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Data Fusion Algorithm Based on Fuzzy Logic *

Hao Ding, Haifeng Ji, Zhiyao Huang and Haiqing Li

National Laboratory of Industrial Control Technology, Department of Control Science and Engineering
Zhejiang University
Zhejiang University, Hangzhou 310027, P.R.China
E-mail：hding@iipc.zju.edu.cn

Abstract - Based on fuzzy logic theory, a new data fusion method for target identification using D-S evidence theory (Dempster-Shafer theory) is presented. By acquiring signals from multiple sources, the belief function assignment value of each transducer is obtained from extracted eigenvalue by using fuzzy logic. The fusion belief function assignment is received by using D-S evidence theory. To solve the problem of combing evidences with high degree of conflict, a modified D-S evidence theory combination rule is introduced. The problem of inconsistent evidence is handled using the method. More accurate result of target identification can be obtained. A comparison of the results of target identification based on separate original data with those based on fusion data shows that the accuracy of target identification is increased.

Index Terms - Data fusion, fuzzy logic, D-S evidence theory.

I. Introduction

Multi-sensor data fusion is defined as the process of integrating information and data from multiple sources to produce the most specific unified data [1, 2, 3]. The process is supposed to obtain more accurate and efficient meaningful information that may not be possible from a single sensor alone [4, 5, 6, 7]. D-S evidence theory is an efficient method processing uncertain information in data fusion, but the combination result may be unacceptable if the evidences highly conflict with each other [8]. In the presented work, a modified combination rule of D-S theory is proposed to solve the problem of evidences with confliction, which is related evidence focus to the amount of useful information of evidences. Fuzzy logic provides a new tool to solve the uncertain problem and describe the fuzzy characteristics of target. Especially, fuzzy logic is fit for describing and processing the uncertain information from multiple sensors [9]. In this work, a novel data fusion algorithm combining the two methods mentioned is proposed. The target is easily recognized based on the new fusion algorithm. The simulation demonstrates that the performance of target identification is improved.

II. Multi-sensor data fusion algorithm

A. *Belief Function Assignment*

Belief function assignment is a reasoning method that represents the belief degree of supposed type of target. There are many different formulas of belief function assignment, but the impact of the number of targets is not considered in most formulas [10, 11, 12]. In this work, the number of target is introduced to the construction of belief function assignment. Therefore, belief function assignment value $m_i(q_j)$ can be written as the following form:

$$m_i(q_j)=\frac{C_i(q_j)}{\sum_{j=1}^{n}C_i(q_j)+N(1-R_i)(1-\alpha_i\beta_i\omega_i)} \quad (1)$$

where α_i is the maximal correlation coefficient of the i-th sensor; $C_i(q_j)$ is the correlation coefficient between i-th sensor and type of target q_j; N_c is the number of type of target; N is the sum of the sensors; β_i is the correlation assignment value; R_i is the reliability coefficient of i-th sensor; ω_i is the environment weight coefficient, its range of set is $[0,1]$ which can be obtained according to the property of sensor and the expert experiences. $C_i(q_j)$ may be replaced with subordinate degree value μ_{ij}.

There is no any specific criterion of definition of subordinate degree value, so subordinate degree value related to the properties of sensor and the parameter measured is obtained according to expert experiences. In this work, the most common trapezoid function is selected as the subordinate degree function to analyse the simulation results. The subordinate degree value of each fuzzy set is calculated as the following equation:

$$\mu_{A_i}(x)=\begin{cases}\dfrac{x}{\min_i} & 0\le x_i\le \min_i\\ 1 & \min_i<x<\max_i\\ \dfrac{1-x}{1-\max_i} & \max_i\le x\le 1\end{cases} \quad (2)$$

where $[\min_i,\max_i]$ denotes the main distribution range of the eigenvalue extracted from signal of target, i ($1\le i\le n$) $i=1,2,\cdots n$ denotes some specific type of target.

B. *D-S Combination Rules*

Theorem 1 (D-S combination rules): U is defined as a set in which the elements are all possible combination of the elements in X, all elements in U are incompatibility, then

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U is defined as identification frame of X. Assuming that m_1 and m_2 are two independent belief function assignment of U, and after combined, the belief function assignment is $m = m_1 \oplus m_2$, supposing that two belief function BEL_1 and BEL_2 belong to the same identification frame U, so m_1 and m_2 are the corresponding belief function assignment respectively, $A_1, \cdots, A_i$ and $B_1, \cdots, B_j$ are the corresponding focuses.

Here introduce a new function as follows:

$$K = \sum_{\substack{i,j \\ A_i \cap B_j = \phi}} m_1(A_i) m_2(B_j) < 1 \tag{3}$$

then

$$m(C) = \begin{cases} \dfrac{\sum_{\substack{i,j \\ A_i \cap B_j = C}} m_1(A_i) m_2(B_j)}{1-K} & \forall C \subset U \quad C \neq \phi \\ 0 & C = \phi \end{cases} \tag{4}$$

where, if $K \neq 1$, a fusion belief function assignment value is confirmed; if $K = 1$, m_1 and m_2 are contradiction, therefore the two belief function assignments can not be combined.

Theorem 2 (conflict evidence combination rules): There exist drawbacks in D-S combination rules. For instance, the combination result may be unacceptable if the evidences highly conflict with each other [13]. When the conflict evidences are combined, the D-S combination rules must be modified. In combination rules, the evidence weight can focus on smaller subsets or larger subsets if needed, and the algorithm can determine the focused weight according to the size of subsets.

Supposing a new function as in the following:

$$s = \frac{\|A_i \cap B_j\|}{\|A_i\| + \|B_j\| - \|A_i \cap B_j\|} \tag{5}$$

where $\|\cdot\|$ is the cardinality of set, which denotes the coefficient of focalizing down.

If $K \neq 1$ and $A_i \cap B_j \neq 0$, then two evidences are combined as follows:

$$m(A_i) = m_1(A_i) \times m_2(B_j) \times \frac{1-s}{1-K} \times \frac{m_1(A_i)}{m_1(A_i) + m_2(B_j)} \tag{6}$$

$$m(B_j) = m_2(A_i) \times m_2(B_j) \times \frac{1-s}{1-K} \times \frac{m_2(B_j)}{m_1(A_i) + m_2(B_j)} \tag{7}$$

If $K = 1$, the combination equation is given by:

$$m(A \cup B) = m_1(A) \times m_2(B) \tag{8}$$

The modified combination rules are capable of handling inconsistent evidence and related evidence focusing to the amount of information resident in pieces of evidence. So the combination results based on the new combination rules are more reasonable.

C. Decision-Making Rules

After the belief function assignments combined, the decision-making rules based on the belief function assignment value are introduced to achieve the final identification result. The process of decision-making can be written in the following form.

Assuming $\exists A_1, A_2 \subset U$ satisfies the equation below.

$$m(A_1) = \max\{m(A_i), A_i \subset U\} \tag{9}$$

$$m(A_2) = \max\{m(A_i), A_i \subset U, A_i \neq A_1\} \tag{10}$$

$$\text{if} \begin{cases} m(A_1) - m(A_2) > \varepsilon_1 \\ m(U) < \varepsilon_2 \\ m(A_1) > m(U) \end{cases} \tag{11}$$

where ε_1 and ε_2 are the threshold values, A_1 is the final identification result.

III. DATA FUSION OF TARGET IDENTIFICATION

The identification capability of each single sensor is limited because the field environment influences the performance of sensors, and the target is easily recognized in terms of the information from multiple sources, so the method of data fusion may be applied effectively to target identification. After the related signals are acquired from multiple sensors, the eigenvalues of signals are extracted, and the each eigenvalue is transformed into subordinate degree value through subordinate degree function that is constructed according to practical background. The subordinate degree value is regarded as the correlation coefficient of belief function assignment value of each sensor. Therefore, the belief function assignment may be calculated and combined using (1) and the correlation coefficient obtained. On the basis of fusion result and decision-making rule, the type of target can be identified. The process of multi-sensor target identification is shown in Fig.1.

IV. ANALYSIS RESULTS AND DISCUSSION

In order to demonstrate the validity of the data fusion algorithm, an example of multi-sensor data fusion is given.

Assuming that four sensors are used to identify the type of plane in the air. Supposing that $U = \{o_1, o_2, o_3\}$ is an identification frame, where o_1, o_2 and o_3 are used to describe the fighter plane, bomber plane and civil aircraft respectively, and U is the belief function assignment of uncertainty. Because the type of target is stochastic and fuzzy, the belief function can be defined as the method mentioned above.

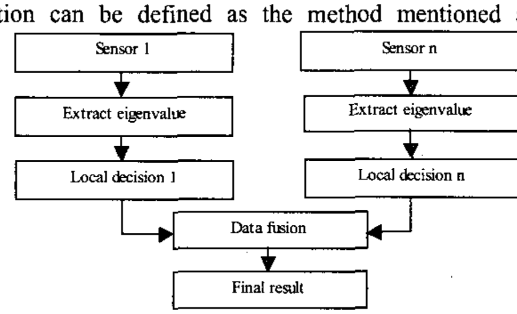

Fig. 1 The process of target identification

Supposing that the belief function assignment values are shown as Table I.

TABLE I
BELIEF FUNCTION ASSIGNMENT OF THE TARGET TYPE

	o_1	o_2	o_3	U
m_1	0.20	0.60	0.10	0.10
m_2	0.50	0.25	0.15	0.10
m_3	0.00	0.00	0.00	1.00
m_4	0.00	1.00	0.00	0.00

Where $m_i(\cdot)$ denotes the belief function assignment value based on the eigenvalue of measurement signals. From Table I above, we can see that there exists confliction between the evidence from sensor 3 and from sensor 4. Then according to the foregoing conflict evidence combination rules, firstly, the two evidences acquired from sensor 3 and sensor 4 respectively are combined. m_5 is shown as Table II, which denotes the belief function assignment value after combined.

TABLE II
THE COMBINATION RESULT

	o_1	o_2	o_3	U
m_5	0.00	0.667	0.00	0.333

Secondly, $m_1(\cdot)$ and $m_2(\cdot)$ acquired from sensor 1 and sensor 2 respectively are combined. m_6 denotes the belief function assignment value after the two evidences from sensor 1 and sensor 2 are combined. The combination result is shown as Table III.

TABLE III
THE COMBINATION RESULT

	o_1	o_2	o_3	U
m_6	0.374	0.516	0.088	0.022

Then according to the combination rules (D-S combination rules), the fusing result of the evidence m_5 and the evidence m_6 is shown as Table IV.

TABLE IV
THE COMBINATION RESULT

	o_1	o_2	o_3	U
m	0.180	0.768	0.042	0.010

From Table IV above, we can see that the belief function assignment value of uncertainty is dropped to 0.01 by data fusion technology. At last, on the basis of the result of data fusion, the method of decision-making based on belief function assignment value is used to obtain the final identification result of the type of plane. In the work, $\varepsilon_1 = \varepsilon_2 = 0.3$ is selected as the threshold value, according to the previous decision-making rules, o_2 is the final result of identification, namely the type of plane detected is bomber plane. Table V shows the final identification accuracy of this research.

TABLE V
ACCURACY OF IDENTIFICATION

	Fighter plane	Bomber plane	Civil aviation
Single sensor	90%	80%	85%
Multi-sensor data fusion	97%	92%	87%

From Table V above, we can see that the usage of data fusion technology based on D-S evidence theory and fuzzy logic can effectively improve the capability of target identification and increase the accuracy of identification.

V. Conclusions

This paper proposes a new data fusion algorithm based on fuzzy logic and D-S evidence theory. In the new algorithm, a modified combination rule of D-S theory is introduced, which can solve the problem of evidences with confliction. In order to verify the data fusion algorithm, an example of target identification system is provided. The analysis results above show that the new data fusion algorithm is effective, and improves the accuracy of identification relative to the only usage of a single sensor.

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