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A Knowledge-Based Engineering APP Framework for Enhancing Reuse and Efficiency in Complex Product Design Collaboration

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Abstrat:

The design and development of complex products require multidisciplinary collaboration and cooperation among distributed teams. Designers have accumulated extensive heterogeneous knowledge, such as design expertise, processes, examples, and analysis programs. Traditional simulation methods are discipline-specific and inefficient in sharing and reusing models in a collaborative environment. This heterogeneity and disciplinary barriers hinder efficient collaboration.To improve this, we propose a knowledge structure based on engineering applications (APPs) that supports the rapid reuse and service of product knowledge. This approach aims to enhance the efficiency of knowledge utilization and the overall design process in complex product development.

Keywords:

Simulation models, Engineering-APP, Complex Product development.

1. Introduction

In the actual complex product development process, due to the differences in design activities and design tools, enterprise designers have accumulated a large number of private design software programs, calculation formulas and models, etc. These dynamic design knowledge resources are scattered in personal computers or servers for relevant personnel to use, it is easy to lose this kind of knowledge due to changes in personnel positions and server changes, resulting in a waste of dynamic knowledge design resources. Due to the decentralized nature of such dynamic knowledge storage, there is no unified management mechanism, resulting in the inability to effectively realize the sharing of dynamic knowledge design resources. At the same time, this kind of dynamic knowledge has poor portability, and each application needs to reconfigure and interactively modify the underlying resources for specific problems in order to realize the correct invocation of this kind of dynamic knowledge [1]. On the other hand, humans and computers cannot achieve a common understanding of such dynamic knowledge, so it is difficult for designers other than the creators of knowledge to use such dynamic design resources.

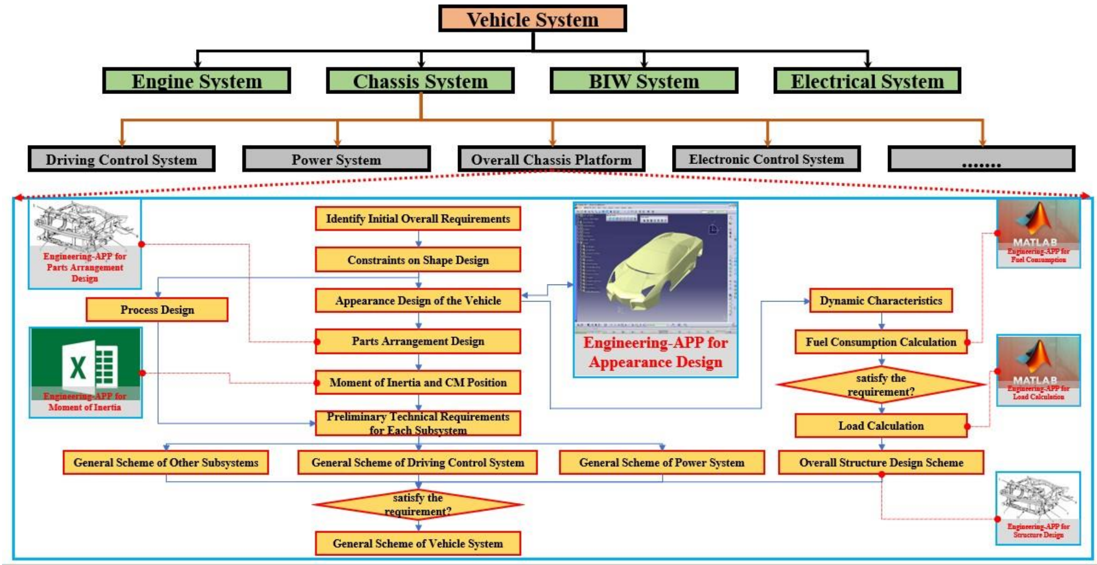
Therefore, this paper firstly introduces the definition and requirements of engineering APP in product design, introduces the construction method and development strategy of engineering APP, and explains the encapsulation and management mode of engineering APP. At the same time, the engineering APP ontology design technology based on DKRSP is proposed to construct the mapping relationship between vehicle domain ontology and APP, so as to realize the efficient transfer of product knowledge and improve the knowledge service method [2].

2. Definition of Engineering APP

Engineering APP is a modeled product design unit of technology, experience, knowledge and best practices for specific design application scenarios. Different from the previous knowledge components, in today's product design system, product design based on engineering APP transforms tool operation components and adapters into lower-level technical support for calling tool resources and data resources, and transforms professional design and product design functions into the upperlayer service that can be called by the APP [3]. At the same time, in order to serve the complex product collaborative design process oriented to design decisions, on the basis of analyzing the process model, build the process engine and the service orchestration engine of the design module, and according to the needs of the professional designer's role to call knowledge services, Build the mapping relationship between engineering APP and complex product domain ontology.

As shown in Fig.1, in the design process of the vehicle system, designers have accumulated a lot of design experience, data information, calculation program codes and software tools. From the perspective of the overall design process of the vehicle system, dynamic knowledge such as vehicle shape design, location arrangement, sub-system technical requirement analysis, power fuel calculation, and overall structure calculation can be further encapsulated into engineering APPs. The engineering APP can realize the rapid reuse of the above-mentioned product dynamic knowledge resources. By encapsulating knowledge units and design activities in a structured way, engineering APP can achieve the purpose of knowledge units automatically serving design activities. The engineering APP has the characteristics of being embeddable, which ensures the loose coupling with the embedded system. At the same time, the driver of the engineering APP and its specific content also maintain the loose coupling, so as to improve the ability of the engineering APP to cope with the task changes of the product design system [4].

Fig.1 Vehicle design system based on engineering APP design



3. Requirements of engineering APP

Research shows that in the field of product design, the reusable design based on adaptive design and variant design has an absolute advantage, accounting for about 70% of the design work. Product design is a highly complex knowledge-intensive process. Enterprises and research institutes will accumulate a lot of knowledge resources during the design and development of complex product systems, such as product parameters, standards, calculation formulas, template files, software tools, etc. Among them, how to quickly apply the previous knowledge resources to the product design of new models has become a hot issue in the current design field [5].

In the practical application of knowledge resources, they often face the challenges of scattered knowledge storage, high threshold of use, different knowledge structures and tight tool coupling. Considering the prominent role of dynamic type knowledge in the current knowledge design resources, this section proposes the engineering APP technology, that is, through the analysis of data, models and design tools in the product design process, the componentized encapsulation is carried out to realize the automation of knowledge reuse. This section takes the vehicle system design shown in Fig.2 as an example to further illustrate the requirements of complex product design for engineering APP:

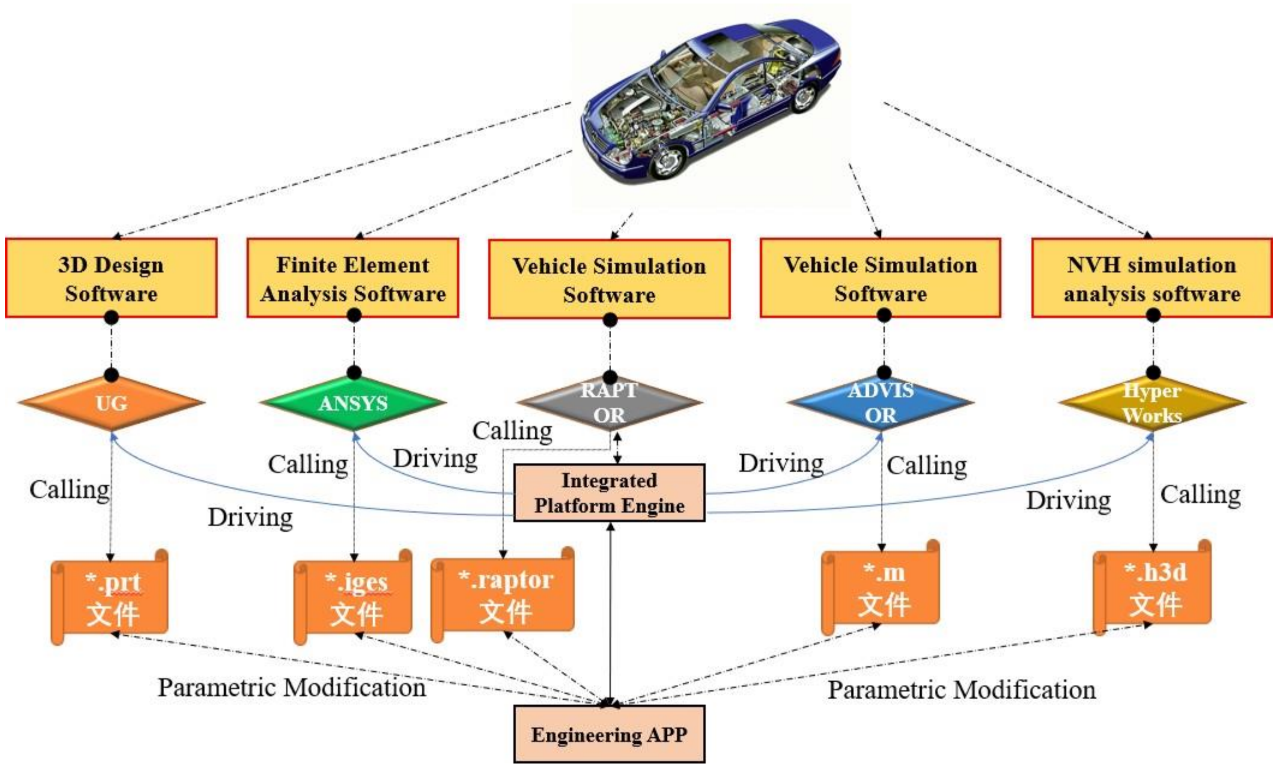


Fig.2 Design mode for Vehicle system

(1) Realize the management and reuse of dynamic knowledge of product design. The vehicle system design involves the overall three-dimensional design structural model of the vehicle, finite element analysis, virtual simulation simulation, power and fuel performance simulation, NVH simulation and related design documents (*. prt, *. iges, *. raptor, *. m, *. h3d, etc.). Due tothe lack of effective management of these knowledge resources in the traditional product design system, decentralized knowledge cannot form a comprehensive and systematic solution. The engineering APP technology can effectively integrate all parts of knowledge in the product design and development process.

Realize the integration of design software tools. Complex product design cannot be separated from the support of software tools, including CAD, CAE and some self-made optimization design software. For example, the following software is mainly involved in the design of ground unmanned subgrade platform: 1) 3D structure design software of unmanned platform - UG; 2) Structural finite element analysis software - ANSYS; 3) Armored vehicle simulation software - RAPTOR; 4) Armored vehicle power simulation software - ADVISOR; 5) NVH simulation analysis software - Hyperworks. These professional software tools are usually complex to operate and require certain professional software knowledge. Through the engineering APP technology, various design software tools can be effectively integrated, and the operation steps can be simplified while using these tools' powerful solving ability.

(2) Realize the integration of product design system. In the actual design process of vehicle system, it is not enough to only manage dynamic knowledge and integrate design tools; It is necessary to further integrate the knowledge in the product design process with the design tools, and provide the call interface. During the product design, the call is made according to the interface standard, so as to realize the efficient integration of the engineering APP and the product design system.

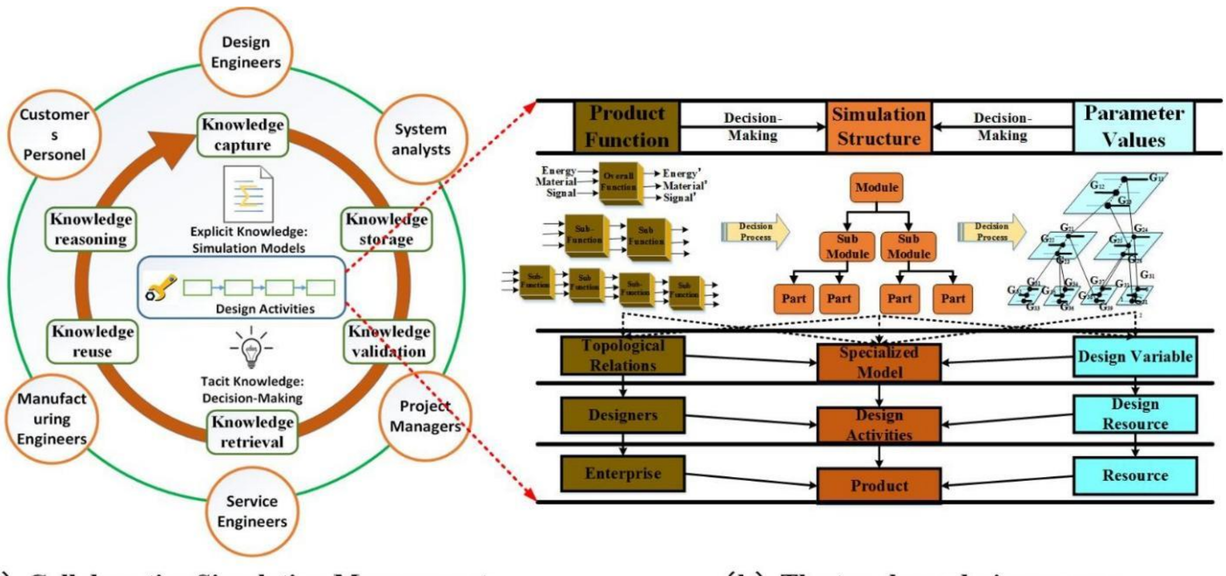
(3) Realize the support of product collaborative design. In the distributed knowledge resource environment, enterprises use computer technology to realize knowledge services to promote product design and development. At the same time, all departments of the enterprise also hope to improve their product design and development capabilities through the knowledge service platform. How to support collaborative design between or within enterprises based on engineering APP technology is another important demand for the development of engineering APP technology.

4. A framework for integrated and collaborative simulation management

Nowadays, personal customers and users' requirements of complex product market are transformed to specific information taken up with manufacturing complex product during the design process. As shown in Fig.3(a), the design and development of complex product generally requires a synergy of multi-disciplinary development team. When applying simulations into the complex products development, Multi-disciplinary Collaborative Simulation (MCS) is assigned to integrate simulation models and decision-making process, which aims to support the collaboration between members of the development team [6]. The solution proposed aims to address a specific issue on representing an integrated and collaborative simulation space. To give an overview of Integrated and Collaborative Simulation Management (ICSM) scheme as well as its key components, a framework is shown in Fig.3 (a). In the outsides of the figure, Collaborative design team and users with different roles can participate in the collaborative design environment, meanwhile in the center of the figure, product design lifecycle stages of knowledge management are in connection with specific design activities. As for every activities, explicit knowledge of simulation models and tacit knowledge of decision-making process is connection with an integrated simulation models, namely Engineering-APPs.

Before developing the integrated simulation models, collaborative design process of complex product should be taken into special consideration [7]. According to the top-down design principle, the complex product design process based on the product topological function and physical structure is illustrated in Fig.3 (b). As described in Fig.3 (b), it should be determined first the function set according to the customers' design demands. Then each function can be further divided into a set of sub-functions and sub-flows. When the overall functions of complex product are decomposed zigzag, simulation modules are also designed or selected form an available module base. The simulation module could be further decomposed into a set of sub- modules and parameters whose values should to be determined.

In the propulsion of product design process, there is the most critical step in determining the performance of the collaborative simulation called the decision-making process. The decision-making process includes a lot of design experience and experts decision, which is intangible knowledge with unstructured, unformatted and unencoded features. Section 4 will discuss it the in detail.

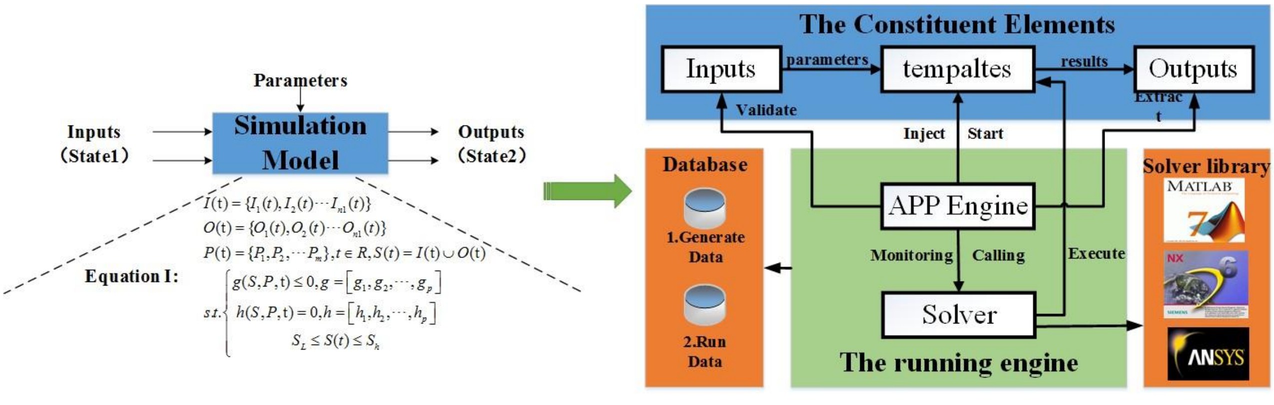


(a) Collaborative Simulation Management (b) The top-down design process

Fig.3 The design framework of complex product development

5. Formulation of collaborative simulation for Engineering-APP

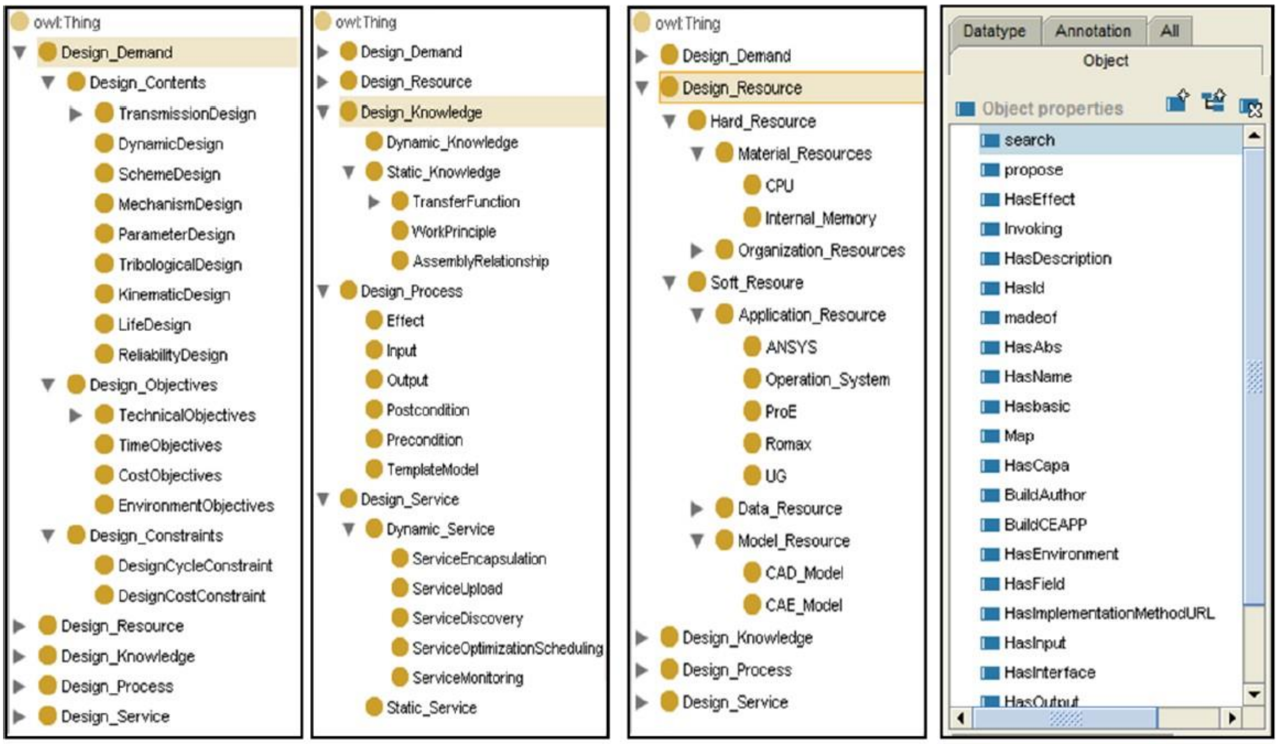
Simulation models for complex product are software representations of mathematical models of the physical prototype. Converting mathematical models to executable simulation models usually depend on manual effort of simulation experts. Such work have various nature as diverse types of simulation exist. The method proposed in this paper is not limited for a specific simulation model type. As shown in the Fig.4(a), each simulation model has inputs and outputs, which are states of design variables in the mathematical sense, and parameters are constants specifying model dynamics. For specific complex design problem, a simulation using a constraint-based representation, as shown in equation I, as shown in Fig.4(a). Based on this, the paper proposes the collaborative simulation model of Engineering-APP synthesizing simulation models and knowledge models as shown in Fig.4(b). The Engineering-APP can be divided into four parts, they are the constituent elements, the running engine, the database, and the solver library. The constituent elements include input parameters, templates, and output parameters, each of which can be managed independently. The operating engine provides the power and support conditions for the operation of the Engineering-APP, and is responsible for the transmission and operation of the internal parameters of the Engineering-APP; Database holds the construction data and running data of the Engineering-APP; Solver library manages the required solvers. The Engineering-APP can be widely used in the control and monitoring algorithms of various tasks, such as structural design, testing and fine-tuning control system, and support decision making. The same model can be used for all of these tasks, and the difference is how to use the inputs and outputs of the Engineering-APP.



$$I(t)=\{I_1(t),I_2(t)\cdots I_{n1}(t)\}$$
$$O(t)=\{O_1(t),O_2(t)\cdots O_{n1}(t)\}$$
$$P(t)=\{P_1,P_2,\cdots P_m\},t\in R,S(t)=I(t)\cup O(t)$$
$$s.t.\begin{cases} g(S,P,t)\le 0, g=[g_1,g_2,\cdots,g_p] \\ h(S,P,t)=0, h=[h_1,h_2,\cdots,h_p] \\ S_L\le S(t)\le S_k \end{cases}$$

(a)The structure of simulation model (b)The structure of Engineering APP

Fig.4. Difference structure of simulation and Engineering-APP



(a) (b) (c) (d)

Fig.5 Classification of DKRSP Ontologies

6. Ontology design of engineering APP based on DKRSP

The goal of process ontology based on DKRSP (Demand-Knowledge-Resource-Service-Process) is to simplify the management of the design process and make the engineering APP knowledge model transparent and visible to all design participants. The automated process through ontologies and process rules makes it possible to combine engineering apps into product design process chains. These rules provide a powerful reasoning mechanism for the construction of procedural knowledge. In the construction and invocation process of the engineering APP, the following five types of design information are mainly involved: D (design Demand) refers to the specific design task requirements obtained by the external system, K (design Knowledge) refers to the structured data information, Static and dynamic knowledge such as design rules and program codes, R (design Resources) refers to the sum of software and hardware resources and design capabilities that support the operation of engineering APPs, and S (design Services) refers to the service technology provided to meet the design requirements , P (design Process) refers to the real-time running status and business process of the engineering APP on the basis of design requirements, design knowledge, design resources and design services.

Engineering APP ontology consists of design requirement ontology (D), design knowledge ontology (K), design resource ontology (R), design service ontology (S) and design process ontology (P), and each ontology is related to each other. The definition of the DKRSP concept and its hierarchical relationship is shown in Fig.5(a)(b)(c). In Figure 5(d), the main object properties associated with these concepts are represented. These properties are used to relate the conceptual classes and instances of the engineering app to the product design process.

7. Conclusion

Based on the combination of SysML-based hierarchical design structure model and domain ontology-based, this paper proposes an engineering APP design model that supports the design and reuse of dynamic design resources. The model makes a detailed analysis of the requirements, structure, calling method and semantic level of the engineering APP, and verifies the feasibility and effectiveness of the engineering APP through the design case of automatic transmission.

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