Study on the collaborative design architecture of tractor performance prototype

Yiwei Wu 1, Zhili Zhou1,2,3

1 School of Vehicle and Traffic Engineering, Henan University of Science and Technology, Luoyang, China;
2 Henan Key Laboratory of Vehicle Energy Saving and New Energy, Luoyang, China
3 Email: zzli@haust.edu.cn

Abstract. The tractor performance prototype characterizes the multidisciplinary performance properties of tractor and plays an important role in the iterative upgrade process of new product performance. In order to meet the needs of collaborative development for tractor new products, the functions of distributed design and remote interconnection, and the performance verification of product system-level design, this paper analyzes the tractor collaborative development organizations and functions from the tractor performance prototype collaborative design theory. The performance prototype collaborative design process model is established with UML, and the design supporting environment characteristics are extracted. On this basis, a collaborative design architecture is constructed, and the key technologies which include the collaborative modeling and simulation, tool integration, data management and resource platform construction are proposed and analyzed. Through the preliminary study on the collaborative design architecture of tractor performance prototype, this paper aims to provide the theory and technical mode for developing the tractor digital, networked and intelligent design system.

1. Introduction

Agricultural machinery is one of the ten key sectors of “Made in China 2025”. Tractor as an important agricultural power machine, the innovative design of which faces the problem of integration with advanced manufacturing. In order to meet the needs of tractor new product development, it is necessary to promote digital, networked and intelligent design [1-2]. The tractor performance prototype describes multidisciplinary static and dynamic performance properties of tractor, and provides a model basis for tractor collaborative design, distributed virtual test and digital production.

Modern tractors are high-end intelligent equipment which integrates new and high technologies, such as advanced manufacturing and intelligent control, new-generation information communication and new materials. The tractor performance prototype comprises series of factors including user requirements, system components, product technology, development process, test and maintenance, project management and work environment, covering knowledge of mechanical, electronic, hydraulic, control, software, information, management, and system engineering [3-4]. The development tasks have characteristics of new technology, wide field, and difficult innovation, which require digital collaborative design technology with multidisciplinary crossover, multi-technology integration and multi-field penetration. In traditional mode, tractors should undergo stages of design, physical prototype test, industrial test, improved design, re-formation, re-test and production. This mode follows serial process, which has drawbacks such as the difficulty of introducing knowledge from
downstream departments to early design, lack of information exchange between departments, long product development cycle, high cost, low efficiency, etc. Each link is relatively independent so that it is unable to respond quickly to technology updates and customer needs, and difficult to meet the needs of the future intelligent manufacturing system construction and development [5-6].

At present, the development of tractor new products mainly focuses on virtual modeling and assembly of geometric prototypes, which lacks verification of system-level performance. The existing product data management (PDM) or product lifecycle management (PLM) is mainly based on the local area network (LAN) architecture, which is not suitable for the application expansion of tractor enterprises, difficult to support the vertical coordination of product planning, overall design, detailed design, test verification and manufacturing in product lifecycle. Based on tractor performance prototype collaborative design architecture, this paper intends to study key technologies of performance prototype collaborative design, improve development efficiency, save development costs, thus improving the international competitiveness of China's tractor manufacturing enterprises.

2. Theoretical analysis of collaborative design of tractor performance prototype

2.1. Tractor performance prototype collaborative design concept

Performance prototype is proposed with the development of digital prototyping technology, which creates product function model and verification environment model through virtual modeling based on geometric prototype, utilizes computer aided engineering (CAE) tools for co-simulation analysis and realizes visual display with visualization tools [7-8]. The essence of performance prototype is digital prototype, which includes performance indicators, simulation models and results, and external supporting environment such as standards, tools, processes and platforms.

Tractor performance prototype collaborative design is to organize experts and groups from various fields by enterprises according to market demand to carry out concurrent design using information and communication technology, tools, platforms and resources to build tractor digital model with computer support in distributed network. The process has characteristics of distribution, openness, hierarchy, parallelism, interaction, dynamics, collaboration and integration; the content is to decompose tractor products, establish multidisciplinary models, and obtain multidisciplinary optimization design plans while the goal is to create digital, networked, and intelligent tractor products.

2.2. Tractor performance prototype collaborative design organizations

The performance prototype collaborative design runs through the product lifecycle. Figure 1 shows the tractor collaborative development organizations and functions in the development process. The organizations include product user group, project responsible group, product design group, performance analysis group, process design group and product manufacturing group.

![Figure 1. Tractor product collaborative development organizations and functions.](image-url)
Tractor performance prototype is developed by distributed organizations through heterogeneous tools, platforms and resources. The organizations form an alliance which is interrelated, thus conflicts are inevitable in collaboration process. It is necessary to build a collaborative design environment to support decision making, coordinate relationship, and integrate information, tools, platforms and resources for product lifecycle to control design process, maximizing the benefit of collaboration.

2.3. Tractor performance prototype collaborative design process model

Tractor performance prototype collaborative design is a systematic project of phased information sharing and comprehensive decision making. Figure 2 shows a design process model based on the unified modeling language (UML). The design process can be described as follows:

Firstly, the project group creates project, clarifies overall design task, allocates staff and resource, and assigns task to each collaborative group. Then, each group accepts sub-design tasks, conducts structural design, performance analysis and process design through network, conducts conflict coordination and decision making. Finally, groups submit results to perform global optimization of product and output product data and product prototype.

As can be seen from Figure 2, the project management subsystem is responsible for defining design process, planning project, configuring resources, controlling design process timely, publishing tasks, coordinating conflicts, and providing a communication environment. The product data management subsystem is responsible for configuring product structure, submitting design tasks, archiving design files, controlling file versions, and managing permissions. They form a distributed collaborative design supporting environment, in which the structural design, performance analysis and process design of the tractor product belong to the engineering application part.

Figure 2. Tractor performance prototype collaborative design process model.
2.4. Tractor performance prototype collaborative design supporting environment analysis

Through the above analysis, the supporting environment should have the following functions:

1. To ensure that participants can operate heterogeneous system models, the supporting environment should have sufficient openness and flexibility to support heterogeneous design.

2. The collaborative relationship between groups requires participants to exchange and share information and resources for timely communication and feedback, therefore, the supporting environment should provide an information exchange tool.

3. The design task coupling degree is high, while design activity relationship and process are complex, which requires to provide a perfect scheduling and control mechanism.

4. It is inevitable that conflicts and information inconsistencies will occur, so the supporting environment is required to provide conflict resolution tools.

5. Collaborative work of CAE, PDM and other tools involves issues of knowledge sharing and mutual communication, which requires a unified user interface for the supporting environment.

6. Each group needs to keep abreast of the project progress and information describing the product, including component information, electronic files, and heterogeneous data, information approval, change and decision making, so the environment needs to support product data management.

To sum up, the supporting environment should have information communication, knowledge and tool sharing, product data and process data management, and distributed process coordination capabilities. In addition, the environment should achieve designer collaboration, design process collaboration, and application-level collaboration.

3. Tractor performance prototype collaborative design architecture

Based on the analysis of the collaborative design concept, organizations, design process and supporting environment, this paper constructs an architecture from the perspective of structural reusability. Figure 3 shows the architecture, which presents a three-layer structure.

![Figure 3. Tractor performance prototype collaborative design architecture diagram.](image)

The composition and function of each layer is described as follows:

1. The base layer is located at the bottom, composed of basic network environment, basic library of database, knowledge base, model library, etc., resource components of computation resources, storage resources, software resources, etc., basic protocols and standard specifications to be followed, which are used to provide support for system construction and operation of collaborative design.
(2) The core layer is in the middle, which is composed of three parts. The resource virtualization packaging and operation management system is in charge of packaging and sharing independent, heterogeneous, and local resources as well as providing real-time management and optimization scheduling services. The enterprise service bus (ESB), as the connection center, provides functions of communication, service interaction, application integration, service quality and security monitoring. Performance prototype collaborative design application tools and platforms provide enabling tools and platforms for application system, such as registration and service management tools, collaborative process and project management tools, integrated modeling, simulation and optimization tools, etc.

(3) The application layer is on the top, providing a unified web-based tractor performance prototype collaborative design system interface, which enables distributed users to develop specialized application systems, and achieves full lifecycle management of the design process.

4. Tractor performance prototype collaborative design key technologies

4.1. Performance prototype collaborative modeling and simulation technology
Tractor performance prototype collaborative design is a systematic project, which requires the decomposition of system into subsystems of different levels, the collaborative modeling and simulation of subsystems in a distributed environment and the integration into a system model to support performance verification process in the product design phase.

Multidisciplinary collaborative modeling and simulation methods mainly include interface-based method, method of high level architecture (HLA), language-based method, and method of functional mock-up interface (FMI). The interface-based method utilizes data interaction interfaces and co-simulation function provided by software to enable integration and co-simulation of models. The HLA-based method creates models by software in each disciplinary field as federates and integrates them into federation according to the HLA specification to achieve co-simulation [9]. The language-based method uses a unified modeling language to describe subsystems in different disciplinary fields. Modelica is the current commonly used modeling language, which is a non-proprietary, object-oriented and equation-based language developed by the Modelica association [10]. It has an open standard library of disciplines such as mechanical, electrical, electronic, hydraulic, and control. FMI is a tool-independent open interface specification for model exchange from different simulation environments through model coupling and multi-level co-simulation, which includes Modelica and non-Modelica tools of MODELISAR collaborators [11].

The methods have lots of commercial software support, which can realize co-simulation and analysis. However, the interface-based method has shortcomings of poor openness, no unified standards, difficult expansion, and cannot support distributed simulation. The HLA-based method overcomes shortcomings of interface-based method, but still requires software to provide interfaces with HLA, split the coupling relationship between subsystems, configure model interfaces for different simulation applications, and write integration code. Modelica-based method has advantages of simple and efficient modeling, high model reusability and maintainability, which can well support modeling and simulation of parametric models from different disciplinary fields, but it is difficult to directly support field models of distributed parameters such as structure, electromagnetic, fluid, heat, etc. It is also difficult to directly apply existing professional software models such as machinery, electronics, control, and power. The FMI-based method follows the FMI protocol and supports loosely coupled integration of multidisciplinary software. Considering the coupling, feedback and mutual influence of heterogeneous models in different fields, the co-simulation, process management and authority management of different software are realized, and a professional collaborative simulation environment is provided for product system design, analysis and verification.
4.2. Performance prototype collaborative tool integration technology

Tool integration refers to integrating tools in different disciplines into a performance prototype collaborative design system according to standardized model descriptions and interface standards for ensuring smoothness and correctness of data flow and interoperability in simulation analysis.

The traditional tool integration adopts tight coupling method, of which the tools are closely interfaced according to performance prototype requirements for specific system [12]. The integration is strong, tools and discipline models are deeply encapsulated, and the interface relationship is clear. But it is difficult to implement tool plug and play, and the hard coding method limits dynamic tool integration. In addition, the system is highly coupled and cannot achieve loose integration.

At present, the integration mode has gradually changed from a peer-to-peer mode to an integrated mode based on service oriented architecture (SOA) [13]. The tools involved in the tractor performance prototype development include commercial software and self-developed software and platforms for design, manufacturing, analysis, optimization, management, testing and other processes. By using the SOA-based mode, the tools can be integrated to provide underlying services through the framework. The mode uses flexible data integration, process integration, and interface integration to enable distributed and heterogeneous tools to provide users with transparent and convenient functional services, which can achieve standardization and scalability of integration.

4.3. Performance prototype collaborative data management technology

Product data is the basis for each stage of tractor performance prototype collaborative design, it is necessary to ensure the consistency of global product data and the coordinated management of the design process, provide a unified database control interface, so that the collaborative design team can work under a unified interface while designers can easily retrieve and access data.

At present, tractor manufacturing industry generally adopts the product data management system to manage digital product data and design process. However, the commercial product data management software is basically a kind of general-purpose software with few solutions for the tractor industry, and the data management functions required for performance prototype collaborative design cannot be fully satisfied because of management granularity, so that it is difficult to achieve tight integration between design models and simulation analysis models [14].

Tractor performance prototype collaborative design data has characteristics of multi-source, heterogeneous and distributed. To achieve the physical distribution and logical unity of product information, customization and secondary development need to be carried out based on the existing functional framework of data management software in the collaborative design system. Meanwhile, the management method should be optimized according to design process, and specific usage and management specifications should be established to support information exchange in collaborative modeling and simulation process, which will realize interoperability and reuse of simulation models, and interconnection with design and test systems to form a collaborative environment.

4.4. Performance prototype collaborative resource platform construction technology

The collaborative design resource platform is an organic combination of various hardware and software resources such as model resources, computing resources, storage resources, network resources, and equipment resources in different regions and professions for the collaborative design system environment. Through digital supporting environment and software system, various resources are linked together, various application systems and networks are integrated, and a platform supporting tractor performance prototype collaborative design is provided, which is the key to realize information communication, tool sharing, data management.

Tractor performance prototype design resources are so diverse and complex that the exchange, sharing and application system interoperability are difficult. There are still no good solutions in terms of resource acquisition, classification, expression, integration and operation. The systematic, structured, and specialized platform based on resource services is still not perfect.
Cloud computing is a new technology that is currently used in system integration and data sharing. It can shield the complexity of IT infrastructure and platforms, and provide networked functions with high reliability, scalability, configurability and on-demand services [15]. The tractor performance prototype collaborative design resource platform needs to be highly flexible. Therefore, the advanced cloud concept should be adopted to build resource service platform in collaborative design system according to the needs of performance prototype integration design and simulation, and establish virtualized resource pool to realize on-demand sharing, reuse and collaborative interoperability of resources, and system dynamic optimization and coordinated operation through the cloud.

5. Conclusion
Performance prototyping and collaborative design technology are the research hotspots in the field of product development. Their application in the research and development process of tractor innovative products is in line with the requirements of the future intelligent manufacturing system construction and development of enterprises. Collaborative design of tractor performance prototype based on architecture, which adopts technologies of system construction, collaborative modeling and simulation, tool integration, data management and resource platform construction to establish a tractor collaborative design system platform, will play an important role in the realization of virtual research and development in product lifecycle of tractor products. In this paper, the technologies involved in tractor performance prototype collaborative design are initially studied. The in-depth research work will be carried out around these technologies in the later period.

References
[1] Ji Zhou 2015 Intelligent Manufacturing——Main Direction of "Made in China 2025” China Mechanical Engineering 26 2273
[2] Luo X, Liao J, Zou X 2016 Enhancing agricultural mechanization level through information technology Transactions of the CSAE 32 1
[3] Kolonay R 2014 A physics-based distributed collaborative design process for military aerospace vehicle development and technology assessment International Journal of Agile Systems & Management 7 242
[4] Yan X, Duan G, Xu L 2017 CAD/CAE integrated research of discipline model for complex product virtual prototyping Computer Integrated Manufacturing Systems 23 2081
[5] Zhao Y, Yang W 2010 Technological Development of Agricultural Tractor Transactions of the CSAM 41 42
[6] Yuan Y, Zhang X, Wu C 2011 Interaction Control System of Agricultural Machinery Virtual Test Transactions of the CSAM 42 149
[7] Han X, Zhao Y, Yang H 2016 Concept Research of Aerospace Product Digital Mock-up Computer Simulation 33 6
[8] Zheng D, Liu K, Liu J 2015 Research on the Technology and System of Aircraft Behavior Digital Mock-up Aeronautical Science and Technology 26 5
[9] Ieee B E 2010 IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)-- Framework and Rules IEEE 1
[10] Desideri A, Hernandez A, Gusev S 2016 Steady-state and dynamic validation of a small-scale waste heat recovery system using the ThermoCycle Modelica library Energy 115 684
[11] Bertsch C, Ahle E 2014 The Functional Mockup Interface—seen from an industrial perspective Proceedings of the 10th International Modelica Conference 96 27
[12] Hou B, Li B, Chai X 2004 Research on the Multidisciplinary Tools Integration in the Virtual Prototyping Design and Simulation Environment Journal of System Simulation 16 234
[13] Wang S, Tian X, Huang L 2013 Research on integration technology of PDM and CAPP system based on SOA Machinery 51 77
[14] Bai X, Guo Y 2014 Research and Application of Product Data Management in Cooperative Design Computer Technology and Development 24 166
[15] Jula A, Sundararajan E, Othman Z 2014 Cloud computing service composition: A systematic literature review *Expert Systems with Applications* **41** 3809