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An uncertain information fusion method based on possibility theory in multisource detection systems

Linna Ji [a], Fengbao Yang [b,*], Xiaoxia Wang [a], Lei Chen [a]

[a] Information and Communications Engineering College, North University of China, Taiyuan, Shanxi 030051, China
[b] Science College, North University of China, Taiyuan, Shanxi 030051, China

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ABSTRACT

In multisource detection systems, the information representing detection characteristics is uncertain, also the relationship between detection characteristics and detection performance has uncertainty, meanwhile the influence degrees of each characteristic on the performance are also different. In order to represent and process these uncertain information effectively, this paper proposes an uncertain information fusion method based on possibility theory. Firstly, possibility distributions of a series of characteristic parameters about sensor information are constructed, and effective detection characteristics are extracted through the similarity measurement according to the similarity based on distances. The uncertain relationship between detection characteristics and detection performance is quantified, and a certainty calculation method of possibility distributions is proposed based on the combination of holistic and local characteristics. According to the above certainty, the weights of each characteristic are obtained to achieve the fusion of possibility distributions. Finally, the metallic and nonmetallic adhesive structure is taken as a case, and this case shows that this method not only considers the differences of the various characteristics contributed on adhesive performance, but also can achieve the fusion of possibility distributions under different situations. It is a more reasonable fusion method and fits the reality well in practice, also it provides new method and new idea for the fusion of possibility distributions.

1. Introduction

With the rapid development of sensor technology, computer science and information technology, it is possible to multi-channel information acquisition, processing and fusion [1,2]. In the actual operation of multisource detection systems, because of the complexity of the environment, the limitation of sensor or observer itself, and the imperfection of information acquisition technology or method, the information obtained from the sensors usually has many kinds of uncertainty such as random, unknown, imprecise and incomplete, also the characteristics extracted from sensor information are uncertain. If the uncertain information was not processed or fused effectively, the fusion effect will reduce, and bring unpredictable risks to the detection system [3,4].

Detection characteristics reflect the performance status of the detection system from the different aspects, degrees and levels. The characteristics are extracted from sensor information directly with the existing methods. These methods do not consider the correlation and redundancy among the characteristics, causing that the extracted characteristic parameter is more and the correlation among the characteristics is larger. Meanwhile the fusion model becomes complicated, and it is inconvenient to apply in practical engineering because large amount of information need to be dealt with, and processing speed is slow. In the aspect of information fusion, the traditional Bayesian reasoning and neural network require a lot of prior knowledge to achieve information fusion, while the prior knowledge is not easy to obtain in practical engineering applications. So it has a lot of limitations to deal with uncertain information with the traditional linear and deterministic signal processing and the methods based on prior knowledge.

In view of the above questions, this paper takes multisource detection systems as research object, and proposes an uncertain information fusion method based on possibility theory. Firstly, multisource uncertain information need to be represented uniformly, and the similarity based on distances was used for similarity measurement in a series of characteristic parameters about sensor information. Then effective detection characteristics are extracted by means of combination and deletion to eliminate the correlation and redundancy among the characteristics. Considering that the detection characteristics have different contributions on detection

* Corresponding author.
E-mail address: jln880812@163.com (L. Ji).

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performance, a certainty calculation method of possibility distributions is proposed based on the combination of holistic and local characteristics. According to the above certainty, the weights of each characteristic are obtained to achieve the fusion of possibility distributions, which lays a foundation of performance recognition in multisource detection systems.

2. Unified representation of uncertain information

Sensor information carries the information reflecting detection performance of systems. Due to the limitation of sensor itself, and the strong interference of natural environment influence, detection characteristics are usually uncertain. In the actual operation of multisource detection systems, a component is tested repeatedly, and the information obtained from each sensor may be different, from which the characteristics extracted are also of difference accordingly. In order to deal with the uncertainty and differences of the information effectively, the information is represented uniformly through constructing possibility distributions of a series of characteristic parameters in the framework of possibility theory. Its advantages are that it does not need priori knowledge and computational complexity is low.

The analysis and study on a number of detection information show that the information representing detection characteristics can be considered to obey Gaussian distribution approximately [5]. Let X be value space of detection information, and possibility distribution functions are constructed with statistical method. The specific processes are as follows:

(i) A component is tested m times, and a series of characteristic parameters can be extracted from sensor information such as mean, mean square value, variance, rate, signal autocorrelation sequence, each order origin moment and center moment etc. Let $x_k(n)$ be the kth detection information, then some characteristic parameters of the information are:

mean: $\mu_{x_k} = \frac{1}{N}\sum_{n=0}^{N-1} x_k(n)$

mean square value: $\varphi_{x_k}^2 = \frac{1}{N}\sum_{n=0}^{N-1} x_k^2(n)$

variance: $\sigma_{x_k}^2 = \frac{1}{N}\sum_{n=0}^{N-1} (x_k(n) - \mu_{x_k})^2$

rate: $p_{X_k} = \frac{\sigma_{x_k}}{\mu_{x_k}}$

autocorrelation sequence: $r_{x_k} = \frac{1}{N}\sum_{n=0}^{N-l+1} x_k(n)x_k(n+l)$

where N denotes the length of the signal.

(ii) Taking mean square value as an example, we can calculate the mean M_φ of m mean square values about sensor information.

$$M_\varphi = \frac{1}{m}\sum_{k=1}^{m} \varphi_{x_k}$$

(iii) The variance σ_φ of m mean square values is calculated.

$$\sigma_\varphi = \sqrt{\frac{\sum_{k=1}^{m} (\varphi_{x_k} - M_\varphi)^2}{m}}$$

(iv) The possibility distribution function of mean square value can be constructed with M_φ and σ_φ.

$$\pi_\varphi(x) = \frac{1}{\sqrt{2\pi\sigma_\varphi^2}} \exp\left(-\frac{(x - M_\varphi)^2}{2\sigma_\varphi^2}\right)$$

By the same token, possibility distribution functions of other characteristic parameters can be constructed.

3. The extraction of detection characteristics

Because detection characteristics exist different degrees of correlation and redundancy, the above characteristic parameters need to similarity measurement to extract effective detection characteristics. A similarity calculation method among possibility distributions is proposed, and the combination and deletion are used to make the correlation among these characteristics minimum. Here the definition of similarity is given [6,7] firstly.

Definition 1. Let X be a universe of discourse, real function $s : \mathcal{F}(X) \times \mathcal{F}(X) \to \mathcal{R}^+$, for $\forall A, B, C \in \mathcal{F}(X)$, s satisfies the following conditions:

(i) $s(A, B) = s(B, A)$;
(ii) $s(D, D^c) = 0, \forall D \in \mathcal{P}(X)$;
(iii) $s(C, C) = \max_{A,B\in\mathcal{F}(X)} s(A, B)$;
(iv) if $A \subset B \subset C$, then $s(A, B) \geq s(A, C)$, and $s(B, C) \geq s(A, C)$.

Then s is called the similarity on the set $\mathcal{F}(X)$, where $\mathcal{P}(X)$ is power set of classical set, and $\mathcal{F}(X)$ is power set of fuzzy set.

Owing to the difference of properties and dimension about each characteristic, these characteristics can not carry on similarity measurement directly, and they must be mapped to the interval [0,1], that is, $X = [0,1]$. For $A, B \in \mathcal{F}(X)$, if possibility distribution functions of A and B are discrete, then the similarity of possibility distributions π_A and π_B is defined as:

$$s(\pi_A, \pi_B) = 1 - \frac{\sum_{i=1}^{n} \lambda_i H(A_{\lambda_i}, B_{\lambda_i})}{\sum_{i=1}^{n} \lambda_i} \quad (1)$$

where, λ_i is cut-set level, and n is the number of cut-set levels. $H(A_{\lambda_i}, B_{\lambda_i})$ denotes Hausdorff distance of the sets A_{λ_i} and B_{λ_i} [8].

If possibility distribution functions of A and B are continuous, then the similarity of possibility distributions π_A and π_B is defined as:

$$s(\pi_A, \pi_B) = 1 - \frac{\int_0^1 \lambda H(A_\lambda, B_\lambda) d\lambda}{\int_0^1 \lambda d\lambda} = 1 - 2\int_0^1 \lambda H(A_\lambda, B_\lambda) d\lambda \quad (2)$$

The similarities among possibility distributions of the characteristic parameters are calculated with the above method. According to the similarities, the effective detection characteristics are extracted through reducing the dimension of the characteristics, also removing and merging the characteristics of large correlation.

4. The construction of possibility distribution between detection characteristics and detection performance

Detection characteristics reflect the performance status of the detection system from the different aspects, degrees and levels, and the relationship between detection characteristics and between detection performance exists fuzziness and uncertainty. The fuzzy and uncertain relationship between the both is quantified through possibility distribution function. According to a lot of experiments, the detection characteristics can be divided into three categories: