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Uncertainy Reasoning Research Based on the Expert System of Mechanical Product Design

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Abstract: Uncertainty problem is the focus of the Expert System Research. This study utilizes the thought of Expert System's confidence as guidance and the mechanical products design as example to introduce the process of the uncertainty reasoning research of the expert system detailedly. In the process of uncertainty research, we firstly propose a new matching algorithm of uncertainty reasoning for matching the method of the first component of rules. Compare with the existing method, this algorithm taking fully into account of the experts' judgement for known first component of rules and realistic conditions' influence for the first component of rules. It makes the algorithm's result fit the actual rules choosing better. Furthermore, in the process of uncertainty dissemination, this study uses a new algorithm to solve the supporting conclusions' evidence confidence. Compare with the existing method, the confidence of conclusions which use this algorithm are all over 0.8. As the result, it shows the uncertainty problem in inference engine has been solved very well. And it also improves the choosing decision-making function of the expert system.

Key words: Expert system, reasoning of uncertainty, confidence, machine design

INTRODUCTION

Expert system is a computer software system to solve problems and make decisions established by people's knowledge, experience and skill in a certain area. It can present expert results for complex problem (Zhao and Feng, 2012).

Inference engine is the core of the expert system and uncertainty is the key problem need to be solved in reasoning process. The issue of uncertainty is making decisions and reasoning with insufficient information. This study studies and proposes a new method of uncertainty reasoning which is based on the expert system of mechanical product design. This method presents the expert mechanical product design scenario by dealing different knowledge. So this method is efficient and highly practical.

UNCERTAINTY REASONING

Process of reasoning of uncertainty: Reasoning of uncertainty is the rule for confirming the assertion of top-level or first component to find conclusion part or second component (Johnson and Kelafunuo, 1989). In the rule-based expert system, the essence of uncertainty reasoning is the same, although there are huge differences between the basic idea and method of dealing problem. It consists of three parts:

- Description of knowledge uncertainty
- Description of evidence uncertainty
- The update algorithm of uncertainty

The description of knowledge uncertainty is to clearly present the value when the evidence is true and the conclusion is true or false; the description of evidence uncertainty is also need to clearly present the value when the evidence is true or false; the update algorithm of uncertainty make the uncertainty can spread in reasoning network and finally obtain the solutions of the problems (Li, 1991).

Presentation of knowledge uncertainty: In the rule-based expert system, this study in production rule form to describe knowledge, as follows:

$$\text{If } E_1 \text{ and } E_2 \text{ and} \ldots \text{ and } E_n \text{ then } H(cf(H, E), \varphi)$$

Each of the first component of rules $E_i (i = 1, 2, \cdots n)$ consists of $cf(E_i)$ and λ_i this set of parameter. $cf(E_i)$ means the confidence of first component. λ_i is the first component E_i's weight, it values in [-1,1], when $\lambda_i>0$ means the degree of first component E_i is true; when $\lambda_i<0$ means the degree of first component E_i is false. So, the way to present the first component E_i is true is $\lambda_i = 1||_i|$; $cf(H, E)$ means the conclusion's confidence of first component E_i is true; φ is threshold value of rules ($\varphi \geq 0.2$).

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Description of evidence uncertainty: The description of evidence is expressed by cf(E_i'), it reflected the certainty of the given facts (Chen, 2011). The certainty factor values in [0,1]. For the given evidence E', if can affirm it is the firm conclusion of fact, it will have (E_i') = 1; if the evidence just can prove some degree of the certainty, it will have 0<cf(E_i')<1, if the evidence proved it has some assumption, or the evidence cannot determine whether it is true or false, it will have cf(E_i') = 0.

Matching degree processing of first component of rules: The precondition of the rule E_1…,E_n uses matching degree to express the similarly of the two when the certainty factor cf(E_n) and relevant evidence cf(E_{in}') are not entirely consistent (Chen, 2011). This study designs a new matching degree arithmetic to calculate the degree of match and uses matching arithmetic to check the setting of the first component of rules whether meet the threshold value of rules and then decide whether to activate this rule.

The matching arithmetic specific descriptions as follow:

For the matching set of first component, if it have:

$$cf(E_n) \wedge cf(E_n'),$$

then:

$$cf(E) = \min\{cf(E_n), cf(E_n')\}$$

so for the rule R:

If E_1 and E_2 and… and E_n then H(cf(H, E), φ)

exists as follow:

$$cf(E_1'),\ cf(E_2'), \cdots, cf(E_n')$$

so according the first component condition E_n and evidence E'_n, conclude the formular of the matching degree of rules is:

$$G(R) = \sum_{i=1}^{n} (\lambda_i \times \min\{cf(E_i), cf(E_i')\} \times \frac{\min\{cf(E_i), cf(E_i')\}}{cf(E_i) + cf(E_i')})$$

In the equation G(R) means the matching degree of first component set and evidence set of rule R. If the matching degree G(R)'s result meet the threshold value of the rule φ (φ≥0.2), then the matching degree of evidence set and first component of rules set tend to close and match the rule's activate requirements, the rule R be activated.

Spread of uncertainty: Every evidence and rule is given a confidence in knowledge base of expert system (Wang, 2005). When we add the information provided from users into inference engine to reasoning, the final reasoning conclusion is more fit with physical truth, because the intervention of confidence method makes full consideration of domain-specialist knowledge's experience. In the reasoning process in inference engine, evidence and rule's uncertainty are related the truth of whole reasoning (Zhang, 2011). To make the final reasoning result is more close to actual situation, this study uses the new algorithm to calculate the evidence confidence in reasoning process, as follow:

$$CF(E_i) = 1 - \frac{\lambda_i \times (cf(E_i) + cf(E_i'))}{\sum_{i=1}^{n} cf(E_i) + cf(E_i')} \quad 0 \le \lambda_i \le 1 \quad 0 \le \lambda_i \le 1 \qquad (1)$$

$$CF(E_i) = 1 - \frac{(1 - |\lambda_i|) \times (cf(E_i) + cf(E_i'))}{\sum_{i=1}^{n} cf(E_i) + cf(E_i')} \quad -1 \le \lambda_i < 0 \quad i = 1, 2, \cdots n \qquad (2)$$

Because of the different rules support different way of conclusion, so this study sets different solutions for the different conclusion expression of different rules:

- The solution for the single rule support conclusion's reasoning process, as follow:

If it exists the following rule forms:

If E_1 and E_2 and… and E_n then H(cf(H, E), φ)

Then the confidence of the conclusion is CF(H) = cf(H, E)×CF(E).

In the above, cf(H, E) has been given from experts, it means the confidence degree of the truth of evidence E_i. By calculating Eq. 1 or 2 the evidence's confidence for supporting the conclusion $CF(E_i)_i$ = 1, 2,…n, then confidence of evidence combination is:

$$CF(E) = CF(E_1 \wedge E_2 \wedge \cdots \wedge E_n) = \min\{CF(E_1), CF(E_2), \cdots CF(E_n)\}$$

- The solution for the multi-rules support conclusion's reasoning process, as follow:

The multi-rules support conclusion can divides into serial rule and parallel rule, the two forms (Bian, 2010).

Serial rule: For the known rule's abstract model $R_1$and R_2.

There is $R_1: a \rightarrow b \quad cf(b,a),\ R_2: b \rightarrow c \quad cf(c,b)$

From the known evidence a, we deduced the synthetic confidence of rule R_2 is:

$$CF(c, a) = CF(c, b) \times \max(0, CF(b, a)) i = 1, 2, \cdots n$$

In the above, for the abstract first component a, if exists $a_1 \wedge a_2 \wedge \cdots \wedge a_n$, then CF (b, a) = min{CF(H)} i = 1, 2,…n; for the abstract first component a, if exists $a_1 \vee a_2 \vee \cdots \vee a_n$ then CF (b, a) = min{CF(H)} i = 1, 2,…n; CF(c, b) has been known, given by expert; CF(H) is the confidence of the different first components of the rule.

Parallel rule: Setting condition of known rule model R_i, rules as follow:

If E_1 then H_i CF(H_i, E_i) i = 1, 2,…n when exists the following multi-regular parallel rule:

If R_1 or R_2 or… orR_n then R(H_i) CF(R(H_i), R_i)

Make:

$$H = \frac{\sum_{i=1}^{n} CF(H_i, E_i)}{i}, \; CF(R(H_i), R_i) = \min\{cf(E_i)\}$$

then R(H_i)'s synthetic confidence is:

$$CF(R(H_i), E_i) = CF(R(H_i), R_i) + H - CF(R(H_i), R_i) \times H$$

APPLICATION EXAMPLE

Examples of relevant parameters' explanation: Part of knowledge showed in Table 1.

Part of rules of rule table showed in Table 2.

Comparison table of part of knowledge parameters of first component of the rule: E(cf(E_i), λ_i), H(cf(H, E))

Comparison table of part of evidences cf(E'_n) from users:

Uncertainty reasoning process of instance: This study introduces the uncertainty reasoning process of expert system by taking processing a component belongs to lathe spindle box (Lu, 2005) for example, details as follow:

- Choosing the different knowledge of first component of the rule.According to the given evidences, it makes the evidence selection in comparison table and the serial number of knowledge in knowledge table correspond

Table 1: Knowledge table

No.	Description of knowledge content
E_1	Small-batch Production
E_2	medium-batch Production
E_3	large-batch production
E_4	HT150
E_5	HT200
E_6	HT350
E_7	cast iron
E_8	cast steel
E_9	accuracy class IT6
E_{10}	accuracy class IT7
E_{11}	accuracy class IT8
E_{12}	surface roughness Ra:0.8~1.6 μm
E_{13}	surface roughness Ra<0.4 μm
E_{14}	Surface
E_{15}	Bearing support hole
E_{16}	Hole diameter ϕ95 mm
E_{17}	Hole diameter ϕ64 mm
E_{18}	Hole diameter ϕ52 mm
E_{19}	Hole diameter ϕ 40 mm
E_{20}	Upper deviation+0.018
E_{21}	Upper deviation+0.025
E_{22}	Lower deviation-0.018
E_{23}	Lower deviation-0.012
E_{24}	Upper deviation+0.018
E_{25}	Lower deviation-0.012
E_{26}	Change the level of original accuracy£¬improve the level of accuracy
H_1	heavy boring-Semi-fine boring-fine boring
H_2	heavy boring-Semi-fine boring-fine boring-delicate boring
H_3	expand-coarse ream-finish ream
H_4	heavy boring-semi-fine boring-fine boring-floating boring cutter fine boring

Table 2: Rule table

No.	Description of rules
R_1	If E_1 and E_5 and E_7 and E_{10} and E_{12} Then H_1 or H_4
R_2	If E_1 and E_5 and E_7 and E_9 and E_{13} Then H_2
R_3	If E_{10} and E_{12} and E_{15} and E_{18} and E_{20} and E_{23} Then H_1
R_4	If E_{10} and E_{19} and E_{24} and E_{25} Then H_1
R_5	If (R_3 and E_{26})or (R_4 and E_{26}) Then H_4

- The corresponding rules in scan rule table, uses the parameters from comparison table of knowledge parameters of first component of rules and according to the equationr of the matching degree of rules to judge which rules are the practicable rules which concluded from the given evidences, details as follow:

  The matching degree of rule R_1:

$$G(R) = 0.15 \times \min\{0.8, 0.85\} \times \frac{\min\{0.8, 0.85\}}{0.8 + 0.85} + 0.2 \times \min\{0.9, 0.95\} \times \frac{\min\{0.9, 0.95\}}{0.9 + 0.95} + 0.2 \times \min\{0.9, 0.95\} \times \frac{\min\{0.9, 0.95\}}{0.9 + 0.95} + 0.2 \times \min\{0.8, 0.85\} \times \frac{\min\{0.8, 0.85\}}{0.8 + 0.85} + 0.25 \times \min\{0.9, 0.8\} \times \frac{\min\{0.9, 0.8\}}{0.9 + 0.8} = 0.38561643$$

Table 3: Knowledge parameters table

	E_1	E_2	E_3	E_4	E_5	E_6
R_1	0.8				0.9, 0.2	
	0.15					
R_2	0.8				0.8, 0.2	
	0.1					
	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}
R_1	0.9			0.8		0.9
	0.2					
	0.2					0.25
R_2	0.9	0.85				
	0.2	0.2				
R_3				0.8,		0.85
				0.2		0.2
R_4				0.9,		
				0.2		
	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}	E_{18}
R_2	0.85					
	0.3					
R_3			0.9			0.9
			0.2			0.2
	E_{19}	E_{20}	E_{21}	E_{22}	E_{23}	E_{24}
R_3		0.85,			0.8, 0.1	
		0.1				
R_4	0.9					0.85
	0.4					0.2
	E_{25}	E_{26}	H_1	H_2	H_3	H_4
R_1			0.9	0.9		
R_2				0.85		
R_4	0.85		0.9			
	0.2					
R_5		0.9, 0.5				0.95

Table 4: Comparison table of part of evidences

No.	Evidence	No.	Evidence
E_1	0.85	E_5	0.95
E_7	0.95	E_9	0.85
E_{10}	0.85	E_{12}	0.80
E_{13}	-0.2	E_{15}	-0.20
E_{18}	0.85	E_{19}	0.85
E_{20}	0.9	E_{23}	0.80
E_{24}	0.85	E_{25}	0.80
E_{26}	0.85		

G(R)'s result greater than the threshold value of rule 0.2, so rule R_1 be activated.

So in a similar way, like the example of R_1, The threshold value of R_2 rule's conclusion is 0.40086195, G(R)'s result greater than the threshold value of rule 0.2, so rule R_2 be activated. The threshold value of R_3 rule's conclusion is 0.39430278, G(R)'s result greater than the threshold value of rule 0.2, so rule R_3 be activated. The threshold value of R_4 rule's conclusion is 0.41029005, G(R)'s result greater than the threshold value of rule 0.2, so rule R_4 be activated.

- Conclude the confidence of supporting rule conclusion according to the activated rules

R_1 correspond the single rule support conclusion, $CF(H) = CF(H, G_n) \times CF(G)$.

The $CF(H, G_n)$ is know, the value is 0.9, uses the Eq. 1, got:

$$\sum_{i=1}^{n} cf(E_i) + cf(E_i') = 0.8+0.85+0.9+0.95+0.9+0.95+0.8+0.85+0.9+0.8) = 8.7$$

$$CF(E_1) = 1 - \frac{0.15 \times (0.8 + 0.85)}{8.7} = 0.9715517$$

$$CF(E_5) = 1 - \frac{0.2 \times (0.9 + 0.95)}{8.7} = 0.9574713$$

$$CF(E_7) = 1 - \frac{0.2 \times (0.9 + 0.95)}{8.7} = 0.9574713$$

$$CF(E_{10}) = 1 - \frac{0.2 \times (0.8 + 0.85)}{8.7} = 0.9715517$$

$$CF(E_{12}) = 1 - \frac{0.25 \times (0.9 + 0.8)}{8.7} = 0.9511494$$

$$CF(E) = \min\{0.9715517, 0.9574713, 0.9574713, 0.9715517, 0.9511494\} = 0.9511494$$

$$CF(H) = CF(H, G_n) \times CF(G) = 0.9 \times 0.9511494 = 0.8560345$$

So, the confidence of R_1 rule's conclusion is 0.8560345.

In a similar way, like the example of R_1, the confidence of R_2 rule's conclusion is 0.86881185;the confidence of R_4 rule's conclusion is 0.80802918.

For rule R_5, it belongs to the multi-rules' parallel rule, chose:

$$CF(R(H_i), R_i) = \min\{cf(E_i)\}\min\{\min(0.886881185, 0.85), \min(0.80802918, 0.85)\} = 0.80802918$$

$$H = \frac{\sum_{i=1}^{n} CF(H,E)}{i} = \frac{0.886881185 + 0.80802918}{2} = 0.84745518$$

So, $R(H_i)$'s synthesize confidence is:

$$CF(R(H_i), E_i) = CF(R(H_i), R_i) + H - CF(R(H_i), R_i) \times H = 0.80802918 + 0.84745518 - 0.80802918 \times 0.84745518 = 0.97071585$$

is rule R_5's conclusion confidence.

By the instance can see, according to the relevant evidences given by users, we can reason out the confidence correspond to relevant rules and the results all over 0.8. Especially the rule R5 almost reach to 0.97, so it

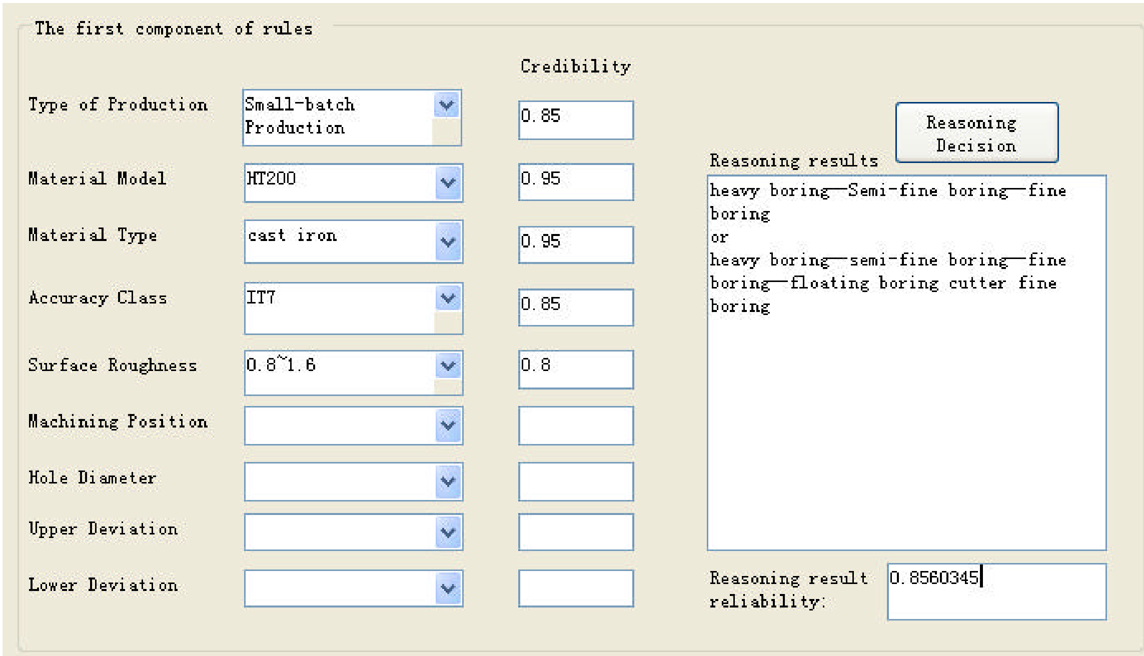

Fig. 1: Expert system reasoning interface

proved that by this study's new algorithm worked in uncertainty reasoning process, the conclusion confidence is basic close to the practical requirements and the reasoning results are better.

Expert system reasoning interface showed in Fig. 1.

CONCLUSION

Combining with the thought of confidence method, this study proposes two new algorithms. One is matching algorithm of rules based on confidence, another is a new algorithm which is used for evidential reasoning in uncertainty reasoning process. This study introduces the uncertainty reasoning process of expert system by taking mechanical product design as an example. It concludes the conclusion confidence more close to the practical requirements and makes the uncertainty problem which has been gotten a good solution in inference engine.And it improved the choosing decision-making function of expert system and enhanced the confidence of reasoning conclusion.

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