Application of tractor virtual test technology in product innovation design

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Abstract. As a necessary link for product development and evaluation, tractor testing covers new technologies in multidisciplinary fields and plays an important role in the research and development of product life cycle. This study discusses the research status of tractor test and evaluation technology and analyzes the new technology associated with the test and evaluation technology. Aiming at the problem of poor reusability, poor interoperability and weak expansion of the current tractor virtual test model, a virtual tractor-based test technology based on the architecture was proposed. The middleware technology, test data management technology, modeling technology and test environment construction technology in the tractor virtual test system were analyzed. Taking the tractor power shift transmission as an example, the application of the architecture-based virtual test system was verified, which pointed out the direction for the design verification of tractor innovative products.

1. Introduction
Tractor testing is an important part of the innovative product development of tractors. In this process, performance tests are conducted on the design and manufacturing of new products, and product performance is evaluated [1]. The tractor test is divided into performance and durability evaluation tests. The traditional tractor test verifies that the resource consumption is large, and the period of product performance improvement is long. With the goal of smart and precise agriculture and with network, digital, and intelligent technology at its core, tractors are being developed toward high-power, high-speed, low-consumption, intelligent, precise, and efficient duplex operations. The above mentioned development trends set high requirements for the generalization, intelligence, scalability, and reusability of tractor test and evaluation technology [2]. Virtual test and evaluation technology improves product iteration quickly and shortens new product development cycle. This technology can be tested and verified in all aspects of tractor innovative product design, and new product development efficiency is improved. This study analyzes the characteristics and application status of physical prototype and virtual test and evaluation technologies for tractors. Therefore, a tractor-based test and evaluation technology based on architecture is proposed and analyzed.

2. Research status of test and evaluation technology for a physical prototype of tractors
A physical prototype test of tractors evaluates the performance of a real product after product design and manufacturing and verifies the rationality of design and manufacturing. Domestic and foreign tractor enterprises and relevant test institutions have conducted in-depth research on tractor test technology and obtained various advanced test technology and methods to conduct product testing
efficiently, economically, and accurately [3]. In accordance with different test sites, the physical prototype test of tractors includes indoor bench, testing ground, and field tests.

2.1. Indoor bench test technology
Indoor bench test evaluates the performance of the key components of a tractor. The test conditions are easy to control and are non-restricted by working season and environmental conditions. The dynamometer is used to generate the resistance to simulate the tractor field work load. Feng et al. [4] standardized the rules for compiling tractor load spectra by studying the tractor load. In an indoor bench test, the loading modes include motor, eddy current retarder, hydraulic dynamometer, and mechanical closed loading. Among these modes, motor loading is easy to control and has a fast response. Therefore, the loading mode of an indoor bench test is mainly motor loading. Indoor bench tests are limited by the response performance of a loading device. A load spectrum is similar to a field load in the statistical distribution of loads, but it is far from the random load in the field.

2.2. Proving-ground test technology
An indoor bench test ensures the performance of components, but the performance of the system and tractor after component assembly must be evaluated by a proving-ground test. Standardized testing ground and flow are used to evaluate tractor performance. The conditions of the testing ground are easy to control, and the test period can be shortened by strengthening the conditions.

2.3. Field test technology
The field test uses the actual working conditions of tractors, and the results of this test reflect the real performance of tractors. A field test environment is severe. The collection and transmission of test data generally adopt a wired mode, which reduces the loss of data and noise pollution. The wireless transmission mode can be used for remote monitoring of the test process; field test has practical problems, such as inconvenience of instrument operation and poor reliability of instrument operation caused by test conditions. The physical prototype test of a tractor also involves measurement and control, network bus, and data management technologies. An advanced control algorithm is the core of measurement and control technology. Neural network [5], fuzzy [6], and genetic [7] algorithms have mature applications. The network bus technology links sensors, test controllers, test execution agencies, and other nodes. Data communication between nodes is simple and reliable. Data management technology can classify statistical test data, support the functions of test data storage, data analysis, and test result output.

3. Status of tractors’ virtual test and evaluation technology
With the development of virtual technology, the virtual test and evaluation technology for tractors has developed rapidly to satisfy the requirements of digitalization and remote network in the innovative design of tractor products. Subjects, environments, processes, and results have been digitized in the tractors’ virtual test and evaluation and have also accurately simulated the physical prototype of the tractor during each product development phase. The virtual test has the advantages of low product test cost, short iterative optimization period, high recycling rate, and green and safe test process over the physical prototype test. Therefore, the virtual test is the main direction of the tractor test and evaluation development. In accordance with the different emphases of virtual technology, the current tractor virtual test is divided into four categories, namely, virtual experiments based on a simulation analysis, virtual prototype, virtual reality, and virtual instrument.

3.1. Virtual experiments based on a simulation analysis
Virtual experiments based on a simulation analysis involves various contents. The simulation analysis technology is applied to all kinds of tractor virtual experiments. The virtual experiment based on simulation analysis includes the traditional system of mathematical model simulation, numerical calculation, and parameter relationship discrimination and other research activities in the early stages
of the simulation technology. This technology has become the basis of the virtual experiment of tractors and is reflected in any stage of the virtual test.

3.2. Virtual experiments based on a virtual prototype
Virtual experiments based on a virtual prototype refer to establishing a digital prototype that is equivalent to the physical prototype function. The test of the virtual prototype is parallel to the various stages of the new product design, and the test process can be repeated. The cycle is short, and the iterative improvement of the product is convenient.

The virtual prototype has the same mechanical and hydraulic systems as the physical prototype. By applying the boundary conditions, the performance test of shifting and reversing the power shifting drive of tractors can be completed; this performance test may effectively replace several physical prototype tests. Zhang embeds the tractor 3D model into the ADAMS software, and conducts a static and dynamic virtual prototype test on the tractor's roll stability. The error between the virtual and the actual vehicle test results was less than 5% [8]. At present, virtual trials based on virtual prototypes have been widely used in many research fields. The multidomain, interdisciplinary, collaborative modeling, and distributed interaction experiments of a complex product virtual prototype have been the research focus of virtual prototype experiments.

3.3. Virtual experiments based on virtual reality
Virtual experiments based on virtual reality refers to establishing a virtual experimental vision with immersive, interactive, and conceived features in the computer. These features are used to test and verify the virtual tractor. Virtual reality technology can build several factors, such as atmosphere, electromagnetism, soil, crops, and other comprehensive working environments for tractors. The AGCO (Allis-Gleaner Corporation) has used VR technology in conducting ergonomic design tests on various types of tractors. Currently, many virtual reality simulations, subject–object modeling, and test process control software in the virtual experiment based on virtual reality are available. These experiments exhibit their own characteristics in terms of modeling speed and accuracy; however, a unified virtual reality test platform and interface specification have not been established.

3.4. Virtual experiments based on virtual instrument
Virtual experiments based on virtual instrument refers to the test method for comprehensive processing, analysis, display, and storage of a sensor acquisition signal in the tractor test system in the computer. Virtual instrument has strong expansibility, high efficiency and flexibility, and reliable data sharing, thus focusing on virtual testing equipment.

Zhang et al., [9] et al. used virtual instrument technology to establish a tractor comprehensive test system and conducted virtual tests on the fuel economy and electrical performance of tractors. The virtual test results were consistent with the actual vehicle test. At present, virtual experiments based on virtual instruments mainly use the graphical programming language LabVIEW to write test programs and build modules for the acquisition, processing, display, and storage of experimental data. The network of distributed virtual instruments is the focus of research.

4. Developing tendency of the tractor test and evaluation technology
Currently, the tractor test and evaluation technology is mainly based on physical prototype and component virtual tests. The scope of the virtual test and evaluation has gradually expanded, the system-level joint testing has been developed, and interoperability between tractor systems has been improved. The combination of existing physical prototype test and evaluation technology with virtual test and evaluation is the development trend of tractor test and evaluation technology. This study proposes an architecture-based tractor virtual test and evaluation technology, which integrates tractor physical prototype and virtual tests on a unified platform, mainly to solve the poor interoperability, reusability, and scalability of the test system. The distributed physical test equipment in different regions has been effectively combined to achieve a virtual and actual evaluation comparison.
4.1. System construction technology of test and evaluation

The mature virtual test system includes Distributed Interactive Simulation (DIS), high-level architecture (HLA) developed by the United States, Data Distribution Service, (DDS), virtual proving ground (VPG), and test and training enabling architecture (TENA) [10]. The existing virtual test system in China includes virtual test and evaluation enabling architecture (VITA) developed by the China Academy of Launch Vehicle Technology, virtual range architecture (VRA) developed by the Beijing Institute of Technology, and virtual test support soft framework (VTSF) developed by the North China Electric Power University [11]. The main virtual test architectures are summarized in Table 1.

| System name | Characteristics                                         | Application field          | Development time / Technical status |
|-------------|--------------------------------------------------------|----------------------------|------------------------------------|
| DIS         | Simulation technology framework                        | Universal                  | 1989 / Public                      |
| HLA         | Simulation technology framework                        | Universal                  | 2000 / Public                      |
| DDS         | Distributed data communication                         | Universal                  | 2004 / Public                      |
| VPG         | Weapon equipment full life cycle test platform         | Weapon system              | Confidential                       |
| TENA        | Integration of the software and hardware test resources of proving ground | Military training         | 2010 / Confidential                |
| VITA        | Similar to TENA                                        | Aviation, Military industry| 2014 / Confidential                |

In Table 1, most of the mature virtual test systems are based on HLA and have unique architecture and application characteristics in their respective fields, which have a certain reference value for virtual tests in tractor. Therefore, on the basis of the research of HLA open technology framework and virtual test and evaluation technology, designing and planning the tractor virtual test system structure from the perspective of structural reusability and easy implementation are feasible. On the basis of the tractor performance test requirements, test techniques and specifications, and HLA standards, a tractor virtual test and evaluation system is constructed, as demonstrated in Figure 1.

![Figure 1. Tractor virtual test and evaluation architecture.](image-url)
The middleware is the core of the tractor virtual test and evaluation system. It defines the operating mechanism of the tester, physical prototype test, and virtual test in the tractor virtual test and evaluation system. The middleware connects the support, integration, and tool layers in tandem and provides the underlying foundation for the application layer. When a physical prototype remote-distributed test and evaluation is present in the architecture, the real-time performance of the control signal is an important problem that the middleware technology must solve. The support layer is composed of various standard databases, which store tractor virtual test data, and test process models, and interconnect these data and models with the middleware. The integration layer incorporates distributed and heterogeneous test resources, including tractor physical prototype test, virtual test, external network test system, and test auxiliary equipment, such as printers and projectors. These devices are interconnected with the middleware through a gateway. The tool layer provides a virtual test platform, which solves test problems, including a virtual-test-integrated development environment, test process design tools, test result analysis tools, and test aids. The application layer is the top layer of the virtual test system of a tractor. The user builds a test and evaluation system on the basis of the test and evaluation requirements and manages the life cycle of the test process.

4.2. Test and evaluation data management technology
Numerous data sources in the support layer of the tractor virtual test and evaluation system involve environmental data (soil, atmosphere, temperature, and humidity), tractor model, test standards, test procedures, and test result data. Moreover, data distribution and flow direction management significantly impact system operations. Currently, the experimental evaluation data are considered an extensively decentralized storage and are managed through program variables and data files. Moreover, satisfying the requirements of the test and evaluation for real-time data exchange are difficult. The distributed database technology will implement the global database mode maintenance and conversion matching of various databases in the test architecture support layer and store and supply various data in real time, including the data generated by the test operation, data to be extracted from visualization, and the test control data. Afterward, this technology will update the historical database to improve the reusability of the virtual test.

4.3. Test and evaluation modeling technology
The model-based tractor tests and evaluations, including environmental, tractor, test standard, test flow, and user construction models, are complex, thereby requiring the same modeling language and method. The modeling technology in the tractor field mainly focuses on transfer function theory modeling, software interface, and multidisciplinary integrated modeling methods. The software interface modeling method lacks a unified interface standard. The coupling relationship between models established by different software is poorly decoupled, and the run time management is difficult. No uniform specification and framework is available in the integrated modeling approach. The HLA can provide a unified specification and framework for tractor-integrated modeling and simulation. The models established by the simulation software in different fields are integrated and co-simulated as members of the federation, thus improving the scalability of virtual experiments.

4.4. Test and evaluation environment construction technology
The test environment is the boundary of a tractor test validation and supports multiple test applications. The test environment of a tractor is mainly the field load environment. The treatment of the measured field load and the “virtual soil” applied to the tractor test and evaluation system are the main contents of the test environment. The measured load in the field is susceptible to noise pollution given factors, such as tractor vibration. Tractor field loads are nonstationary random loads, and the noise can be effectively eliminated through adaptive, data-driven empirical mode decomposition methods. By using the load data after noise reduction, the tractor test and evaluation environment model is constructed on the basis of the Synthetic Environment Data Representation and Interchange Specification to define the boundary for the test and evaluation.
4.5. **Tractor PST distributed virtual test system application example**

The tractor PST virtual test system requires multi-disciplinary distributed modeling, test time management, test data management, virtual work environment management, monitoring services, virtual and real verification and evaluation of test results. The system should have good interoperability, scalability, reusability and real-time performance. According to the requirements of the virtual test system and the characteristics of HLA and DDS system, the HLA-DDS-based tractor PST virtual test system is established. The logical structure is shown in Figure 2.

**Figure 2.** Logical structure of system.

In Figure 2, HLA standardizes the information interaction standard between different virtual test simulation models. The unified standard improves the interoperability and reusability of the system. The data interaction of the nine federates is carried out through the Run Time Infrastructure. When hardware devices participate in the virtual test, the real-time data transmission requirements are increased, and the system delay affects the virtual test process. DDS is data-centric, providing real-time and efficient distributed data interaction services, and hardware devices participate in virtual experiments as domain members. The bridge component implements data conversion and delivery between federates and domains. The PST virtual test system can make full use of PST existing models and equipment resources to realize data interaction between models and devices, and reduce the difficulty of virtual test system development. The tractor PST virtual test system platform is shown in Figure 3. The system data transmission delay and throughput performance are shown in Figure 4.

**Figure 3.** Tractor PST virtual test system platform.

**Figure 4.** PST virtual test system performance main performance indicators.
When the system transmits data volume up to 4000 KB, the delay is 9.1 ms, and the system data transmission throughput is close to 20Mbps. The system can efficiently perform PST performance virtual test tasks.

5. Conclusion
Currently, the test and evaluation of tractors mainly use the traditional physical prototype test. Virtual test technologies, such as virtual prototype, reality, and instrument, have a certain degree of reflection, but a gap from the virtual test of true meaning still exists. On the basis of architecture, the virtual test and evaluation of a tractor combine the existing physical prototype test technology with the virtual test technology and adopt system construction, data management, modeling, and environment construction technologies to establish a tractor test and evaluation platform and thus support the whole life cycle of tractor products. The tractor PST distributed virtual test system verifies the advantages of the system-based tractor virtual test technology in model reuse, interoperability and performance expansion, and provides a reference for the development of tractor test technology.

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