram

In order to obtain the influence relationship between input and output, analyze the neural network algorithm, explore the influence weight of input x_i on output z_k, analyze the neural network weight w, respectively consider the influence of input layer on hidden layer F_{ij} and hidden layer on output layer F_{jk}, and finally calculate the influence weight from input layer to output layer F_{ik}.

The influence of the input neuron relative to the hidden neuron is expressed as:

$$F_{ij} = \frac{|w_{ij}|}{\sum_{i=1}^{n} |w_{ij}|} \quad i = 1, 2 ... n; j = 1, 2 ... m \tag{8}$$

The influence of the hidden neuron relative to the output neuron is expressed as:

$$F_{jk} = \frac{|w_{jk}|}{\sum_{j=1}^{m} |w_{jk}|} \quad \mathrm{j} = 1, 2 ... m; \mathrm{k} = 1, 2 ... l \tag{9}$$

The influence of the input neuron on the output neuron can be obtained from equations (8) and (9):

$$F_{ik} = \sum_{j=1}^{m} F_{ij} \times F_{jk} \quad i = 1,2...n; j = 1,2...m; \mathrm{k} = 1,2...l \tag{10}$$

The influence weight of the input parameter to the output parameter can be obtained by normalizing the influence:

$$q_i = \frac{F_{ik}}{\sum_{i=1}^{n} F_{ik}} \quad i = 1,2...n; \mathrm{k} = 1,2...l \tag{11}$$

q_i represents the influence weight of a single evidence in the whole evidence body. When importing the D-S synthesis rule, considering normalization, it needs to be adjusted to obtain the influence weight coefficient:

$$Q_i = q_i \times n \tag{12}$$

According to the neural network iteration, the influence weight coefficient of the input parameters on the output parameters is obtained. Combined with the D-S synthesis rule, that is, the evidence support of each evidence to the focal element A is different, and its judgment is determined by the influence weight, which Q_i can be obtained by substituting into equations (6) and (7).

$$m(A) = Q_1 m_1(A) \oplus Q_2 m_2(A) \oplus ... Q_n m_n(A) = \frac{\sum_{\cap A_i = A} \prod_{i=1}^{n} Q_i m_i(A_i)}{K} \tag{13}$$

$$K = 1 - \sum_{\cap A_i = \varnothing} \prod_{i=1}^{n} Q_i m_i(A_i) = \sum_{\cap A_i \neq \varnothing} \prod_{i=1}^{n} Q_i m_i(A_i) \tag{14}$$

By fusing multiple evidences according to formula (13), we can obtain the trust of the evidence to each focal element in the recognition framework and obtain the final synthesis result.

4. Simulation and Analysis

In order to verify the rationality and robustness of the improved method studied in this paper, it is necessary to design reasonable experiments to simulate and analyze the improved method in terms of evidence quantity, conflict problem and comprehensive performance.

(1) Evidence experiment

With the increase of evidence, the conflict coefficient will become larger and larger, and the increase of evidence is actually the process of increasing support for a focal element. Set the identification framework $\Theta = \{A, B, C\}$, in which the events are mutually exclusive events, the evidence source $m_1, m_2 ... m_{10}$, and the trust of standard evidence to the focal element in the identification framework is $m_0 = \{0.5\ 0.3\ 0.2\}$. The basic probability values of 10 groups of evidence sources for focal elements are as follows, in which m_9 "0 complete negation" and "1 complete trust" conflict evidence m_{10} is the evidence consistent with the size of the evidence m_8.

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Table 1. Basic Assignment Probability of Evidence

	A	B	C	Influence weight
m_1	0.5853	0.3791	0.0357	0.15
m_2	0.1680	0.5756	0.2565	0.08
m_3	0.2591	0.3936	0.3473	0.09
m_4	0.7387	0.1461	0.1151	0.17
m_5	0.5560	0.2960	0.1480	0.13
m_6	0.2870	0.5881	0.1249	0.06
m_7	0.2893	0.5814	0.1293	0.07
m_8	0.5462	0.2728	0.1810	0.12
m_9	0	1	0	0.03
m_{10}	0.5462	0.2728	0.1810	0.1

In order to explore the relationship between the improved method and the amount of evidence, the evidence is gradually increased from less to more, and the evidence is synthesized. In order to avoid the influence of the order of evidence synthesis on the experiment, the evidence is randomly arranged for three experiments. The order of the first experiment is: 1-2-3-4-5-6-7-8; The order of the second experiment is: 4-6-1-3-7-2-8-5; The order of the third experiment is: 7-3-2-5-6-1-4-8.

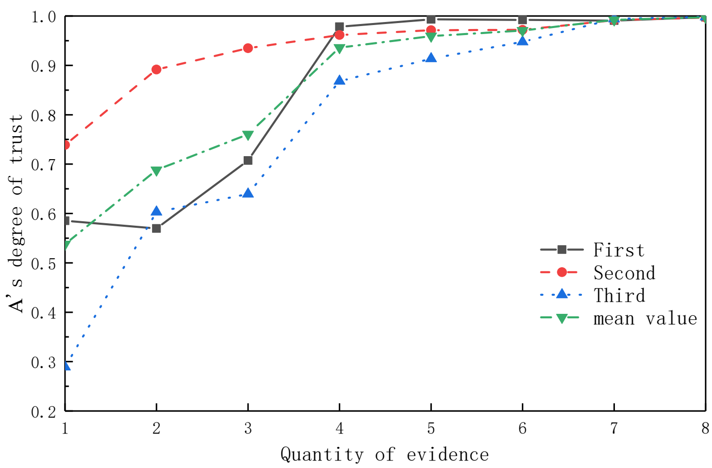

Figure 4. The relationship between the amount of evidence and A 's trustworthiness

It can be found from Figure 4 that with the increase of the number of evidence, the trust of the synthesis result in the focal element A gradually increases and approaches 1. After the number of evidence is 4, the rising trend of trust tends to be flat, the highest trust is 0.9782 for the first time, the lowest trust is 0.8681 for the third time, and the average trust is 0.9359, indicating that the improved method has strong robustness and significantly reduces the dependence on a single evidence when the number of evidence is greater than or equal to 4; When the number of evidence reaches 7, the degree of trust in has reached more than 0.99, indicating that A has been fully trusted. By changing the order of evidence synthesis, it can be found that when the number of evidence is less than 4, the result of evidence is greatly affected by a single evidence, but the overall support of Jiao yuan

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increases with the increase of the number, which is consistent with the reality, indicating that with the increase of evidence, the process of gradually trusting A . The comparison of three experiments shows that when the number of evidence is less than 4, the improved method has requirements for the sequence of evidence synthesis, and the synthesis result is greatly affected by the initial evidence. When the evidence is greater than or equal to 4, the synthesis result tends to be stable and less affected by a single evidence.

(2) Conflict problem experiment

The original D-S evidence theory has the problem of trust conflict, that is, a certain evidence completely trusts or negates A . Replace the evidence m_9 with m_1 to m_8 one by one, obtain the comparison of the synthetic results, and carry out the simulation analysis of the ability of the improved method to solve the problem of trust conflict.

Table 2. The trust degree of focal element A before and after replacement m_9

Replace	Have m_9	No m_9	**Error ratio**
m_1	0.9954	0.9951	0.03%
m_2	0.9977	0.9978	0.02%
m_3	0.9964	0.9967	0.02%
m_4	0.9824	0.9837	0.14%
m_5	0.9944	0.9950	0.06%
m_6	0.9968	0.9972	0.03%
m_7	0.9972	0.9975	0.03%
m_8	0.9931	0.9938	0.07%

It can be seen from table 2 that in the improved method, when the number of evidence is greater than or equal to 7, the trust conflict between "0" and "1" in the evidence does not have much impact on the synthesis results, and the maximum error ratio is only 0.14%. Although m_9 is "complete negation" to A and "complete trust" to B , due to its small influence weight, the influence weight of other evidence on A is increased, The trust of A increases slightly. Experiments show that the improved method can well solve the trust conflict problem of the original D-S evidence theory, and has a good tolerance for abnormal evidence.

For the problem of evidence failure, its essence is that the basic assignment probability functions of the two evidences on the focal element are consistent, resulting in the evidence regardless of size. Now it will be fused m_8 with the completely consistent ones m_{10}, and the improved method will be used to compare whether there are changes before and after.

Table 3. the trust of focus element A before and after Increase m_{10}

	Have m_{10}	No m_{10}	**Error ratio**
$m_1 \sim m_8$	0.9972	0.9992	0.15%

According to table 3, the synthesis results are inconsistent, which indicates that the evidence m_{10} is not invalid in the synthesis results, and the focal element is supported again because of the emergence of the same basic probability assignment function, which increases the trust of the focal element A ,

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which is in line with the actual situation. Experiments show that the improved method can avoid the case of consistent evidence size. Different evidence has the same basic assignment probability, but its influence weight is different in evidence fusion, so as to avoid the problem of "consistent evidence size".

(3) Comparative experiment

By investigating different examples of improved D-S evidence theory, the simulation analysis experiment of comparing the improved example with the improved method is carried out. The improved examples involved in the comparison are: traditional D-S evidence theory [2], Yager method [7], Deng Yong method [10], Murphy method [11], Duan Wanchun method [13], Kang Jian method [15] and this method.

Table 4. m_1, m_2, m_3, m_4 fusion results under different methods

method	A	B	C	Θ
D-S evidence theory	0.5965	0.3977	0.0116	0
Yager method	0.0012	0	0	0.9988
Deng Yong method	0.6816	0.2439	0.0745	0
Murphy method	0.782	0.2096	0.0084	0
Duan Wanchun method	0.8473	0	0.0001	0.1526
Kang Jian method	0.7137	0.286	0.0003	0
this method	0.9782	0.0217	0	0

It can be seen from table 4 that the method in this paper has the highest trust in A, very low trust in B, and completely denies C and Θ. Compared with other methods, this method has the most concentrated trust, that is, it has a high concentration of trust in Jiao yuan, which is consistent with the initial setting. Although the traditional D-S method, Murphy method, Deng Yong method, Kang method and Duan Wanchun method have high trust in A, they still have partial trust in B and the whole set Θ. Yager method and Duan Wanchun method assign partial trust to the complete set, indicating that they do not know which focal element to assign. Compared with other methods, this method can judge the synthesis results more accurately, and there is no case that the trust is assigned to the complete set.

5. Conclusion

Based on the original D-S evidence theory, BP neural network is used to improve the D-S evidence theory. The influence weight is used to reduce the conflict between evidences, and an improved D-S evidence theory method based on the influence weight of evidence is obtained. The improved method combining neural network and D-S evidence theory is excellent in dealing with evidence conflict. The internal relationship between evidences is shown in the synthesis process, so that the synthesis result is not affected by a single abnormal evidence. When the amount of evidence is greater than 4, the convergence speed is fast, and when the amount of evidence is 7, the trust degree of a single focal element has exceeded 0.99; Compared with other existing improved methods, the trust of this method is more concentrated and not assigned to the complete set. Under the condition of reducing evidence conflict, the result can be judged more accurately and intensively.

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