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Research of Tool-Coupling Based Electro-Hydraulic System Development Method

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¹Abstract - This paper introduces a new kind of tool-coupling based electro-hydraulic system development method including designing character-oriented electro-hydraulic system development and design procedure, co-simulation based system coupling strategy, client-server model management method. An integrated development platform is designed for co-simulation among AMESim, Matlab/Simulink, Flowmaster, Saber and Simplorer. The platform can manage each simulator's models and co-simulation procedure. The result illustrates tool coupling based electro-hydraulic system development method can improve the efficiency of multi-team collaborative design for electro-hydraulic system and also can analyze and evaluate the performance of integrated electro-hydraulic system at the initial stage of the design procedure.

Keywords - Development Method, Electro-hydraulic System, Model Management, Tool-based

I. INTRODUCTION

Since electro-hydraulic systems develop toward high integration, intelligence and automation, the coupling degree and complexity of electro-hydraulic systems increase and designers face more difficulties of building highly coupled system model^[1]. Therefore, a new method which can highly integrate different subsystem models and predict the performance of the integrated system model is needed. Currently, model-based mechatronics system design method is widely used, however, because the complex electro-hydraulic system is often designed by a team which consists of different research groups, the conventional design approach cannot satisfy the demand of multi-team collaborative design. During multi-team collaborative design different teams have their own simulator tools and their own subsystem models which can only be used to analyze the performance of corresponding subsystems and optimize the subsystems, but the subsystem models cannot be used for coupling and integrated to predict the performance of the whole system^[2].

Tool-coupling based electro-hydraulic system development procedure is designed for integrated design process which consists of many different sub-teams. Different roles and iterative design processes can help the whole research team analyze and predict the performance

of integrated electro-hydraulic system in the phase of integrated system analysis of model-based design procedure. Co-simulation based electro-hydraulic system design is an integrated design method which use co-simulation to couple subsystem models of different simulator tools into a top system model by the united system simulating platform and predict, analyze and optimize the whole system's performance^[3]. Meanwhile, the module of simulation data processing can help designers replace subsystem models by black-box approach in order to improve the simulation efficiency. Electro-hydraulic system model management method can be used to manage subsystem models, simulation data of interface and top system model which is treated as a project model based on a client-server structure. During procedure of co-simulation design, subsystem model, project model and simulation data can be stored into server, uploaded and downloaded by client. All the information of models and data can be checked, retrospected and shared.

II. TOOL-COUPLING BASED ELECTRO-HYDRAULIC SYSTEM DESIGN PROCEDURE

A. Model-Based System Design Method

As in Fig.1, Model-based design method is widely used for application of product design. Currently, most of simulator tools adapt O-O (object-oriented) modeling method and bond graph theory to describe physical system and to build model^[5]. In this paper, the application scenario of tool-coupling based simulation method is the phase before HIL (Hard-In-Loop) simulation. The system model includes controller models and actuator models. The actuator models are built by simulator tools based on O-O modeling method (for example, MWorks and AMESim) and controller models are built by simulator tools which can transport controller models into C code or executable program that hardware can directly use (such as, MWorks or Matlab). In the phase of integrated system analysis, all the subsystem models can be integrated to analyze the performance of the whole system and the controller system model having been analyzed and optimized can be directly used to in the phase of HIL and semi-physical simulation.

B. Tools-coupling Based Electro-Hydraulic System Development Procedure

During electro-hydraulic system design procedure, different research groups concern different areas which causes each group has different simulator tools and

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models from other teams. A standard working flow can be useful to improve the efficiency of multi-team collaborative design. As in Fig.2, subsystem designer upload subsystem models into server. Integrated system

Fig.1. Model-based simulation procedure

Fig.2. Working Flow of System Designers

As in Fig.3, integrated system designers get subsystem models from servers and couple these models into a top system model by co-simulation. Then they can simulate and analyze the top system model and access the project model and simulation data interactively in order to improve the model-reuse and time-cost of the similar system. Meantime, the simulation data of subsystems' interface can be used for training the RBF simulator which can be used to replace the subsystem model of other simulators in order to improve the efficiency of co-simulation.

Fig.3. Working Flow of Integrated System Designer

III. CO-SIMULATION BASED ELETRO-HYDRAULIC SYSTEM DESIGN METHOD

designer download the subsystem models and run co-simulation of the whole system. At the same time, project model and interface data can be iteratively accessed to improve the efficiency of simulation and analysis.

A. Introduction of co-simulation

Co-simulation approach represents a particular case of simulation scenario where at least two simulators solve coupled differential-algebraic systems of equations and exchange the data which can be used to couple with the equations during run-time with each other. Take an example of integrated mechatronics system and simulation data management system, the system adapts co-simulation among Matlab/Simulink, Flowmaster, AMESim, Saber and Simplorer, as see in Fig.4.

Fig.4. Co-simulation of Integrated Mechatronics System and Simulation Data Management System

There are three types of co-simulation. The example used a type named **co-simulation** which means the leading platform and subordinate platform simulate and calculate their own models at the same time, and exchange data at the point of the communication step. So the integrated model can be treated as discrete model, but during the communication step the models are all continuous integral. The interface of co-simulation can be achieved by exchanging data between the two kinds of software at the point of communication step.

The co-simulation module in integrated mechatronics system and simulation data management system treats Saber and Matlab/Simulink as the leading platform and other simulator tools as subordinate platform. Different simulator tools run co-simulation by S-function in Matlab. While running co-simulation, different kinds of simulator tools simulate their own models by their solvers and

communicate with each other at the communicational time step point.

Fig.5. Structure of Co-simulation Platform

B. S-function in Simulink and Interface Design

Matlab\Simulink provides users self-defining function- S-function. S-function can be built by C code, C++ code, Fortran and M code. The interfaces between other simulator tools and Simulink are almost achieved by this function. S-function can be treated as a block in Matlab\Simulink.

The block in Simulink contains a group of input, a group of state variables and a group of output. Among them, output is a function for sample time, input and state variables, as in Fig. 6.

Fig.6. Principle of Block in Simulink

The equations below describe the relationships between input, output and state variables⁷.

$$y = f_0(t, x, u) \quad (\text{Output}) \quad (1)$$

$$\dot{x}_c = f_d(t, x, u) \quad (\text{Derivative}) \quad (2)$$

$$x_{d_{k+1}} = f_u(t, x, u) \quad (\text{Update}) \quad (3)$$

where, $x = [X_c; X_d]$

Models which satisfy the mathematical descriptions of ODE (ordinary differential equations) above can be treated as a block in Simulink⁸.

TABLE I
FUNCTION METHOD OF S-FUNCTION

Name of Function	Description of Function
mdlInitializeSizes	Initialize the parameters of blocks (For example, numbers of input or output)
mdlInitializeSampleTimes	Initialize the sample time of blocks
mdlStart	Operation in simulation start
mdlOutputs	Calculation of Output
mdlDerivatives	Derivation
mdlUpdate	Update discrete status variables
mdlTerminate	Operation in simulation ending

As in Table I, S-function provides different functional methods. As in Fig.7, taking interface design of co-simulation between Matlab\Simulink and Flowmaster as an example, S-function calls the Com function which Flowmaster provides to complete this job. Firstly, in the stage of initialization, S-function and models in Flowmaster initialize and set the initial values of each

models. In the stage of single-step calculation, S-function send the input values to Flowmaster, control the solver of Flowmaster to run each step of calculation and get the returned values by S-function, meanwhile, Simulink use the returned values to calculate the input values of Flowmaster at the next calculation step. The single-step calculation repeats till simulation ends⁹.

Fig.7. Interface Design of Flowmaster and Simulink

C. Alternative Method of Block-Box of Neural Network

The application scenario of this method is after the first integrated simulation, while changing the parameters of one subsystem, the other subsystem models, which slow the simulation speed of integrated model severely but influences prediction of the integrated system little, can be replaced by the black-box of neural network^[10].

Neural network simulator need to be trained by simulation data of co-simulation interface. During co-simulation is running, the simulation data of co-simulation interface can be recorded in Mat file. After simulation, the recorded data can be used to train the neural network simulation which can be treated as a black-box.

Fig.8. Training of Neural Networks Simulator

Fig.9. Neural Network Black-box Replacing the Subsystem Model

IV. ELECTRO-HYDRAULIC SYSTEM MODEL MANAGEMENT METHOD

A. Management System Based on Client-server Structure

Fig.10. Management System Based on Client-server Structure

Management system based on client-server Structure is a platform which can manage subsystem models, project models and simulation data. Also, the information of the models and simulation data can be checked and shared through the client. First, the subsystem models, project models and the simulation data need to be packaged into a special form that the management system can identify and all the information of them can be written into XML file. Client can upload the packaged models to the virtual warehouse in server [11]. Server gets the information of models and simulation data from the XML file and then records it into database. Meantime, element information of models or simulation data can be sent into SVN in order to get the corresponding version number which will be recorded into database through the server. Client can be used to check the models' and data's information through the database [12].

B. Storage and packaging method with XML File

The models of each subsystem can be packaged by Matlab/GUI. The model information can be described in the XML file though the systems. In the XML files, such as TABLE II, <GeneralInfo> describes model information and in TABLE III, <OutputInfo/InputInfo> describes interface information of subsystem models [13].

TABLE II
<GENERALINFO> IN XML

Type	Rule
Author	Name of author
Description	Description of model
Type	Type of subsystem model
Time	Creating time
Project	Name of project model

TABLE III
<OUTPUTINFO/INPUTINFO> IN XML

Type	Rule
Description	Description of interface
Name	Name of interface
Type	Type of interface :Input/Output
Valuetype	Type of data

V. EXAMPLES

Take example of CSIMS, a platform for co-simulation of Suzhou Tongyuan, a model of fuel distributor is built by this system. Fuel distributor consists of constant pressure valve, differential pressure valve, air bleed valve, chain valve, throttle body, pulse width modulation fast solenoid valve, oil return valve, angular displacement sensor, q valve, minimum pressure valve main lines, start electromagnet, and parking electromagnet. Flue distributor and electronic controller work together to adjust the flue flow of engine at different statement. The flue flow can be divided into main flow path and vice-flow path to transmit the engine according to regular rules in order to achieve the adjustment of engine and stability of engine. The change of flue flow in flue distributor can cause the rotation speed of engine unstable. The stability of differential valve plays an important role in changing of flue flow in flue distributor. The changing of differential pressure can be caused by the trace leak of parking electromagnet.

So the tank and pipeline are modeled in Flowmaster, the motor of motor-driven pump is modeled in Simplorer, the control system of motor 'PID controller' is modeled in Matlab, the switch signal of parking electromagnet is modeled in Saber, and the fuel distributor is modeled in AMESim¹⁴. The co-simulation is used to test the influence of switch signal of parking electromagnet on the stability of differential valve, as in Fig.11, co-simulation strategy is shown, and in Fig.12., system model is shown.

Fig.11. Co-simulation strategy for flue distributor

Fig.12. Model of co-simulation for flue distributor

Fig.13. Compare co-simulation with original results ^[15]

The simulation result shown in Fig.13, the flow of main flow path nozzle is same as the result got from the paper ^[15]. Result shows co-simulation can be used for electro-hydraulic system design. And the control signal which the PID controller gives is used to train the neural network simulator. And the comparison between co-simulation and black-box approach is shown in Fig.14. Result illustrates block-box approach can be used to replace the subsystem model.

Fig.14. Compare result data of subsystem models with black-box

VI. CONCLUSION

Tool-coupling based electro-hydraulic system design method can be used for the former phase of integrated system model design. The platform of co-simulation couples all the subsystem models into the top system model and run the simulation. Black-box approach based on neural network can improve the calculating speed and efficiency of simulation. Model management system based client-server structure can help designers to manage the models, projects and simulation data which can improve the efficiency of design and reuse of models.

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