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Research on integrated simulation platform framework for satellite control system

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***Abstract*—In the simulation of independent satellite control system, there are some problems, such as independent simulation of each disciplines, and the lack of unified management of data. A multidisciplinary integrated simulation platform for satellite control system design is developed based on vertical "task flow" and horizontal "multidisciplinary" Architecture. The efficient task schedule management and simulation data unified management are realized. Finally, an application example of the satellite control system design is given by using the integrated simulation platform, the data exchange and sharing of the control system analysis and the solar panel modal analysis are realized.**

Keywords- satellite control system; integrated simulation; task management; Simulation data management

I. INTRODUCTION

Satellite control system is one of the most important subsystems of the whole satellite. It involves many disciplines, such as light, aircraft, electricity, heat, materials, mechanics and fluid analysis. Each discipline has its own unique analysis model and method. The satellite control system involves design, analysis, simulation and verification based on physical hardware. It also includes program design, technical design, software design, system test and other processes, all of which require a lot of data transmission and collaboration of design simulation test.

At present, the simulation design of the satellite control system is mostly in the form of independent design of each individual. Such design method can't be used well in the time of the interactivity difference of time consuming, so that the simulation result differs greatly from the test data. With the increasing number of satellite models, the current design simulation has not adapted to the development of future satellites, and it is imperative to have more interactive tools, which can be traced back, simulation and automation and standardization of data management.

In order to meet the requirements of satellite simulation tasks, an integrated simulation platform is constructed in this paper, and the unified universal model interface is used to realize the communication and combination of various model and analysis software of satellite control system. By establishing the unified standard single computer model and system simulation model of the satellite control system, the modularization and parameterization of the simulation process are realized, so that the design of the satellite control system is carried out under the unified software platform.

II. CONSTRUCTION OF INTEGRATED SIMULATION PLATFORM OF SATELLITE CONTROL SYSTEM

Various modeling simulation software, such as ProE, Patran/Nastran, MATLAB/Simulink, ANSYS, etc., is involved in the development of a satellite control system. These software can be called through system commands and execute their own script code. The integrated simulation platform of satellite control system can be established based on system command and parametric simulation module.

The whole integrated simulation platform is divided into three levels: basic resource layer, support platform layer and data application layer. According to the top-level planning, step-by-step implementation of the design idea, We can use the platform to carry out model task. In this way, the layers are separated from each other and related to each other. The upper layer invokes the service provided by the bottom layer as a top layer support, a hierarchical and extensible software platform architecture is established.

It mainly includes the satellite control system simulation the tools needed to design, data resources, knowledge resources and hardware resources in the basic resource layer, which provides necessary foundation support for the construction and operation of the platform.

In Data application layer, in order to meet the individual needs of models and specialties, the analysis and simulation tasks of different professional development stages are carded out; The simulation model libraries of the whole product are established; Different professional simulation models and simulation results are managed according to data packet ; as the smallest unit of data management, data packet is applied to different professional simulation of satellite control system, such as mathematical simulation, parametric modeling and simulation, finite element simulation and so on.

The core function of support platform layer is to complete the work, such as the simulation task creation, the task decomposition, the task dispatch, the simulation analysis, the result return and the data management. It has the functions of simulation task management, simulation template management, simulation data management, knowledge base management, remote computing service and so on.

A. Simulation Task Management

1) Simulation Task Distribution

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Based on the simulation task management module, the model project team was built, and the project objective was decomposed into WBS (work decomposition structure), which was refined into executable tasks. Each task as a work package contained complete deliverables, progress, resources and other information. Through the simulation task management module, the project progress was monitored and adjusted in real time to realize the dynamic control of the three major elements of the project (time, cost and quality).

2) Simulation Task Execution

The person in charge of the subsystem uses the task Kanban function provided by the simulation task management to obtain the task information and assign the simulation engineer (or himself) to complete the task. Simulation tasks can be done in the design of our professional/native systems, and also access to remote computing services, to call high-performance computing resources, completed with the shared resources of simulation data management. Finally, task execution status is fed back to the server. And then the data of the solution is submitted to the server. After being approved by the model master, it is automatically saved to the simulation data management module.

B. Simulation Template Management

Simulation template management is based on the multidisciplinary tools integration, to the design of the parameterized model driven, templated packages as well as to the research and development process, so as to realize the organic integration of tools, knowledge and data, the simulation method. Then, expert simulation templates are integrated by simulation methods, theoretical and empirical formulas, and guidance interfaces. With the guidance of simulation method, the standardization of simulation process and the support of automatic simulation, the designer can carry out the simulation work accurately and quickly.

1) Integration of Multidisciplinary Simulation Tools

In the course of many years' work, experts of satellite control system design have accumulated rich engineering methods, business experience and application rules of tool software, which are the core knowledge resources of enterprises. In the platform, these rules and methods are packaged into modules with a standard form so that engineering personnel can quickly complete the design work through modular configurations to significantly improve the quality and efficiency of the engineering design.

It provide visual process package environment and visual template interface packaging tool for that designer to complete the construction of the simulation template, and the key to the process construction is the simulation tool componentization and general multidisciplinary model package interface.

Design goal of simulation tool componentization is to enable a single functional submodule in the application process to implement cooperation work of the process by multidisciplinary model encapsulation interface. The component encapsulation technology of multidisciplinary simulation tools is developed by COM technology, it supports object design and independent of development language, and can separate the interface from implementation.

The universal model encapsulation interface can make the data island of each simulation software accessible, so that the data between the simulation software can be shared and the process can be controlled to realize the joint simulation. At the same time, the function expansion of the multidisciplinary joint simulation platform is realized by the standardization of the multidisciplinary model encapsulation interface. The universal model encapsulation interface is implemented using FMI technology to ensure that the simulation models designed in different modeling simulation tools have uniform model description format and data storage mode. The model encapsulation interface is shown in Figure 1:

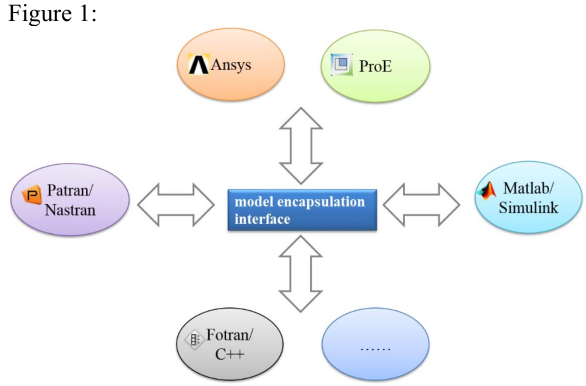

Figure 1. Diagram of universal model encapsulation interface

2) Design and Encapsulation of Simulation Process

Because the editing environment of the simulation process is provided for user, so the designer can use the visual process designer to generate the business process template by "drag and pull". Using template encapsulation, data flow and control flow between different tool software are got through. It supports the automatic execution of the process and the operation of human-machine interaction, and controls, such as tart, tentative, stop, restart, cancel, are supported during the execution of process nodes.

3) Design of Human-Computer Interaction Interface

The corresponding human-computer interaction interface is configured in the encapsulated process template. By using the interface configuration tool, engineers can define human-computer interface controls with rich forms according to the needs of the process, and hide the unrelated parameters in the background, then provide a professional and concise human-computer interface to the user.

C. Simulation Data Management

In simulation data management , it needs to provide data management functions for the whole process of simulation life cycle, and can help developers to realize the classification organization, unified storage, version management, data sharing, analysis processing and pedigree Association for the whole satellite control system. The core of simulation data management is to manage the model by organizing simulation data. It can receive product design data pushed by the enterprise data system (PDM), and can extend the model tree nodes that define and manage the simulation data organization, and have the "post correlation" ability of the simulation project and the data and simulation model tree.

The analysis object of this paper is a satellite control system, so analyzing the object structure tree is based on the need of the simulation, pulling and reconstructing the information from the PDM product tree, which is consistent with the analysis. Analysis types correspond to different types of simulation analysis of an analytical object, such as corresponding mathematical simulation and ultra-real-time simulation in the scheme stage, corresponding cable network design and semi-physical simulation in the development stage, etc.

D. RemoteComputing Services

To improve the performance and efficiency of computing services, it provides workstation scheduling management, computing service management, computing task management, computing resource management, statistical analysis, calculation results management and other functions in the platform. The simulation model can be used for job scheduling, job submission, job monitoring and result viewing directly over remote service without local simulation analysis by uploading and downloading.

Before the simulation calculation, users can configure various tasks in IE (analysis model to be solved, parameters to be solved, job name to be analyzed, etc.), and then submit jobs. After submission, the job begins to be solved in the high-performance computing job queue system, and job monitoring is displayed on the web page. Users can monitor the status of jobs remotely and intervene if necessary. By monitoring operations, the operation can be aborted in the list of computing jobs, while the results are saved, and the historical calculations can be selected to rerun. When the calculation is complete, the user can see a list of the resulting files, view the contents of the files, and download the result file to the local by individually or packaged.

III. APPLICATION EXAMPLE- SIMULATION ANALYSIS OF THE INFLUENCE OF SOLAR ARRAY ON SATELLITE ATTITUDE MOTION

Satellites are usually with multiple large flexible appendages. Especially, flexible rotating appendages , such as solar array, have great influence on satellite attitude It is necessary to consider the influence of disturbance torque of solar array rotation on satellite attitude.

Because the vibration of the flexible attachment is the same as that of the satellite itself, and the motion of the flexible appendages is described by the distribution parameters of infinite freedom degrees, the solution of the system is very complicated. Therefore, the finite element method is usually used in project to transform the system into system solution of a finite freedom degree. Satellite dynamic equation with flexible appendages is established by using hybrid coordinate combined with the rigid body attitude coordinates and the discrete modal coordinates. According to translation of flexible appendages relative to spacecraft and expression of rotational coupling coefficient, it is important to determine translational coupling coefficient and rotational coupling coefficient of flexible appendages relative to its own coordinate origin.

B_{tran} is the translational coupling coefficient, its expression is given as follow:

$$B_{tran} = \sum_k m_k \phi_k$$

B_{tran} is the translational coupling coefficient of solar array relative to the coordinate origin in the flexible appendages coordinate system.

Where m_k – finite mass elements, if N is the truncation number, ϕ is a matrix of 3×N, then ,we can obtain N order modal matrix by finite element modal analysis.

B_{rot} is the rotational coupling coefficient, its expression is given as follow:

$$B_{rot} = \sum_k m_k \tilde{r}_k \phi_k$$

Compared with the translational coupling coefficient, there is a new parameter $\tilde{r}$, which is diagonal matrix of a vector.

If $r = [r_x, r_y, r_z]^T$,then $\tilde{r} = \begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix}$.

In order to restrain the coupling interference of solar array, it is need to obtain the accurate coupling coefficient of solar array. Finally, the coupling coefficient is added to the satellite motion equation, and Simulink analysis is used to realize the simulation of satellite attitude motion. The analysis process is shown in Figure 2.

In the environment of integrated simulation platform, the process of modeling analysis and design is shown in Figure 3:

First: According to the input parameters, the whole machine CAE model of solar array expansion state is formed automatically;

Second: in the pre-process of parameterized Patran, The model grid, material properties, constraints and boundary conditions are set up automatically to conduct modal analysis of solar array;

Third: Nastran calculation is submitted, and then it automatically extracts the vibration frequency of the first ten order mode and the displacement and stress cloud map of the vibration type;

Fourth: With carrying out matrix calculation by Matlab , the translational coupling coefficients and rotational coupling coefficients of flexible appendages relative to the motion of rigid body coordinate system are obtained. As shown inTable I and Table II:

Finally: it extracts the calculation results and automatically generates the calculation report.

IV. CONCLUSION

It has realized the comprehensive application of simulation software such as ProE, Patran, Nastran, Matlab and so on in the integrated simulation platform. It can realize the automatic and parameterized operation of the typical analysis process. The platform makes full use of information technology to get through design, simulation and verification and establishes a multidisciplinary joint simulation platform covering design, simulation and verification. So that the design efficiency is greatly improved, and the development and production cycle is shorten.

With the study of simulation process management, simulation template management, simulation data management and high performance computing integration, an integrated simulation platform for satellite control system design was constructed. Various simulation work of the control system is carried out on this platform. The simulation process of multidisciplinary type is normalized, the classification organization, unified storage, version management, data sharing, analysis and processing, pedigree Association of the simulation data are realized.

So that different professional engineers can conduct online collaborative simulation and high performance calculation based on the unified software integration platform. The application shows that the normalization degree and efficiency of analysis simulation can be significantly improved on the platform, and proves that the platform can effectively realize accumulation and sharing of simulation data.

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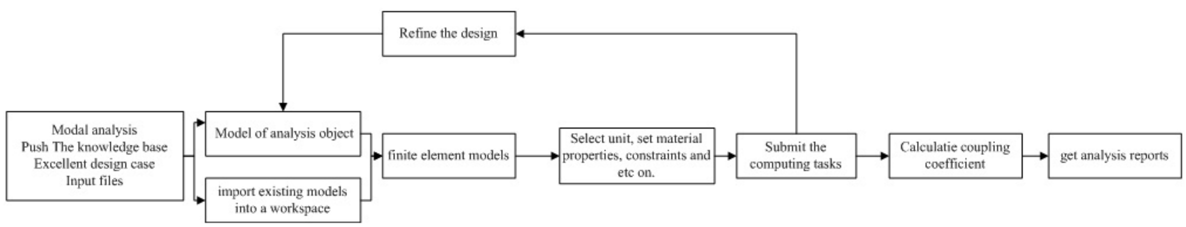

Figure 2. Flow chart of Modal analysis.

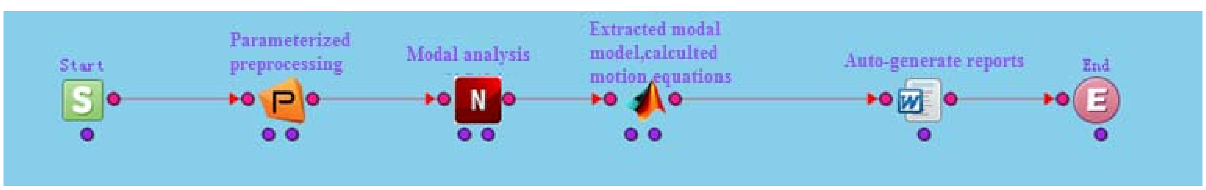

Figure 3. Flow chart of joint simulation design.

TABLE I. THE TRANSLATIONAL COUPLING COEFFICIENT OF THE 10 ORDER MODE

	1-order	2-order	3-order	4-order	5-order	6-order	7-order	8-order	9-order	10-order
X-direction	-0.00018	-7.7358	-0.00024	0.548754	-0.00036	-0.00277	3.073192	0.014516	3.039311	-1.46144
Y-direction	-0.54178	-0.001	4.427062	-0.00155	7.440506	3.068092	0.002696	-1.12388	0.004894	8.81E-05
Z-direction	-6.9061	0.51053	0.73637	0.92082	1.2641	2.3412	2.5487	3.5602	3.616	6.0016

TABLE II. THE ROTATIONAL COUPLING COEFFICIENT OF THE 10 ORDER MODE

	1-order	2-order	3-order	4-order	5-order	6-order	7-order	8-order	9-order	10-order
X-direction	38.87488	-0.00018	-7.08005	0.000799	5.432461	5.710006	0.008347	-2.71636	0.015468	-0.00213
Y-direction	-0.00016	5.173279	0.00129	8.048926	0.00124	-0.00632	6.675576	0.014506	2.965045	-0.26097
Z-direction	-0.00117	-41.3868	-0.00047	0.644708	8.14E-05	-0.00102	1.24169	0.005882	1.242942	-0.68426