Proceedings of the 2015 International Conference on Machine Learning and Cybernetics, Guangzhou, 12-15 July, 2015

Information fusion in multi-source fuzzy information system with same structure

JIANHANG YU[1], WEIHUA XU[1,2]

[1]School of Mathematics and Statistics, Chongqing University of Technology, Chongqing 400054, P.R. China
[2]The Key Laboratory of Intelligent Perception and Systems for High-Dimensional Information,
Nanjing University of Science and Technology , Ministry of Education, Nanjing 210094, P.R. China
E-MAIL: yujh2013@foxmail.com, chxuwh@gmail.com

Abstract:

With the arrival of the information age, information fusion technology have become more and more important in the field of information service. The main goal of information fusion is to combine different sources information to obtain a single composite of the potential comparable alterative solutions. Multiple information sources can forms an information box if they have same structure, namely, there are same object set and same attribute set. The information fusion is a process from an information box to an information table. In this paper, we proposed two approaches for fuzzy information fusion in multi-source environment with same structure. Furthermore, a case about expert evaluation are carried out to verify the proposed fusion ways and using the fuzzy rough accuracy to test the fusion approaches.

Keywords:

Fuzzy information fusion; Same structure; Information box; Fuzzy rough accuracy

1. Introduction

In the information time, huge amounts of data can be collected then information fusion have become the research focus point in the field of information technology. Data fusion is a wide concept and serval definitions have been proposed in many literatures [1, 5]. In general, the data fusion is an process of aggregating data from multiple sources into a single composite with higher information quality. It can be viewed from different perspectives by different domains, being the most common branches: image fusion, multi-sensor fusion and information fusion. The information fusion theory was first used in the military field. It is defined as a multi level and multi aspects process which deal with probe, the Internet, estimation and combination of multi-source information and data. In order to obtain the accurate state of battlefield situation and identification, complete and timely and threat assessment. With the process of Internet mass information, information fusion has received more and more attentions from related fields. The multi-source information fusion is one of the most important part to the information service in the huge data age and many productive achievements have been obtained. Usually, the multi-source information can be divided into isomeric information, heterogeneous information and multi-lingual information. There are many research works on multi-source information fusion. For example, applying the multi-source information to drilling engineering geological characteristic parameter prediction is becoming one of the most significant research areas. Ma researched formation drillability prediction based on multi-source information fusion [4]. Cai et al. investigated the multi-source information fusion based fault diagnosis of ground-source heat pump using Bayesian network [2]. Ribeiro et al. study an algorithm for data/information fusion, which includes concepts from multi-criteria decision-making and computational intelligence, specially, fuzzy multi-criteria decision-making and mixture aggregation operators with weighting functions [8].

Information system is the information form of expression and the basis structure of the information fusion. One information system is a data table that describes the relationships between objects and attributes. There are a lot of uncertainty in the process of information fusion. The rough set theory are usually used to uncertainty measure in information table. Rough set theory which was first proposed by Pawlak in 1980s, is one of the effective mathematical tools for data analysis and knowledge discovery. In the reality application, there are a lot of information systems in which knowledge attributes are vague or ambiguous. To describe this kind of information precisely we need to rely on fuzzy sets theory. The theory of fuzzy sets was proposed by Zadeh in 1965, is an extension of classical crisp set theory for the study of intelligent systems characterized by fuzzy information [14]. It has been one of the major tools in

978-1-4673-7220-6/15/$31.00 ©2015 IEEE

the field of intelligent information processing. If each attribute induces a fuzzy set on the sample space, we call this kind of information system is fuzzy information system. If all fuzzy sets induced by attributes can define a fuzzy covering on the sample space and the fuzzy information system is called fuzzy covering information system. Recently, many topics have been widely investigated by using rough sets and fuzzy sets. Fuzzy rough sets were proposed by Dubois and Prade to deal with fuzzy information systems [3]. They have been demonstrated to be useful in the fields of data mining, pattern recognition, knowledge discovery, decision support, power system, machine learning and so on.

With the development of science and technology, there are more and more ways for people to obtain information. To one information system have multiple information sources. Usually in different ways collect the information may have different value for the one information system. Every information source can construct an information system and if all information sources are fuzzy information then construct multiple fuzzy information systems. There are few researches that focus on communication between information systems [6, 9]. Wang investigated the homomorphisms between fuzzy information systems, where homomorphisms are based upon the concepts of consistent functions and fuzzy relation mappings [10]. Follow the Wang's work Zhu classify consistent functions as predecessor-consistent and successor-consistent, and then proceed to present more properties of consistent functions [12]. Recently, Wang do some new researches about fuzzy information systems and their homomorphisms [11]. In this paper, we discuss the multi-source information fusion under the fuzzy context. The multi-source fuzzy information we will study which have same objet set and attribute set but different attribute values. This kind of multi-source fuzzy information is named multi-source fuzzy information with same structure.

The remainder of this paper is organized as follows. In Section 2, some basic concepts of rough sets and fuzzy sets are simply introduced. In Section 3, we discuss the structure of the multi-source fuzzy information and define two approaches for fuzzy information fusion. Followed, we illustrate the approaches with one case. The paper ends with conclusions shown in Section 4.

2 Preliminaries

In this section, we simply review some basic concepts related to rough sets and fuzzy sets. More detailed demonstration can reference the literature [7, 13, 14]. Throughout this paper, U is a finite non-empty set of objects, $P(U)$ is the power set of U and the $F(U)$ is the set of all fuzzy subset of U.

2.1 Rough sets

A 4-tuple $I = (U, AT, V, f)$ is an information system. The U is a finite non-empty set of objects, called the universe. AT is a non-empty finite set of attribute. With every attribute $a \in AT$, a set of its values V_A is associated. $f : U \times AT \to V$ is a total function such that $f(x, a) \subseteq V_a$ for every $a \in AT, x \in U$. For any subset of attributes $A \subseteq AT$, we can define an equivalence relation $IND(A)$ as follows.

$$IND(A) = \{(x, y) \in U \times U : a(x) = a(y), \forall a \in A\}. \quad (1)$$

The equivalence class containing x with respect to A is $[x]_A = \{y \in U | (x, y) \in IND(A)\}$. Such a partition of the universe is a quotient set of U and is denoted by $U/A = \{[x]_A | x \in U\}$. The basic concept $X \in P(U)$ and $A \subseteq AT$, one can characterize X by a pair of lower and upper approximations which are

$$\begin{aligned} \underline{A}(X) &= \{x \in U | [x]_A \subseteq X\}, \\ \overline{A}(X) &= \{x \in U | [x]_A \cap X \neq \emptyset\}. \end{aligned} \quad (2)$$

Here, $pos(X) = \underline{A}(X)$, $neg(X) = \sim \overline{A}(X)$, $bn(X) = \overline{A}(X) - \underline{A}(X)$ are called the positive region, negative region and boundary region of X. The approximation accuracy and roughness of concept X in attribute set A is defined as follows, respectively.

$$\alpha_A(X) = \frac{|\underline{A}(X)|}{|\overline{A}(X)|}, \ \rho_A(X) = 1 - \alpha_A(X). \quad (3)$$

They are often used in the uncertainty measure of rough set theory. The $|X|$ means cardinality of the set X.

2.2 Fuzzy sets and fuzzy rough sets

A fuzzy subset A of U is defined as a function assigning to each element x of U, the value $A(x) \in [0, 1]$ and $A(x)$ is referred to as the membership degree of x to the fuzzy set A. For any $A, B \in F(U)$, we say that A is contained in B, denoted by $A \subseteq B$, if $A(x) \leq B(x)$ for all $x \in U$, and we say that $A = B$ if and only if $A \subseteq B$ and $A \supseteq B$. The support set of a fuzzy set A is a set defined as

$$supp(A) = \{x \in U | A(x) > 0\}. \quad (4)$$

Given $A, B \in F(U)$ and $\forall x \in U$, the union and intersection of A and B are defined as:

$$\begin{aligned} (A \cup B)(x) &= A(x) \vee B(x); \\ (A \cap B)(x) &= A(x) \wedge B(x). \end{aligned} \quad (5)$$

Where "$\vee$" and "$\wedge$" are the maximum operation and minimum operation, respectively.

Let $A = (x_1^a, x_2^a, \cdots, x_n^a)$ and $B = (x_1^b, x_2^b, \cdots, x_n^b)$ are two fuzzy sets. There are many kind definitions between two fuzzy sets's distance and close degree. We introduce the basic relative Minkowski distance between fuzzy set A and B.

$$d_M^{'}(A, B) = (\frac{1}{n}\sum_{i=1}^{n}|A(x_i) - B(x_i)|^p)^{\frac{1}{p}} \quad (6)$$

And the maximum-minimum method compute the close degree between fuzzy set A and B.

$$r_{ij} = \sum_{k=1}^{n}(x_k^a \wedge x_k^b)/\sum_{k=1}^{n}(x_k^a \vee x_k^b). \quad (7)$$

In general, based the close degree we can construct a fuzzy relationship matrix $R = (r_{ij})_{|AT|\times|AT|}$. Then, we can construct a pair lower and upper fuzzy rough approximation of fuzzy set $A(x)$ based the relationship matrix.

$$\begin{aligned} \underline{Apr}A(x) &= \wedge\{A(y) \vee (1 - R(x, y))|y \in U\}, \\ \overline{Apr}A(x) &= \vee\{A(y) \wedge R(x, y)|y \in U\}. \end{aligned} \quad (8)$$

If each attribute(or object) induces a fuzzy set on the sample space, we call this kind of information system is fuzzy information system. In fact, in a fuzzy information system both the object and attribute can be describe as a fuzzy set.

3. Multi-source fuzzy information fusion

With the approaches for people to obtain information are more and more abundant, the information can be accessed is the largest in history. The information explosion produce a lot of fuzzy information source, namely, multi-source fuzzy information. Investigate some special properties of them and take information fusion are the focus topic in the information technology field. In this section, we just only discuss the three sources fuzzy information fusion. Three more sources fuzzy information fusion can be obtained by step through the fusion principles.

3.1. Multi-source fuzzy information with same structure

According the Zadeh proposed the extension principle, Wang study the fuzzy information systems and their homomorphisms. There are some definitions, propositions and corollary are shown in [11]. Based the previous study work we discuss the multi-source fuzzy information system which have same structure.

Definition 3.1. Let $\widetilde{I}_1 = (U_1, AT_1, V_1)$ and $\widetilde{I}_2 = (U_2, AT_2, V_2)$ are any two fuzzy information tables, respectively. f is a mapping from $\widetilde{I}_1$ to $\widetilde{I}_2$ satisfies the following conditions:

(1) $f(U_1) = U_2$; (2) $f(AT_1) = AT_2$.

If f is bijection from $\widetilde{I}_1$ to $\widetilde{I}_2$, then f is referred to as a isomorphism from $\widetilde{I}_1$ to $\widetilde{I}_2$. Especially, if $U_1 = U_2$ and $AT_1 = AT_2$, that $\widetilde{I}_1$ and $\widetilde{I}_2$ have same structure as shown in Figure 1, we will discuss this kind multi-source fuzzy information. The same method can be used to determine whether the three or more fuzzy information tables with same structure.

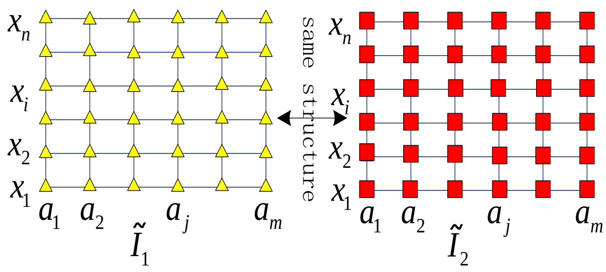

Figure 1. Multi-source Inf. with same structure

There is a group fuzzy information ($\widetilde{I}_1$, $\widetilde{I}_2$, $\cdots$, $\widetilde{I}_s$) with same structure, for any $\widetilde{I}_i$ have n objects and m fuzzy attributes. Let the s pieces of fuzzy information overlapping together can form an information box have s levels. The process of the multi-source fuzzy information fusion as shown in Figure 2. Every small circle mean the attribute value after fusion. The black black solid circle means the $i-$th object's value under the $j-$th fuzzy attribute.

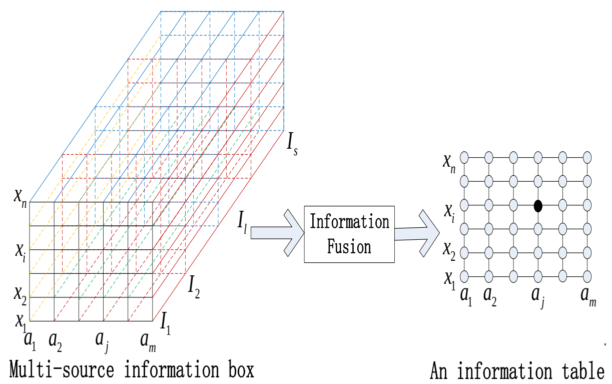

Figure 2. Multi-source Inf. fusion

Example 3.1. Assume the Fund Committee invites some experts to assess the applicant in some fuzzy criterions. Every expert give a score as the membership degree in one attribute fuzzy set and the value of score is belong to $[0,1]$. Here, every expert can be regarded as an information source. Let $\widetilde{I}_1$, $\widetilde{I}_2$ and $\widetilde{I}_3$ are three fuzzy information table with same structure(Namely, there are same object set and attribute set but different attribute value set. It's mean the same indicators of the same applicant by different experts scoring in this example.) from different expert as shown in TABLE 1, 2 and 3, respectively. In the tables $A_1, A_2, \cdots, A_5$ means five fuzzy condition attributes and the d means fuzzy decision. According the formula (7) the fuzzy similarly relation matrix can be obtained and the fuzzy rough lower and upper approximations can be computed about decision fuzzy set $d = \{d_1, d_2, d_3\}$. Followed the fuzzy rough accuracy can be calculated.

TABLE 1. THE EXPERT EVALUATION FROM $\widetilde{I}_1$

	A_1	A_2	A_3	A_4	A_5	d_1
x_1	0.1	0.1	0.5	0.5	0.6	0.4
x_2	0.9	0.9	0.2	0.8	0.6	0.4
x_3	0.8	0.6	0.1	0.9	0.1	0.8
x_4	0.6	0.7	0.1	0.5	0.8	0.6
x_5	0.3	0.7	0.9	0.5	1.0	0.9

According the TABLE 1, use formula (8)we can compute the fuzzy relationship matrix R_1 is

$$R_1 = \begin{pmatrix} 1.00 & 0.41 & 0.26 & 0.45 & 0.53 \\ 0.41 & 1.00 & 0.69 & 0.69 & 0.51 \\ 0.26 & 0.69 & 1.00 & 0.58 & 0.37 \\ 0.45 & 0.69 & 0.58 & 1.00 & 0.65 \\ 0.53 & 0.51 & 0.37 & 0.65 & 1.00 \end{pmatrix};$$

Then, based the formula (1) the fuzzy rough approximations of $d_1(x)$ can calculate as:

$\underline{AT}(d_1) = \{0.4, 0.4, 0.4, 0.4, 0.5\}$;
$\overline{AT}(d_1) = \{0.5, 0.7, 0.8, 0.7, 0.9\}$.

So, the fuzzy rough accuracy α_1 is

$\alpha_1 = \frac{|\underline{AT}(d_1)|}{|\overline{AT}(d_1)|} = 0.58.$

The second expert give the score as TABLE 2, the lower and upper fuzzy rough approximation and accuracy can be computed by the previous ways and the results as follows.

TABLE 2. THE EXPERT EVALUATION FROM $\widetilde{I}_2$

	A_1	A_2	A_3	A_4	A_5	d_2
x_1	0.2	0.1	0.4	0.5	0.1	0.3
x_2	0.8	0.8	0.2	0.6	0.2	0.4
x_3	0.8	0.6	0.2	0.1	0.1	0.5
x_4	0.7	0.5	0.2	0.6	0.1	0.7
x_5	0.3	0.5	0.8	0.5	0.7	0.6

$$R_2 = \begin{pmatrix} 1.00 & 0.39 & 0.29 & 0.48 & 0.46 \\ 0.39 & 1.00 & 0.69 & 0.81 & 0.46 \\ 0.29 & 0.69 & 1.00 & 0.70 & 0.35 \\ 0.48 & 0.81 & 0.70 & 1.00 & 0.48 \\ 0.46 & 0.46 & 0.35 & 0.48 & 1.00 \end{pmatrix};$$

The fuzzy rough approximations and accuracy of $d_2(x)$ can be calculated as:

$\underline{AT}(d_2) = \{0.3, 0.4, 0.4, 0.4, 0.5\}$;
$\overline{AT}(d_2) = \{0.5, 0.7, 0.7, 0.7, 0.6\}$;
$\alpha_2 = \frac{|\underline{AT}(d_2)|}{|\overline{AT}(d_2)|} = 0.63.$

Similarly to previous approaches, the third information source can be computed as the next.

TABLE 3. THE EXPERT EVALUATION FROM $\widetilde{I}_3$

	A_1	A_2	A_3	A_4	A_5	d_3
x_1	0.3	0.1	0.4	0.8	0.8	0.4
x_2	0.5	0.8	0.2	0.7	0.3	0.7
x_3	0.6	0.4	0.2	0.2	0.2	0.4
x_4	0.7	0.6	0.5	0.2	0.3	0.6
x_5	0.2	0.6	0.6	0.4	0.8	0.8

$$R_3 = \begin{pmatrix} 1.00 & 0.48 & 0.33 & 0.38 & 0.61 \\ 0.48 & 1.00 & 0.58 & 0.60 & 0.50 \\ 0.33 & 0.58 & 1.00 & 0.70 & 0.40 \\ 0.38 & 0.60 & 0.70 & 1.00 & 0.58 \\ 0.61 & 0.50 & 0.40 & 0.58 & 1.00 \end{pmatrix};$$

The fuzzy rough approximations and accuracy of $d_3(x)$ can calculated as:

$\underline{AT}(d_3) = \{0.4, 0.4, 0.4, 0.4, 0.4\}$;
$\overline{AT}(d_3) = \{0.6, 0.7, 0.6, 0.6, 0.8\}$;
$\alpha_3 = \frac{|\underline{AT}(d_3)|}{|\overline{AT}(d_3)|} = 0.61.$

3.2. The multi-source fuzzy fusion based f operator

According the Zadeh's fuzzy sets theory, we can get the fuzzy membership degree closer to the 0.5 is more blurred. In the view of the information fusion and practical application, if a person get two scores s_1 and s_2 from two experts, respectively. There are three cases, Case 1: Two experts give the scores are bigger than 0.5, it's mean the person receive more recognition from the two experts. We think the two experts' evaluate are strengthen the recognition degree. Thus, the fusion result should be strengthened. Case 2: If both of the two experts are feel the person is not enough good and give the scores are less than 0.5. Therefore, to the person's final assess should be weaken. Case 3: When the results from two experts are not consistent, namely, $s_1 \geq 0.5$ and $s_2 \leq 0.5$ (or $s_1 \leq 0.5, s_2 \geq 0.5$). Hence, the examine result about this person become more blurred and indistinct. According the above principles we have discussed we define a f operator fusion the fuzzy information and the definition of f as follows.

Definition 3.2. Let f be a binary function on the unit interval, $f : [0,1] \times [0,1] \to [0,1]$ and satisfy the following conditions.

$$f(x,y) = \begin{cases} x + y - xy, \text{ if } x > 0.5 \text{ and } y > 0.5; \\ \frac{xy}{xy+(1-x)(1-y)}, \text{ if } x < 0.5 \text{ and } y < 0.5; \\ \sqrt{xy}, \text{ other.} \end{cases} \quad (9)$$

Based the above definition of f, it's easy to verify that the following properties of f are hold where x, y and z in the corresponding definition domain.

- $f(x, y) = f(y, x)$;
- $f(x, y) \leq f(x, z)$, if $y \leq z$;
- $f(x, f(y, z)) = f(f(x, y), z)$.

Definition 3.3. Let $\widetilde{I}_1$, $\widetilde{I}_2$, $\cdots$, $\widetilde{I}_s$ are s pieces of information sources. Use the f operator, we can fusion the s information sources to one information table.

$$I = f(f(f(\widetilde{I}_1, \widetilde{I}_2), \cdots), \widetilde{I}_s). \quad (10)$$

In experiment, if there are a lot of information sources should be fusion. Then, we can use the f operator to fuzzy information fusion by one ruled order law.

Example 3.2. $(Continued\,from\,Example 3.1)$. By using the f operator deal with the multi-source fuzzy information fusion $\widetilde{I}_1$, $\widetilde{I}_2$ and $\widetilde{I}_3$ we can get the results as shown in Table 4. Followed, the fuzzy rough approximations and accuracy can be obtained.

TABLE 4. THE f INFORMATION FUSION

	A_1	A_2	A_3	A_4	A_5	d_f
x_1	0.01	0.00	0.35	0.63	0.44	0.2
x_2	0.70	1.00	0.02	0.98	0.19	0.5
x_3	0.98	0.58	0.01	0.10	0.00	0.5
x_4	0.96	0.84	0.12	0.33	0.14	1.0
x_5	0.04	0.84	0.99	0.45	1.00	1.0

$$R_f = \begin{pmatrix} 1.00 & 0.23 & 0.03 & 0.16 & 0.35 \\ 0.23 & 1.00 & 0.44 & 0.58 & 0.30 \\ 0.03 & 0.44 & 1.00 & 0.74 & 0.17 \\ 0.16 & 0.58 & 0.74 & 1.00 & 0.31 \\ 0.35 & 0.30 & 0.17 & 0.31 & 1.00 \end{pmatrix};$$

The fuzzy rough approximations and accuracy of $d_f(x)$ can be calculated as:

$$\underline{AT}(d_f) = \{0.2, 0.5, 0.5, 0.5, 0.7\};$$
$$\overline{AT}(d_f) = \{0.4, 0.6, 0.7, 1.0, 1.0\};$$
$$\alpha_f = \frac{|\underline{AT}(d_f)|}{|\overline{AT}(d_f)|} = 0.65.$$

3.3. Fuzzy information fusion based g operator

In the research of plane geometry, we often find a special point substitute some related points. The minimum distance point method is often used in the Euclidean space. We applied this method into information fusion. Let $\widetilde{I}_1$, $\widetilde{I}_2$, $\cdots$, $\widetilde{I}_s$ are multi-source information with same structure. For any object x_i and fuzzy attribute a_j, the membership degree of fuzzy attributes can describe as a s dimensions vector $\mathbf{x_i} = (a_{1j}(x_i), a_{2j}(x_i), \cdots, a_{sj}(x_i))$. We find a point x^* instead original s points and the point x^* satisfy the sum of distance from x^* to x_i is the shortest. Sometimes, the point which satisfy the condition is not only. We can choose one any point of them.

Definition 3.4. Let $S_s = \{(x_1, y_1), (x_2, y_2), \cdots (x_i, y_i) \cdots, (x_s, y_s)\}$ be a series of positive real number pair in $[0,1] \times [0,1]$. The g is a function defined as:

$$g(S_s) = g((x_1, y_1), (x_2, y_2), \cdots, (x_s, y_s)) = (x^*, y^*). \quad (11)$$

The (x^*, y^*) is the point where such that the sum of distance from (x^*, x^*) to $(x_i, y_i)(i = 1, 2, \ldots, s)$ is the shortest and the distance d is

$$d = \sum_{i=1}^{s} \sqrt{(x_i - x^*)^2 + (y_i - y^*)^2} \quad (12)$$

We random generate 100 positive real number pairs belong to $[0,1] \times [0,1]$ and find the minimum distance point as shown in Figure 3.

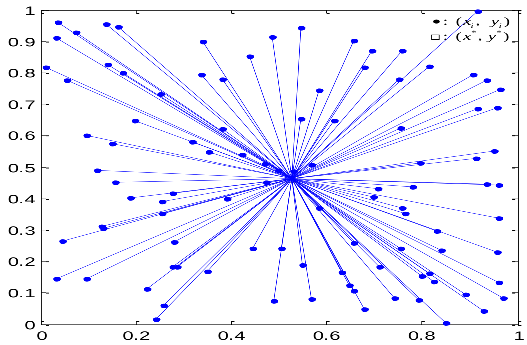

Figure 3. Minimum distance point

Especially, if all $y_i = 0$ $(i = 1, 2, \cdots, s)$, the coordinate plane reduce to one real axis and the distance d is

$$d = \sum_{i=1}^{s} |x^* - x_i|. \quad (13)$$

In the process of multi-source fuzzy information fusion, we can use this way fusion multiple information sources into a composite information table.

Example 3.3. $(Continued\, from\, Example 3.1)$. By using the approach of g operator fusion the $\widetilde{I_1}$, $\widetilde{I_2}$ and $\widetilde{I_3}$ we can get the results as shown in Table 5.

TABLE 5. THE g INFORMATION FUSION

	A_1	A_2	A_3	A_4	A_5	d
x_1	0.2	0.1	0.4	0.5	0.6	0.4
x_2	0.8	0.8	0.2	0.7	0.3	0.4
x_3	0.8	0.6	0.2	0.2	0.1	0.5
x_4	0.7	0.6	0.2	0.5	0.3	0.6
x_5	0.3	0.6	0.8	0.5	0.8	0.8

$$R_g = \begin{pmatrix} 1.00 & 0.56 & 0.57 & 0.83 & 0.72 \\ 0.56 & 1.00 & 0.53 & 0.68 & 0.80 \\ 0.57 & 0.53 & 1.00 & 0.62 & 0.57 \\ 0.83 & 0.68 & 0.62 & 1.00 & 0.78 \\ 0.72 & 0.80 & 0.57 & 0.78 & 1.00 \end{pmatrix};$$

The fuzzy rough approximations of $d_g(x)$ can calculate as:

$\underline{AT}(d_g) = \{0.4, 0.4, 0.4, 0.4, 0.4\}$;

$\overline{AT}(d_g) = \{0.6, 0.6, 0.6, 0.6, 0.8\}$.

And the fuzzy rough accuracy is : $\alpha_g = \frac{|\underline{AT}(d_g)|}{|\overline{AT}(d_g)|} = 0.63$.

4. Conclusions

In this work, we discussed the multi-source fuzzy information fusion where the information sources have same structure. Two fuzzy information fusion approaches are proposed. The information fusion can keep fuzzy rough accuracy almost unchanged and have a slight increase but will save much memory space. That is to say, a lot of useless information have been collected when the information collection. In the process of information fusion, should try to keep more useful information. According the case study we can find through information fusion, some useless information be deleted and useful information is retained. In the age of the information explosion, the increasing amount of information, access to information has become more abundant, the types of information become complex diversity. The research on multi-source information fusion is just started. The multi-source information fusion as a basic work of information technology field is becoming more and more important, the research will also gradually.

Acknowledgements

This work is supported by Natural Science Foundation of China (No. 61105041, No. 61472463 and No. 61402064), National Natural Science Foundation of CQ CSTC (No. cstc 2013jcyjA40051), Key Laboratory of Intelligent Perception and Systems for High-Dimensional Information (Nanjing University of Science and Technology), Ministry of Education (No. 30920140122006) and Graduate Innovation Foundation of Chongqing University of Technology (No.YCX2014236).

References

[1] J. Bleiholder, F. Naumann, Data fusion, ACM Computing Survey, Vol 41, pp. 1-41, 2008.

[2] Baoping Cai, Yonghong Liu, and Qian Fan et al., Multi-source information fusion based fault diagnosis of ground-source heat pump using Bayesian network, Applied Energy, Vol 114, pp. 1-9, 2014.

[3] D.Dubois, H.Prade, Rough fuzzy sets and fuzzy rough sets, International Journal of General Systems, Vol 17, pp. 191-209, 1990.

[4] Hai Ma, Formation drillability prediction based on multi-source information fusion, Journal of Petroleum Science and Engineering, Vol 78, pp. 438-446, 2011.

[5] H. Lee, B. Lee, K. Park, R. Elmasri, Fusion techniques for reliable information: a survey, International Journal of Digital Content Technology and its Application, Vol 4, No. 2, pp. 74-88, 2010.

[6] D.Y. Li, Y.C. Ma, Invariant characters of information systems under some homomorphisms, Information Sciences, Vol 129, pp. 211-200, 2000.

[7] Z.Pawlak, Rough sets, International Journal of Computer and Information Science, Vol 11, pp. 341-356, 1982.

[8] Rita A. Ribeiro, António Falcão, André Mora, José M. Fonseca, FIF: A fuzzy information fusion algorithm based on multi-criteria decision making, Vol 58, pp. 23-32, 2014.

[9] C.Wang, C.Wu, D.Chen, Q.Hu, C,Wu, Communication between information systems, Information Sciences, Vol 178, pp. 3228-3239, 2008.

[10] Changzhong Wang, Degang Chen, Liangkuan Zhu, Homomorphisms between fuzzy information systems, Vol 22, pp. 1045-1050, 2009.

[11] Changzhong Wang, Degang Chen, Qinghua Hu, Fuzzy information systems and their homomorphisms, Vol 249, pp. 128-138, 2014.

[12] Ping Zhu, Qiaoyan Wen, homomorphisms between fuzzy information systems revisited. Applied Mathematics Letters, Vol 24, pp. 1548-1553, 2011.

[13] Xiaohong Zhang, et al., Fuzzy mathematics and Rough set theory[M], Tsinghua University press, Beijing, 2013.

[14] L. A. Zadeh, "Fuzzy sets", inf. Control, Vol 8, pp. 338-353, 1965.