Dynamic Workflow Modeling Based on Product Structure Tree

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Abstract: In order to solve the dynamic modification problem of workflow model in product development process, a method of dynamic workflow modeling is presented based on product structure tree (PST). In the method, a dynamic node was introduced into a workflow template, and the refinement rule of a dynamic node was proposed. Through mapping the components of PST onto the workflow template, the component instances and their affiliation used as refinement input elements, then the dynamic workflow nodes were refined. Validation in the actual engineering case of large-scale antenna development shows that the workflow instance was constructed dynamically at run-time.

Keywords: Product Structure Tree, Dynamic Node, Workflow Refinement Rule, Workflow Instantiating Algorithm.

1. Introduction

Product development process (PDP) is one of the most important business processes for enterprises but it has difficulty in workflow management because of the uncertain and dynamic characteristics. Thus, even though there have been many workflow modeling and management methods, they have limitations to deal with the special characteristics of PDP[1]. For example, utilizing Workflow Management System the large-scale antenna development should integrate hundreds of design links and tasks such as structure design, electrical properties simulation, servo-control, etc., and achieve real-time transmission of design state and data for the demand of product collaborative design. Up to the present, most of workflow management systems (WFMSs) are difficult to meet the demand of PDP, and dynamic workflow modeling has been one of the bottleneck problems. At present, there are two main ways for modeling in WFMSs: the first way uses manual modeling, which the workflow activities and their relations are modeled manually. Another way uses automatic modeling with workflow template, which the workflow templates of general business were constructed by administrator of WFMSs and stored in database in advance. When users executed a task, the workflow model was constructed automatically through selecting the workflow template for the task. This way was adopted in the field of office automation (OA) and product data management (PDM), such as render an account in financial system and design approval in product development.

However, the above-mentioned methods can't meet the demands of workflow modeling in PDP compared with OA and PDM, the workflow models for PDP are more complicated. Firstly, the workflow of product development is very complicated. The development of complex product has hundreds of participants and can produce thousands of design tasks. The relationship between tasks is very complicated. Obviously, the workload of manual modeling is extensive, so it has not engineering feasibility. Secondly, the workflow of product development is a dynamic model. The model is closely related with the product structure which was gradually designed and achieved in PDP. Therefore, the workflow model of product development should be gradual made and refined, it is a dynamic model. So the static workflow template can't meet the dynamic demand.

In fact, much work has been carried out on dynamic workflow modeling [2–9]. The literature [3–5] proposed various methods for flexibility workflow modeling with dy-
dynamic refinement, but didn’t involved the problem product structure influencing on model flexibility, and didn’t involved the process knowledge maintenance and reuse. The literature[6–9] proposed automatic generation of workflow processes based on BOM or Product Data Model. However, the workflow model is not available on product development in fact, is a theoretical model.

The above research indicated the method of dynamic workflow modeling, but in practical application, the rules and input elements for model refinement must be formulated. Obviously, there are various rules and input elements in different applying fields. The reports of refinement rules and input elements for workflow modeling in PDP are unknown so far. The aim of this study was to develop a method that would addressed these two problems.

A dynamic workflow modeling method based on product structure tree(PST) is proposed in this paper. In the method, the component instance and their affiliation used as refinement input element, through mapping the PST onto the component workflow template, the dynamic workflow node was refined, then the workflow model for product development was accomplished.

2. Overview of the approach

The workflow instance is changing with the product structure in PDP, the model can’t be constructed with static workflow template in advance. However, the frame of PDP and the workflow of basic component are relatively fixed; the changing factors can be encapsulated with the dynamic node. Then through refinement for the workflow frame containing the dynamic node based on the PST, the workflow instance of the whole product development can be dynamically constructed at run-time.

The method process was shown in Fig.1 The design workflow template repository(DWTR) is a set of workflow model constructed in advance. There are two kinds of workflow template in DWTL, one is general workflow template for basic components, which was stored by the structure and design characteristics; another one is design frame template for the whole products or their complex components, which contained the dynamic node needing be regenerated at run-time. W₀ is a workflow frame template for product C₀, W₁, ..., Wₙ are general workflow templates, their definition can be seen in section 3.1. The PST is a composite of the part and assembly instance(C₀, ..., Cₙ), instance type and their affiliation. In PDP, the DWTL is static, but the PST is dynamically changing.

3. Constructing dynamic workflow template

3.1. Workflow template definition

Workflow representation can take a number of forms, the models include Petri nets, Unified Modeling Language (UML), Business Process Modeling Notation (BPMN), Directed Network Graph (DNG) and their extension forms [10]. The workflow templates for special product components were constructed with DNG in this paper. The workflow template is a formal description for design process knowledge and experience, and corresponding to a independent work task. For reusing in workflow modeling, each workflow template has been encapsulated with task node [11] WTN, WTN can be a simple design task or a complicated task comprising various sub-tasks.

A WTN is a tuple (TName, TType, CType, Pri, Cp, Dp, Act, CtrlF, DataF);

TName is an identifying property;
TType is a template classification property;
CType is a component type for mapping onto the component;
Pri is the priority for selecting the template automatically, the value range is 0–9, the bigger the numeric of Pri is, the higher priority the template can be selected;
Cp is a set of control ports, includes CI(input control ports) and CO(output control ports), the value of control port is Boolean, which is deduced by activity data.
Dp is a set of data ports, includes DI(input data ports) and DO(output data ports), each data port represent a data field of design task template, the type of data field can be string, number and data file;
Act is a set of the design activities, Act = {A₁, ..., Aⱼ} (j ≥ 0), Aⱼ is a sub-node of the WTN;

CtrlF and DataF are the two views( Control Flow and Data Flow[12]) for activity sequence(shown in Fig.2). CtrlF is the object of control flow representing control routing of Act. CtrlF = {Clink₁, ..., Clinkk}.Clink is
a connect line object comprising two control ports of activities, $Clink = \{Cs, Ce, Con\}$. $Cs$ is the start control port of connect line, $Ce$ is the end control port of connect line, $Con$ records the control conditions of connect line, the result of $Con$ is a Boolean value. While $Cs$ and $Con$ are true, the connect line of $Clink$ is enabled. While $Con, Cs$ and $Ce$ are true, the activity includes $Ce$ is activated.

$Clink \subseteq A_{cp} \times A_{cp}, A_{cp}$ is the union set of whole $Cp$.

$DataF$ is the object of data flow, $DataF = \{Dlink_1, ..., Dlink_i\}$. $Dlink$ is a connect line object comprising two data ports of activities, $Dlink = \{Ds, De, f\}, f : Ds \rightarrow De, Ds$ is the start data port of connect line, $De$ is the end data port of connect line, $f$ is the mapping relation of $Ds$ and $De$. $Dlink \subseteq A_{dp} \times A_{dp}, A_{dp}$ is the union set of whole $Dp$.

3.2. Workflow template classification

According to the structure, workflow template nodes can be classified Atom Node($AN$), Compound Node($CN$) and Dynamic Node($DN$), as shown in Table 1.

1. $AN$ is the simplest workflow template form, which represents a design task cannot be subdivided.

2. $CN$ is a complex workflow template including several sub-nodes, each sub-node can reference other workflow template node.

3. $DN$ is a special workflow template form. In PDP, the component of product and assembly is dynamic change, so the workflow template couldn’t be constructed in the design time.

<table>
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<tr>
<th>$TTtype$</th>
<th>$CType$</th>
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<th>$Dp$</th>
<th>$Act$</th>
<th>$CtRF$</th>
<th>$DataF$</th>
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<tr>
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<td>non-</td>
<td>non-</td>
<td>non-</td>
</tr>
<tr>
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</tr>
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4. Mapping workflow templates onto PST

Mapping workflow templates onto PST is the premise to instantiate the frame node. Based on the component type, search the workflow template database and map the matching workflow template onto the node of PST. A PST saves the assembly relationship of product components, so it can be described a tuple ($C, R_c$). $C$ is a finite set of components, $C = \{C_0, C_1, ..., C_n\}, R_c$ is a finite set of components relationship, $R_c = \{< C_0, C_1 >, < C_0, C_2 >, ..., < C_i, C_j >\}, R_c \subseteq C \times C$.

The process of getting the workflow template mapped onto the component $C_i$ was shown in Fig. 3, the $WTN$ was extracted from workflow template database filter by the component type $CType_i$. Through cycling treatment, all of mapping $WTN$ for PTS were extracted, then the set ($R_{cw}$) of component and workflow template relationship was constructed, $R_{cw} = \{< C_1, WTN_1 >, < C_2, WTN_2 >, ..., < C_i, WTN_j >\}$.

5. Instantiating workflow template

5.1. Workflow instance definition

The workflow instance(WI) is a run-time model constructed for controlling detail PDP based on WTN and instance
5.3. Dynamic node refinement

As shown in Table 1, the Dp, Act, CtrlF and DataF in DN are null, the essence of DN refinement is to accomplish the configuration of them in run-time. The steps of DN refinement are as follows: step 1. extract the children components from the current assembly component mapping the DN; step 2. map each child component and obtain the mapped WTN; step 3. instantiate the each mapped WTN and insert the instance into the Act of DN instance; step 4. connect the control and data flow.
workflow template $WTN_0$ control flow of antenna product design. In the $WTN_0$, the sub node “Subsystem Design” is a $DN$ node, others are $AN$ nodes, so the $WTN_0$ is a frame template. Based on the algorithm, instantiate the each sub node in the $WTN_0$ by order, after refining the $DN$ node “Subsystem Design”, the control flow $WTN_0$ was shown in Area ⑤, the parent node of “Subsystem Design” was mapped onto $C_0$. $C_0$ has three children components ($C_1$, $C_2$, and $C_3$). Through mapping the $WTN$ onto children components, the mapping relations of component and $WTN$ were constructed. As shown in Fig.6, $WTN_1$ was mapped onto $C_1$. The instance ($F_1$) of $DN$ node was refined by sub instances (“Structure System Design”($WTN_1$), “RF System Design” and “Servo System Design”) connected in parallel. $WTN_1$ is also a frame template including the DN node “Component Design”. Through recursive instantiation of all sub nodes, the instance $WTN_0$ was constructed. In fact, the instance of antenna product design is large scale, only a small part was shown in Fig.6.

Based on the method in this paper, the Product Design Process Management System (PDPMS) was implemented and the main interface of PDPMS was shown in Fig.7. In PDPMS the $WTN$ database of large-scale antenna struc-
Figure 6 The WTN instantiation of a certain type antenna
tured design was constructed, then the workflow model can be obtained dynamically in run-time based on the PTS.

Figure 7 The interface of product design process management

7. Conclusion

In this paper, we have presented an approach to deal with modification of product design workflow with changing of PST. The workflow template was encapsulated by task node WTN. In run-time, the WTN was mapped onto the node of PST, and the dynamic node was refined based on the PST, finally the instance of workflow was constructed. With the method, the dynamic node in WTN has increased the flexibility of the workflow template and decreased significantly the workload of building the workflow model in manual.

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References


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