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# Modified D-S evidential theory in hydraulic system fault diagnosis

DONG Zengshou[a], ZHANG Xujing[b*]

*Dept. of Electronic Information Engineering Taiyuan University of Science and Technology Taiyuan,P.R.China*
*[a]ansondon@sohu.com, [b]feitianzhu1987322@126.com*

**Abstract**

In order to solve the problem of hydraulic system fault diagnosis, an information fusion method, which is for hydraulic system fault diagnosis based on modified D-S evidential theory and time space domain, is presented. Accor- ding to the measurement results of the pressure and the temperature and the flux, the belief function assignment of the three sensors, then using the DS rule and decision rule, fused the information in time-space domain, and at last recognize the fault. The simulated experiment shows that the method in evidence conflicted still correct and can avoid index exploded and exactly fixed the fault.



*Keywords:* Modified D-S evidential theory; hydraulic syst- em fault diagnosis; time-space domain; belibelief coefficient

## 1. Introduction

Engineering vehicles working in a wicked environment, and the core component is the hydraulic system,hydraulic system's failure has a hidden, difficult to judge and variability of the site to find fault, which in order to find the cause of failure is difficult.Therefore, the fault diagnosis of hydraulic system should be introduced decision making. Fault diagnosis is usually only a certain type of parameters(Such as: the pressure signal after pretreament) Multi-angle, multi-level analysis, due to received single information,often can not cope with complex and variable fault situation. To gain new meaningful information, where the multi-sensor information fusion is a multi-level information for sensors,comprehensive analysis be combined with certain rules, and last by means of decision-making has reached the fault location purposes.

D-S evidential theory in the field of information fusi- on has a relatively strong theoretical foundation, which deal with the uncertainties arising has the unique advant- ages, thus the research it has been in ascendant.D-S evid- ential theory plagued widely used because there are two main aspects: First, Dempster combination rules exists in the realization of the exponential explosion problem.App- ropriate


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for specific evidence in the organizational struct- ure, construct fast algorithms, and to reduce the number of focal elemnt,use approximate calculation[1,2], etc. To answer;Second,due to environmental factors or human interference caused a high degree of conflict of evidence,lead to DS combination rules failures,.Currently the main way to solve this problem focused on the combination rules or the data model to improve, while the data model to improve need to see the nature of the conflict of the evidence,which have a greater value in solve practical problems of fault diagnosis.

This data fusion algorithm is based on the literature [3] which considers the relations between the number of focal element , types and the target fault. Define a new belief coefficient on the basis of the evidential discount when the evidence was conflict,the final data fusion algorithm by the timespace joint the airspace to locate the fault of the ultimate goal.

## 2. Multi-sensor information fusion algorithm

### *2.1D-S evidential theory*

D-S evidential theory proposed by Dempster,and Sh- afer has to be expanded and developed.and the domain of evidential theory is called recognition framework,denoted by $U$. $U$ is said that all possible values of $X$, denoted by $\{X_1, \ldots X_n\}$,in fault diagnosis which was corresponded with the identification target, namely,all the n failure mo- des. The elements in $U$ are mutually exclusive.

Definition 1: Let $U$ is a recognition framework , the function m: $2^U \rightarrow [0,1]$($2^U$:for the $U$, the set of all subsets) satisfy following conditions: $m(\varnothing)=0$;

$$\sum_{A \subset U} M(A) = 1 ,$$

$m(A)$ is called a basic probability assignment.The $m(A)$ show that the trust degree about this proposition, in fault diagnosis, said the degree of some kind of fault rely on the evidence.

Definition 2: Let $BEL_1$ and $BEL_2$ are two belief function on the same recognition frame,$m_1$ and $m_2$ are the corresponding basic probability assignment. Focal element, respectively are $A_1 \ldots A_k$, and,$B_1 \ldots B_r$, and set

$$K_1 = \sum_{\substack{i,j \\ A_i \cap B_j = \varphi_i}} m_1(A_i) m_2(B_j) < 1 \tag{1}$$

Yet

$$m(C) = \begin{cases} \dfrac{\sum\limits_{\substack{i,j \\ A_i \cap B_j = C}} m_1(A_i) m_2(B_j)}{1 - K_1}, \forall C \subset U, C \neq \phi \\ 0, C = \phi \end{cases} \tag{2}$$

This formula is Dempster combination rule in which $K_1$is inconsistent factor in $m_1$ and $m_2$,namely, the degree of conflicting evidence, the greater $k_1$ the greater conflict between that evidence, if $k_1$=1,then the failure of the classic D-S evidential theory.

### *2.2Modified D-S evidential theory and decision rules*

Solve the problem of DS evidential theory failures in the conflict of evidence, there are basically two ways.First, modify the Dempster combination rule,but Haenni think that dempster combination rule that itself is not an error[4],and the need for further processing of the evidence of the conflict.Second, need to reallocation the conflict evidence,through the introduction of conflict factor k, parameters λ[5].But $k$ is often explained the probability assigned of synthesis where distribute to empty set,this method does not proceed from nature to solve the problem of conflict.In this paper, data fusion method is according to the reference [2] and on the basis given by the Jousselme distance function[5], two pieces of evidence that the distance is between the body mi and $m_j$, according to the size of the distance to see the level of conflict.When number of elements in different subsets is not the same as $A_1=\{O_1,O_2\}$, $A_2=\{O_1,O_2,O_3\}$, this moment the conflict factor $k$ should be changed when recognise the target,therefore need to take into account

the intersection between the elements of subsets to fix $k$, that in line with the uncontainable degree of evidence and the distance modified $k$.

If $m_i$ and $m_j$ are basic probability assignment on the U,where U is the whole recognition framework according to Jousselme distance function[6], evidence can be drawn from the distance between the two: $d_{ij} = \sqrt{\frac{1}{2}(m_i - m_j)D(m_i - m_j)}$, Where the matrix $D$, given the calculation method $d_{ij} = \sqrt{\frac{1}{2}(\|m_i\|^2 + \|m_j\|^2 - 2\langle m_i, m_j\rangle)}$, where $\langle m_i,m_j\rangle$ are the inner product of two vectors, $\langle m_i, m_j\rangle = \sum_{l=1}^{2^n}\sum_{p=1}^{2^n} m_i(A_l)m_j(A_p)\frac{|A_l \cap A_p|}{|A_l \cup A_p|}$

and according to the original conflict factor $k$ and the distance ,and then sum $k$ and $d_{ij}$ ,the average of the sum is new post-conflict factor $k'_{ij}$, the calculate process as follows:

- Calculate the original conflict coefficient and dista-nce, and calculate the coefficient of new conflicts $k'_{ij}$;
- Calculate the discount according to the intersection between the evidence , define the new belief factor $\alpha = \frac{(1/d_{ij})}{\sum_{j=1}^{M}(1/d_{ij})}$;
- Use Dempster combination rule of equation (1) to combine;
- Amend the fusion reasons that belief factor: $m'(C)=\alpha m(C)$;
- Then fused with the next set of evidence, and so on.

When all the fusion are completed, select the rule-based decision making,which is based on basic probability assignment:let $\exists A_1, A_2 \subset U$ ,fit that $m(A_1) = \max\{m(A_i), A_i \subset U\}$, $m(A_2) = \max\{m(A_i), A_i \subset U 且 A_i \neq A_1\}$ ,if there are $\begin{cases} m(A_1) - m(A_2) > \varepsilon_1 \\ m(U) < \varepsilon_2 \\ m(A_1) > m(U) \end{cases}$, Then $A_1$ is the verdict,for which $\varepsilon_1$ and $\varepsilon_2$ are the threshold.

### 3. Hydraulic system fault diagnosis

The main factors affect the hydraulic system including the pollution of hydraulic oil,temperature, system pressure, pump speed and other aspects.At the working scene, because each type of sensor will have 50 to 100 monitoring points located in different locations of machinery, so there are the characters of spatial span and extensive coverage, the corresponding amount of data will increase a lot.For the lower processing time and the higher accuracy that use the time-airspace integration method and over th multi-cycle . System diagram is as the Figure 1.

For the chart , we select pressure, temperature, flow rate of three sensors under the common fault and multi-point monitoring of the equipment,

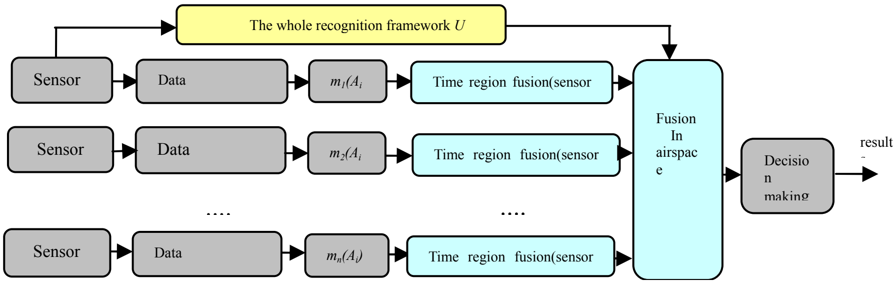


Figure 1. process of fault diagnosis based on D-S evidential

which produces all faults that the whole framework $U$ $=\{o_1,o_2,o_3,o_4,o_5\}$.Corresponding to the five failures, $o_4$ is the complete works, for the $o_5$ is empty set. According to experience, the failure of $o_1$ as a hydraulic pump failure, the failure of $o_2$ as a discharge valve leakage, the failure of $o_3$ as oil temperature is too high. There needs two groups of parameters to be set because of putting to use time-airspace information fusion.$m_{ij}$ show the degree of impact with the target which said sensors $i$ and cycle $j$ , then according to the reference [6] obtaine the basic probability distribution of each evidence, that is, how influence of the three sensors to each failure.Locat the ultimate fault with the modified Dempster-Shafer combination rule and the basic probability assignment .

## 4. Experiment results and simulation

Table 1 the basic probability assignment determined by three sensors

| | $O_1$ | $O_2$ | $O_3$ | $O_4$ | $O_5$ |
|---|---|---|---|---|---|
| $m_{11}$ | 0.60 | 0.15 | 0.20 | 0.05 | 0.00 |
| $m_{21}$ | 0.00 | 0.90 | 0.05 | 0.05 | 0.00 |
| $m_{31}$ | 0.05 | 0.10 | 0.65 | 0.15 | 0.00 |
| $m_{12}$ | 0.50 | 0.10 | 0.30 | 0.10 | 0.00 |
| $m_{22}$ | 0.00 | 0.88 | 0.01 | 0.11 | 0.00 |
| $m_{32}$ | 0.25 | 0.10 | 0.55 | 0.10 | 0.00 |

Table 2 accumulated basic probability assignment of each cycle

| | $O_1$ | $O_2$ | $O_3$ | $O_4$ | $O_5$ |
|---|---|---|---|---|---|
| $m_1$ | 0.2320 | 0.5528 | 0.2150 | 0.0003 | 0.00 |
| $m_2$ | 0.2398 | 0.4492 | 0.3098 | 0.0013 | 0.00 |
| $m_3$ | 0.1187 | 0.3618 | 0.4437 | 0.0057 | 0.00 |

Table 2 is the totally probability distribution of the three cycles in this method, according to decision rules, where, take $\varepsilon_1$ and $\varepsilon_2$ all for 0.1, get that $m(o_1)$=0.0821, $m(o_2)$=0.6908, $m(o_3)$=0.2271, so locate the final fault: Type =discharge valve leakage.

If the measurement results of the first cycle according to classic Dempster combination rule, when the evidence is inconsistent combinations, that is,$m_1,m_1m_2,m_1m_2m_3$, for this combine way where the result is surprise.The result is that all the $m(o_1)$ are zero.The situation of reject show that *m()* is zero all along no matter whatever evidence support the future evidence o1,and the value of *m(u)* has been increased throughout, that is,the unknown probability and then increases.Therefore, the classical combination rules here has expired.

## 5. Conclusion

In view of classic Dempster evidential theory,analyse the impact in reality working state when the evidence are conflict whether the classic evidential combination rule take effect or not.How influence the conflict coefficient according to Jousselme distance function either considering the evidence of different combinations and the exclusion of evidence.Amend the classical Dempster rule by define a new belief factor which for the discount of the evidence.In practice,positioning the failure of the hydraulic system by use time-airspace fusion.Simulation shows that while the failure of the Dempster combination rule, this algorithm can accurately locate the fault.

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