Reduction and Push Technology of Cable Harness Information for Complex Mechatronic Products based on Variable Precision Rough Sets

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Abstract: As energy and signal transmission medium, cable harness is widely used in complex mechatronic products, and cable harness information are the basis and premise conditions of the flexible cable harness assembly simulation of complex mechatronic products system. To retrieve cable harness information from the information management system or repository effectively, a push method of cable harness information for complex mechatronic products based on variable precision rough sets (VPRS) was proposed in this paper. By using the cable harness information reduction method, the cable harness information repository is simplified, and rules which can support the precise push also be distilled from the reduct cable harness information repository. On the basis of the above approach, cable harness wiring designers, assembly process planners and assembly process simulation designers can efficiently share cable harness information during all design processes. Finally, a case is employed to validate the proposed method of this paper.

1 INTRODUCTION

Complex mechatronic products like aerospace vehicles, satellites, aircraft engine, rocket engine, missile and automobile are the complex systems, which composed of mechanical structures, electrical equipments, control equipments, detect equipments (Zhong, 2007), etc. Involved in many disciplinary, complex manufacturing processes, more test links, and long development cycle are the main characteristics of those products. Developing complex mechatronic products requires intensive collaboration between engineers of the mechanical, electronic, control, and software domains in a design team (Bolón-Canedo et al., 2013, Wang et al., 2002, M, 2002). Moreover, the complex mechatronic products design is a typical information or knowledge-intensive process, and involved in complicated interactions among multidisciplinary design teams in a distributed, heterogeneous and dynamic environment, including cooperation, coordination, and communication(Chen et al., 2008, Shen et al., 2000).

As energy and signal transmission medium, cable harness is widely used in complex mechatronic products in fields such as aviation, aerospace, automobile and shipbuilding industry, it is the “link” between electrical equipments and every extension module, the quality of the cable harness wiring has become an important indicator to treasure overall performance and reliability of products (Ning et al., 2009, Shang et al., 2012).

In engineering applications, the cable harness has a complex topology structure covering a lot of geometric topology information, engineering semantic information, management attribute information, physical attribute information, cable harness material information, cable harness auxiliary material information, electrical connector information, electrical function information and decentralized wiring information, et al. Each class of the above information contains additional sub-information, such as physical attribute information of cable harness contains cable harness weight, cable harness density, bending property, tensile property and minimum bending radius, et al.

As is well know, enterprises often occurring

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"massive information" and "information flood" phenomenon frequently due to the increasing of cable harness wiring information, and some information in the repository are redundant and not important for the designers. Consequently, designers spent more and more time to retrieve information from the information management system, and even difficult to retrieve information that meets the design requirements, which are adverse to the cable harness wiring design information sharing and reuse, and also hindered improvement design efficiency and level of the designers (Ji et al., 2013). How to manage the existing cable harness wiring design information effectively and extract guiding significant rules accurately from the vast amounts of cable harness wiring design information have become the key point for enterprises to improve complex mechatronic products development speed and shorten the development cycle.

Information reduction of cable harness is one of the processing techniques, and different methods and tools have been proposed for effective and efficient reduction of information (Farahat et al., 2013, Dai et al., 2013, Ramentol et al., 2012, G et al., 2007). The aim of reduction is to find a minimal attribute subset of the original datasets that is the most informative, and all other attributes can be deleted from the databases with the minimal information loss. Then, on this base, implement the right cable harness wiring designer with the right information in the right place at the right time and at the right cost(Li and Yin, 2009, Naeve, 2005), that is realize the precise information pushing.

2 CABLE HARNESS INFORMATION MODEL AND COLLABORATIVE DESIGN WORK MODEL

2.1 Cable Harness Information Model

The cable harness information model (as shown in Figure 1) mainly describes the relevant information of cable harness properties, such as cable harness geometry information, cable harness physical attribute information, cable harness topology information, cable harness electrical functional information, etc.; each kind of information represents the actual working state information content of cable harness.

In the assembly simulation of complex mechatronic products system of flexible cable harness, wiring design determines the assembly process, assembly process is the basis of assembly process simulation, while cable harness information model is the basis and premise conditions of the above works, and also is the data source which required for each above phase.

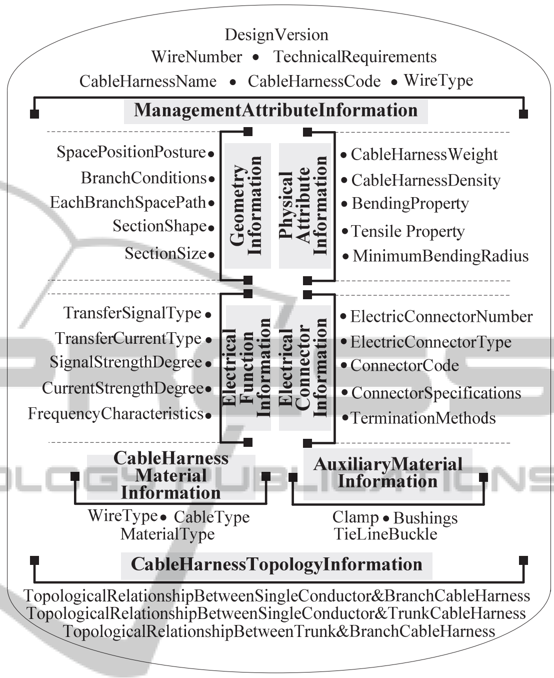

Figure 1: Cable harness information model of complex mechatronic products.

2.2 Collaborative Design Work Model

In this paper, we have built a collaborative design work model for complex mechatronic products, and shown in Figure 2. In this model, we transform the collaborative design task into a whole problem solving task. By applying the task decomposition method and principle, the whole problem solving task will be decomposed into several subtasks: $T_1, T_2, \cdots, T_n$; then allocate these subtasks to the multi-design teams which are set up on the basis of common consensus, trust, and cooperation. Each design team solve its own subtask and composite all the sub solutions ultimately.

The collaborative design work model established in this paper mainly composed of three layers (as shown in Figure 2.): management layer of design organization, management layer of design task and management layer of design activity. The detail description of each layer as follows.

(1) *Management Layer of Design Organization:* to complete the task and realize the goal of the

organization, the project manager must develop a practical and effective form of organization structure according to the situation of the enterprise and the project itself combine each subsystems design experts, designer, analyst, and other participants.

(2) *Management Layer of Design Task:* the main responsibility of this layer is to determine the overall goals and tasks of the product design, and decompose the overall tasks into a series of subtasks combine relevant decomposition principles. The reasonable allocation of those subtasks also finished in this layer.

(3) *Management Layer of Design Activity:* in this layer, each collaborative design team completes the allocated subtask on the collaborative work platform, and implement the task that pushes the design information to the designer in accordance with certain design rules. During the whole design process, collaborative design teams will share and reuse the design information or resources in real time among each other.

Collaborative work platform is the basic foundation for the complex mechatronic products design; it has the necessary hardware and software environment, and also includes the design specifications, resource library and information or knowledge base, covering multiple aspects of the personnel organization, resource allocation, process management and design results concentration, etc. The designers can share the product data material and design resources through the collaborative work platform, and thereby discuss and modify the design solutions.

3 CABLE HARNESS INFORMATION REDUCTION AND PUSH METHOD

The variable precision rough sets model (VPRS), firstly proposed by Ziarko (W., 1993), is an effective mathematical tool with an error-tolerance capability to handle uncertainty problem. Basically, the VPRS

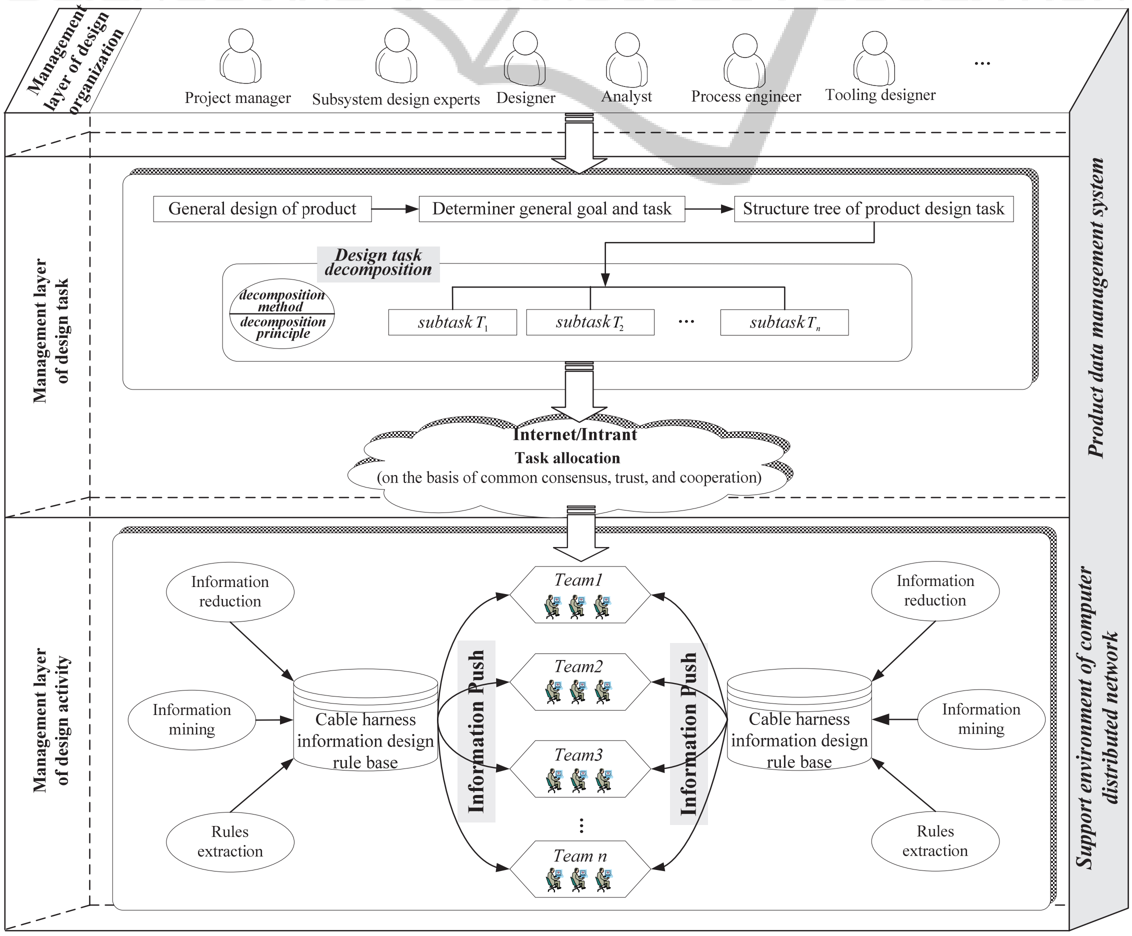

Figure 2: Collaborative design work model for complex mechatronic products.

is an extension of Pawlak's rough set theory (Pawlak, 1991, Pawlak, 1982), allowing for partial classification. By setting a confidence threshold value β, the VPRS cannot only solve classification problems with uncertain data and no functional relationship between attributes, but also relax the rigid boundary definition of Pawlak's rough set model to improve the model suitability. Due to the existence of β, the VPRS can resist data noise or remove data errors (Śle¸zak and Ziarko, 2005). In this paper, we use the approach of VPRS to implement cable harness information reduction and push.

3.1 Roughening Description of Cable Harness Information Push based on VPRS

In this section, we introduce the roughening description method of cable harness information push based on VPRS, and briefly review some notions related with VPRS which can be found in (Ye et al., 2014, Li and Yin, 2009, Mi et al., 2004, GY, 2001, W, 1993).

In form, a quadruple $S=(U,A,V,f)$ is an information system (or called a cable harness information push decision system). Where, $U=\{x_1,x_2,\cdots,x_n\}$ is a non-empty finite set of objects called the universe; each object of universe U represents a case of design (or browsing history of cable harness information) in complex mechatronic products design process. A is a non-empty finite set of attributes, and $A=C\bigcup D$; where C represents condition attribute set, $D=\{d\}$ is decision attribute set, $C\bigcap D=\varnothing$; here, we let the condition attribute set C as the cable harness information attribute, and let the decision attribute set $D=\{d\}$ as the design proposal that the designer will be referenced in a new product development task. An attribute can be defined as $a:U\to V_a$ for every $a\in A$, where $V=\bigcup V_a$ and the set V_a is called the value set of a. $f:U\times A\to V$ is an information function such as for any $a\in A$ and $x\in U$, $f(x,a)\in V_a$. f defines the mapping relationship between the cable harness information and its attribute values.

Definition 1 (*Indiscernibility Relation*). Let $S=(U,A,V,f)$ be a cable harness information push decision system, then with any $B\subseteq A$ there is associated an equivalence relation:

$$IND_A(B)=\{(x,y)\in U^2\mid f(x,a)=f(y,a),\forall a\in B\} \quad (1)$$

Where $IND_A(B)$ is called the $B-$ *indiscernibility relation*. The equivalence classes of the $B-$ *indiscernibility relation* are denoted $[x]_B$ or $U/IND(B)$, it can be abbreviated as U/B.

Definition 2 (*Lower Approximations and Upper Approximations*). Let $S=(U,A,V,f)$ be a cable harness information push decision system and let $X\subseteq U, B\subseteq A$, we can approximate X using only the information contained in B by constructing the $B-$*lower* and $B-$*upper approximations of* X, denoted $\underline{R_B}(X)$ and $\overline{R_B}(X)$ respectively, where

$$\underline{R_B}(X)=\{x\in U\mid [x]_B\subseteq X\}=\bigcup\{[x]_B\mid [x]_B\subseteq X\} \quad (2)$$

and

$$\overline{R_B}(X)=\{x\in U\mid [x]_B\bigcap X\neq\varnothing\}=\bigcup\{[x]_B\mid [x]_B\bigcap X\neq\varnothing\} \quad (3)$$

The lower approximation $\underline{R_B}(X)$ is the set of objects that belong to X with certainty, while the upper approximation $\overline{R_B}(X)$ is the set of objects that possibly belong to X.

Definition 3 (*Consistent and Inconsistent Cable Harness Information Push Decision System*). Let $S=(U,A,V,f)$ be a cable harness information push decision system, C represents condition attribute set, $D=\{d\}$ represents decision attribute set, denote equivalence relation:

$$R_C=\{(x_i,x_j)\mid f_c(x_i)=f_c(x_j),c\in C\} \quad (4)$$

and

$$R_d=\{(x_i,x_j)\mid f_d(x_i)=f_d(x_j),d\in D\} \quad (5)$$

If $R_C\subseteq R_d$, then $S=(U,C\bigcup D,V,f)$ is called *consistent cable harness information push decision system,* otherwise it is called *inconsistent cable harness information push decision system*.

Definition 4 (*Discernibility Matrix of Consistent Decision System*). Let $S=(U,A,V,f)$ be a cable harness information push decision system, C represents condition attribute set, $D=\{d\}$ represents decision attribute set, denote:

$$U/R_C=\{[x_i]_C\mid x_i\in U\} \quad (6)$$

$$U/R_d=\{[x_i]_d\mid x_i\in U\} \quad (7)$$

and

$$D_d([x_i]_C,[x_j]_C)=\{a_k\in C\mid f_k(x_i)\neq f_k(x_j)\} \quad (8)$$

Where, $[x_i]_d\bigcap[x_j]_d=\varnothing$. When $[x_i]_d\bigcap[x_j]_d\neq\varnothing$,

$D_d([x_i]_C,[x_j]_C)=\varnothing$, then $D_d([x_i]_C,[x_j]_C)$ is called decision discernibility set about $[x_i]_C$ and $[x_j]_C$, while,

$$DMatrix=(D_d([x_i]_C,[x_j]_C)\,|\,[x_i]_C,[x_j]_C\in U/R_C) \tag{9}$$

is called the discernibility matrix of consistent decision system.

Definition 5 (*Probability Distribution Function*). Let $S=(U,A,V,f)$ be a cable harness information push decision system and $B\subseteq C$. Denote:

$$R_B=\{(x_i,x_j)\,|\,f_k(x_i)=f_k(x_j),c_k\in B\} \tag{10}$$

and

$$U/R_B=\{[x_i]_B\,|\,x_i\in U\} \tag{11}$$

$$U/R_d=\{P_1,P_2,\cdots,P_r\} \tag{12}$$

Where, $[x_i]_B=\{x_j\,|\,(x_i,x_j)\in R_B\}$. For $\forall x_i\in U$, let $P(P_j/[x_i]_B)=|P_j\cap[x_i]_B|/|[x_i]_B|,(j\le r)$, then, define

$$\mu_B(x_i)=(P(P_1/[x_i]_B),P(P_2/[x_i]_B),\cdots,P(P_r/[x_i]_B)) \tag{13}$$

is the probability distribution functions of the U/R_d .

Definition 6 (*β Lower and Upper Approximations*). Let $S=(U,A,V,f)$ be an inconsistent cable harness information push decision system. Let $\beta\in(0.5,1]$, $A=C\cup D$, $B\subseteq C$, for $X\subseteq U$, denote:

$$\begin{aligned}\underline{R_B^\beta}(X)&=\{x_i\in U\,|\,P(X/[x_i]_B\ge\beta\}\\&=\bigcup\{[x_i]_B\,|\,P(X/[x_i]_B\ge\beta\}\end{aligned} \tag{14}$$

$$\begin{aligned}\overline{R_B^\beta}(X)&=\{x_i\in U\,|\,P(X/[x_i]_B)>1-\beta\}\\&=\bigcup\{[x_i]_B\,|\,P(X/[x_i]_B)>1-\beta\}\end{aligned} \tag{15}$$

$\underline{R_B^\beta}(X)$ and $\overline{R_B^\beta}(X)$ are called β lower approximation and β upper approximation, respectively. Where $P(X/Y)=|X\cap Y|/|Y|$ if $|Y|>0$, and $P(X/Y)=1$ otherwise. $|X|$ is the cardinality of the set X .

Definition 7 (*β Upper and Lower Distribution discernibility matrices*)**.** Let $S=(U,C\cup D,V,f)$ be an inconsistent cable harness information push decision system. $U/R_C=\{C_1,C_2,\cdots,C_m\}$. Denote:

$$D_1^{*\beta}=\{([x]_C,[y]_C)\,|\,M_C^\beta(x)\ne M_C^\beta(y)\} \tag{16}$$

$$D_2^{*\beta}=\{([x]_C,[y]_C)\,|\,G_C^\beta(x)\ne G_C^\beta(y)\} \tag{17}$$

Where, $M_C^\beta(x)=\{P_j\,|\,x\in\overline{R}_C^\beta(P_j)\},x\in U$; $G_C^\beta(x)=\{P_j\,|\,x\in\underline{R}_C^\beta(P_j)\},x\in U$. Denoted by $f(C_i,a_k)$ the value of a_k about the objects in C_i . Define

$$D_l^\beta(C_i,C_j)=\begin{cases}\{a_k\in C\,|\,f(C_i,a_k)\ne f(C_j,a_k)\}, & (C_i,C_j)\in D_l^{*\beta},\\ C, & (C_i,C_j)\notin D_l^{*\beta},\end{cases}\quad l=1,2. \tag{18}$$

then $D_1^\beta(C_i,C_j)$ and $D_2^\beta(C_i,C_j)$ are the β upper and lower distribution discernibility attribute sets respectively. Here, we denote:

$$DMatrix_1^\beta=(D_1^\beta(C_i,C_j)\,|\,i,j\le m) \tag{19}$$

and

$$DMatrix_2^\beta=(D_2^\beta(C_i,C_j)\,|\,i,j\le m) \tag{20}$$

and they are called β upper and lower distribution discernibility matrices respectively in the cable harness information push decision system.

Definition 8 (*Decision Matrix*). Let $S=(U,C\cup D,V,f)$ be a cable harness information push decision system, $S(B)=(U_B,B\cup D,V,f)$, $\forall\beta\in(0.5,1]$ is an attribute reduction decision table after attribute reduction. Let $X_i^+(i=1,2,\cdots,p)$ and $X_j^-(j=1,2,\cdots,q)$ represent the equivalence class of the relation $R^*(B)$. Where, $X_i^+\subseteq Pos_B^\beta(P_r),X_j^-\subseteq Neg_B^\beta(P_r)$, then, define the decision matrix

$$M=(c_{ij})_{p\times q}(i=1,2,\cdots,p;j=1,2,\cdots,q) \tag{21}$$

as

$$c_{ij}=\{(a,f(X_i^+,a))\,|\,a\in B,f(X_i^+,a)\ne f(X_j^-,a)\} \tag{22}$$

Given an equivalence class X_i^+ , take each element of M as a Boolean expression, then the decision rule sets can be expressed as the following Boolean function

$$\alpha_i=\bigwedge_j(\vee c_{ij}) \tag{23}$$

Hence, we can calculate the minimal disjunctive normal form, and get the rule sets of P_r . The rule's support can also be calculated out.

3.2 Rules Generate and Cable Harness Information Push Method based on VPRS

Rule extraction is one of the major forms of data mining and is perhaps the most common form of cable harness information discovery in cable harness information push decision systems (Li et al., 2013, Fan et al., 2005, Mi et al., 2004). To implement rules extraction, two definitions will be given firstly.

Definition 9 (*decision rule*). Given a decision table: $S=(U,C\bigcup D,V,f)$. Let $X\in U/IND(C)$, $Y\in U/IND(D)$, $\forall x\in X$,

$$des_C(X)=\underset{\forall c\in C}{\wedge}(c,c(x)) \tag{24}$$

represents the description of the equivalence class X; $\forall y\in Y$,

$$des_D(Y)=\underset{\forall d\in D}{\wedge}(d,d(x)) \tag{25}$$

represents the description of the equivalence class Y. Define

$$r:des_C(X)\rightarrow des_D(Y), Y\bigcap X\neq\varnothing \tag{26}$$

is the decision rule from X to Y.

Definition 10 (*support of rule r*). Let $S=(U,C\bigcup D,V,f)$ be a cable harness information push decision system, U is called the universe. For each rule $r:des_C(X_i)\rightarrow des_D(Y_j)$, the support can be defined as:

$$Sup(r)=\left|X_i\wedge Y_j\right|/\left|U\right| \tag{27}$$

4 CASE STUDY

To implement the cable harness information push, we designed a decision table like Table 2, and the meaning of each symbol represents can see in Table 1.

Table 1: The meaning of each symbol represents.

Symbol	Meaning	Symbol	Meaning
a_1	stray electromagnetic field	1	capacitance weakness
a_2	cable harness insulation strength	2	capacitance strong
a_3	degree of coupling crosstalk	3	low degree of coupling crosstalk
a_4	distributed capacitance	4	general degree of coupling crosstalk
d	wiring quality of cable harness	5	high degree of coupling crosstalk
Q_1	high quality	6	$M\Omega>300$
Q_2	general quality	7	$100\leq M\Omega\leq 300$
Q_3	low quality	8	$M\Omega<100$

Table 2: Decision table of cable harness information push.

U	C				D
	a_1	a_2	a_3	a_4	d
x_1	1	4	5	8	Q_1
x_2	2	3	6	7	Q_2
x_3	1	4	6	8	Q_3
x_4	2	3	5	7	Q_3
x_5	1	4	6	8	Q_3
x_6	1	4	6	8	Q_2
x_7	1	4	5	8	Q_1
x_8	2	3	6	7	Q_2

According to the equivalence relation R_C and R_D on U, Let
$C_1=[x_1]_A=\{x_1,x_7\}$, $C_2=[x_2]_A=\{x_2,x_8\}$,
$C_3=[x_3]_A=\{x_3,x_5,x_6\}$, $C_4=[x_4]_A=\{x_4\}$.
$D_1=[x_1]_D=\{x_1,x_7\}$, $D_2=[x_2]_D=\{x_2,x_6,x_8\}$,
$D_3=[x_3]_D=\{x_3,x_4,x_5\}$.

The partitions on the universe U generated by the equivalence relation R_C and R_D are $U/R_C=\{C_1,C_2,C_3,C_4\}$, $U/R_D=\{D_1,D_2,D_3\}$. Due to $R_A\not\subset R_D$, the Table 2 is an inconsistent cable harness information push decision table according to the definition 3. Then we use the processing method for the inconsistent decision table to calculate the probability distribution functions on the equivalence class U/R_C, and the results are

$\mu_A(x_1)=\mu_A(x_7)=(1,0,0)$, $\mu_A(x_2)=\mu_A(x_8)=(0,1,0)$,
$\mu_A(x_3)=\mu_A(x_5)=\mu_A(x_6)=(0,1/3,2/3)$,
$\mu_A(x_4)=(0,0,1)$.

When the classification error $\beta=0.7$, the upper approximation set of the set D_1, D_2 and D_3 about the relation R are as follows respectively:

$\overline{R}_A^{0.7}(D_1)=\{x_1,x_7\}$, $\overline{R}_A^{0.7}(D_2)=\{x_2,x_3,x_5,x_6,x_8\}$,
$\overline{R}_A^{0.7}(D_3)=\{x_3,x_4,x_5,x_6\}$.

So we have

$M_A^{0.7}(x_1)=M_A^{0.7}(x_7)=\{D_1\}$,
$M_A^{0.7}(x_2)=M_A^{0.7}(x_8)=\{D_2\}$,
$M_A^{0.7}(x_3)=M_A^{0.7}(x_5)=M_A^{0.7}(x_6)=\{D_2,D_3\}$,
$M_A^{0.7}(x_4)=\{D_3\}$.

And the decision discernibility set is

$D_1^{*0.7}=\{(C_1,C_2),(C_1,C_3),(C_1,C_4),(C_2,C_3),(C_2,C_4),(C_3,C_4)\}$.

Because

$D_1^{0.7}(C_1,C_2)=\{a_1,a_2,a_3,a_4\}$,

$D_1^{0.7}(C_1,C_3)=\{a_3\}$, $D_1^{0.7}(C_1,C_4)=\{a_1,a_2,a_4\}$,

$D_1^{0.7}(C_2,C_3)=\{a_1,a_2,a_4\}$,

$D_1^{0.7}(C_2,C_4)=\{a_3\}$, $D_1^{0.7}(C_3,C_4)=\{a_1,a_2,a_3,a_4\}$.

So we construct the upper approximation discernibility matrix is ($\beta=0.7$):

$$DMatrix_1^{0.7}=\begin{bmatrix}\{a_1,a_2,a_3,a_4\} & & & \\ \{a_1,a_2,a_3,a_4\} & \{a_1,a_2,a_3,a_4\} & & \\ \{a_3\} & \{a_1,a_2,a_4\} & \{a_1,a_2,a_3,a_4\} & \\ \{a_1,a_2,a_4\} & \{a_3\} & \{a_1,a_2,a_3,a_4\} & \{a_1,a_2,a_3,a_4\}\end{bmatrix}.$$

and the upper distribution discernibility formula we solve is

$$\begin{aligned}M_1^{0.7}&=(a_1\vee a_2\vee a_3\vee a_4)\wedge(a_1\vee a_2\vee a_4)\wedge a_3\\&=(a_1\wedge a_3)\vee(a_2\wedge a_3)\vee(a_3\wedge a_4).\end{aligned}$$

From the upper distribution discernibility formula, we know that the attribute sets $\{a_1,a_3\}$, $\{a_2,a_3\}$ and $\{a_3,a_4\}$ are the three distribution reduction of the cable harness information push system (here, accuracy is 0.7), and the attribute a_3 is core attribute.

To obtain the push rule sets of cable harness information, we must construct the decision matrixes of the set D_1 , D_2 and D_3 . Select a set $RED_B=\{a_1,a_3\}$ from the attribute reduction sets, and its equivalence class can be denoted as $U/RED_B=\{C_1,C_2,C_3,C_4\}$. The discernibility matrices we solved for D_1, D_2 and D_3 are shown in Table 3, Table 4 and Table 5.

Table 3: Discernibility matrix of decision D_1.

	C_2^-	C_3^-	C_4^-
C_1^+	$(a_1,1)$ $(a_3,5)$	$(a_3,5)$	$(a_1,1)$

Table 4: Discernibility matrix of decision D_2.

	C_1^-	C_3^-	C_4^-
C_2^+	$(a_1,2)$ $(a_3,6)$	$(a_1,2)$	$(a_3,6)$

Table 5: Discernibility matrix of decision D_3.

	C_1^-	C_2^-	C_3^-
C_4^+	$(a_1,2)$	$(a_3,5)$	$(a_1,2)$ $(a_3,5)$

Table 6: Push rule sets and supports.

Rules	Supports (%)
$r_1:(a_1=1)\wedge(a_3=5)\to(d=Q_1)$	25
$r_2:(a_1=2)\wedge(a_3=6)\to(d=Q_2)$	25
$r_3:(a_1=2)\wedge(a_3=5)\to(d=Q_3)$	12.5

On the basis of discernibility matrices, the minimum disjunctive normal form (DNF) of the Table 3, Table 4 and Table 5 can be expressed as follows:

$$B_1(D_1)=((a_1=1)\vee(a_3=5))\wedge(a_3=5)\wedge(a_1=1)=(a_3=5)\wedge(a_1=1).$$

$$B_1(D_2)=((a_1=2)\vee(a_3=6))\wedge(a_1=2)\wedge(a_3=6)=(a_1=2)\wedge(a_3=6).$$

$$B_1(D_3)=(a_1=2)\wedge(a_3=5)\wedge((a_1=2)\vee(a_3=5))=(a_1=2)\wedge(a_3=5).$$

To sum up the above analysis, the push rule sets and its supports of the cable harness information are express at the Table 6. The support size of the cable harness information rules reflects the degree of information which the designers used. For all cable harness information push rule sets, low support rules should be eliminated. In practice, we can set a threshold of support (e.g. 15%), support is less than the threshold will be eliminated, and push the cable harness information to designers will be more accurately.

5 CONCLUSIONS

This research focuses on the techniques of cable harness information reduction and push. By using those techniques, the design repository is simplified and we can extract rules which can support the precise push of cable harness information. And the methods or techniques proposed in this paper will play an important role in the field of flexible cable harness assembly simulation for complex mechatronic products. Though significant progress has been made on cable harness information reduction and push, there is still much work to be conducted in the future, such as ontology modelling and representation of cable harness information, evaluation of the effect of a cable harness information push, among others.

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