A Collaborative Modeling Method for Multi-Behavior Models of Electromechanical CPS Systems

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***Abstract*—Aiming at the characteristics of large heterogeneity and strong time constraint of airborne electromechanical system, an electromechanical event model and collaborative modeling method based on CPS is proposed. According to the complex characteristics of electrical, gas and hydraulic components of electromechanical system, the model describes the time and space information, proposes the system modeling and processing based on event response, adopts a unified model to capture all kinds of events in electromechanical CPS application, and provides upper level services across applications and data sources, The problem of semantic diversity of spatiotemporal data and consistency of interaction semantics of various models in electromechanical CPS system simulation is solved.**

Keywords- Electromechanical System, CPS, Collaborative Modeling

I. Introduction

With the development of CPS system research, the key technical problems of integration modeling, analysis and simulation verification of computing process and physical process, which are less concerned in the field of general computing, are gradually emerging [1]. As a hybrid system composed of computing, control and physical entities, the behavior of airborne electromechanical system is represented by the interaction of heterogeneous entities such as sensors, computer networks, software multi task scheduling, actuators and physical dynamics, showing the characteristics of multi domain joint, which is the key problem of electromechanical CPS behavior modeling [2].

Professor Wang Ji of National Defense University of science and technology used hypergraph grammar and first-order symbolic logic to model the evolution and monitoring of electromechanical CPS system, and summarized the behavior evolution characteristics of electromechanical CPS system [3]. He Jifeng's team of East China Normal University, aiming at the problem of QoS guarantee in the running process of electromechanical CPS system, gives the RTL based electromechanical CPS-QoS specification and representation, and gives an aspect oriented QoS and UML weaving method, which supports system behavior attribute analysis based on UML architecture model [4]. David garlan abstracts a specific observation view for different domains in electromechanical CPS system, and establishes a behavior model of the domain on the view [5].

The behavior of electromechanical CPS system often covers the calculation process, control process and physical process, forming multiple observation domains reflecting the behavior characteristics of the system [6-8]. State machine, data flow, event model, Simulink, differential and algebraic equations and other methods emphasize the investigation of behavior characteristics and attributes in a single domain, lack of collaborative design support for multi domain models covering computing, control and physics, and are difficult to ensure semantic consistency of multi domain heterogeneous behavior models [9]. Based on the modeling framework of electromechanical CPS system architecture, the scene driven multi domain collaborative modeling method is adopted, and the adaptive behavior modeling method is adopted to realize. Collaborative Modeling for different activity modes and different side features of electromechanical CPS system.

II. Collaborative Modeling of Multi Behavior Model of System

CPS (cyber physical system) is an interdisciplinary and interdisciplinary integrated system. As an advanced development of networked embedded system, CPS is quite different from traditional embedded system. As a multi-dimensional complex system integrating computing, network and physical environment, it realizes real-time perception, dynamic control and information service of large-scale engineering system through organic integration and deep cooperation of "3C" (computation, communication, control) technology as shown in Figure 1.

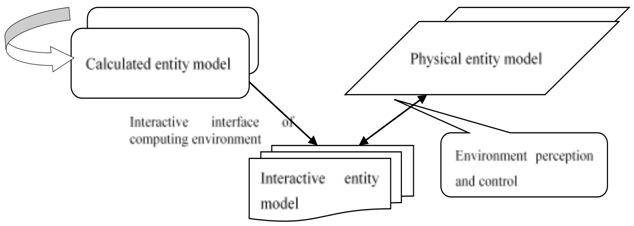

Fig. 1 CPS system structure

Electromechanical system conforms to the typical characteristics of Information Physics fusion. Electromechanical CPS system combines computing and physics, which have close interaction and influence. On the basis of environment perception, it deeply integrates controllable, reliable and scalable networked physical equipment system with computing, communication and control capabilities.

Typical electromechanical system elements mainly include: electromechanical integrated management system, engine control system, fuel system, hydraulic system, power supply and distribution system, braking system, environmental control system, life support system, ejection and lifesaving system, auxiliary power or second power system and public equipment, as shown in the figure. All kinds of entities and systems can be modeled by CPS as shown in Figure 2.

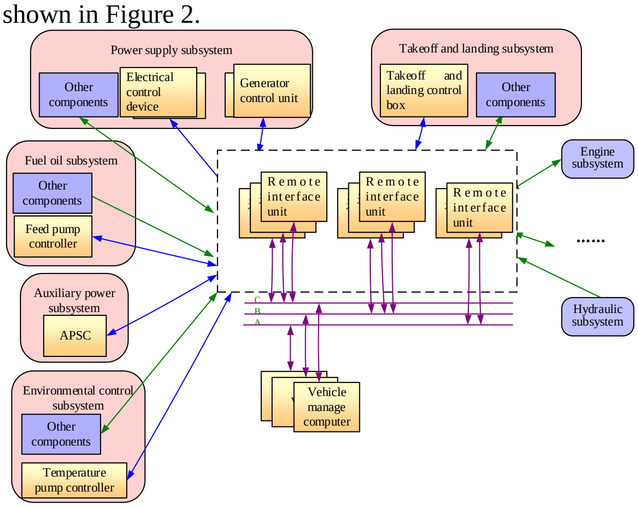

Fig. 2 Typical aircraft electromechanical CPS architecture

Firstly, the behavior model of electromechanical CPS system is established to describe the evolution characteristics of system behavior state. From the perspective of system structure, each behavior model corresponds to a static structure, which is regarded as a view of the electromechanical CPS structure model, and the syntax and semantics of the structure have strict correspondence with the behavior model. In the system structure layer, these behavior models are linked by electro-mechanical CPS structure model, that is, the mapping relationship between these models and electromechanical CPS structure model is defined in the system layer to identify and manage the structure consistency between heterogeneous models. As shown in Figure 3.

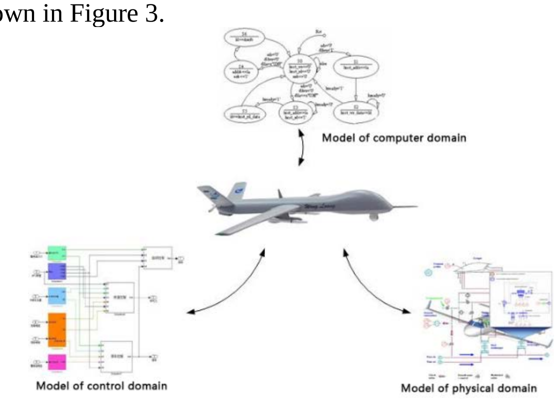

Fig. 3 example of multi-behavior collaborative modeling of electromechanical CPS

Taking electromechanical CPS-ADL as the center and adopting MVC three-layer model architecture, the behavior model of the scene is abstractly encapsulated into a structural view [10-12]. Layer M is the behavior model layer, which describes the calculation, control and physical models; layer V is the view layer, which describes the structure view encapsulated by the behavior model. Layer C is the common structure layer, which represents the structure model of electromechanical CPS constructed by electromechanical CPS-ADL. The principle is shown in Figure 4.

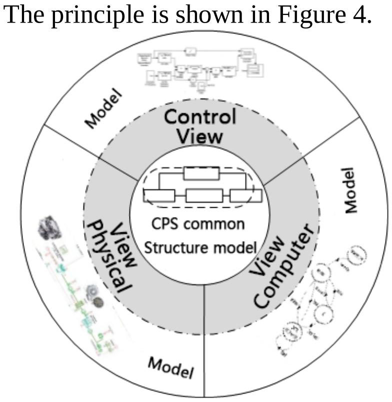

Fig. 4 MVC multi view based behavior and structure model association

The consistency between the view and the structure model is verified by the method of graph theory. The view and the structure model are both composed of components through connectors. Therefore, the components are abstracted into the nodes of the graph, and the connectors are abstracted into the edges. After transforming different views and electro-mechanical CPS structure frames into graphs, according to the corresponding relationship between the components in the view and the structure frame, VF2, a graph isomorphism algorithm, is used to verify the consistency between the view and the electromechanical CPS framework, as well as the consistency between different views. By examining the consistency of each behavior model and structure model in a specific scenario, the weak collaborative modeling method based on Structure Association solves the problem of multi behavior model collaboration in electromechanical CPS system at the weak semantic level.

The multi behavior model in electro-mechanical CPS system describes the fusion of computing process and physical process from different aspects. The cooperation of heterogeneous models is mainly reflected in the correlation of model parameters. For example, in the electromechanical CPS system of motion process control, velocity and acceleration are not only the main parameters to describe the physical process, but also the main parameters of the calculation and control model. The strong collaborative modeling method based on parameter constraints abstracts the relevant parameters of each model and the mapping and transformation relationship between calculation and physical process parameters, and uses the first-order logic method to describe the relationship between parameters, so as to directly describe the collaborative relationship between heterogeneous models at a stronger semantic level.

Let $P = \{p_1, p_2, ..., p_n\}$ be the parameter set of several models in the electromechanical CPS system, $< l, t >$ as a parameter of space time constraints, and then x $f_{p \to c}(P, < l, t >)$ is defined as the physical calculation mapping function of P under $< l, t >$ condition, and $f_{c \to p}(P, < l, t >)$ is defined as the physical calculation mapping function of P under $< l, t >$ condition. By introducing these two mapping functions, the mapping and transformation between the physical process and the computational process of heterogeneous model are realized. Furthermore, $C(P)$ is defined as the first-order limited expression of the value range of the related parameter set P, and $[C(P)]$ is defined as the value range of the constraint $C(P)$. The construction verification rule $s_i|C(P)$ is the behavior set of model m_i, and s is the legal behavior set of multiple heterogeneous models, then $\Lambda_{i=1}^{n} s_i|C(P)>s$ represents the behavior collaboration of model m_i under the parameter constraint $[C(P)]$.

According to the phenomenon that different domain models overlap in the underlying structure of the system, the heterogeneous behavior models are associated through the system structure model from top to bottom, and the weak consistency between the behavior models is analyzed through the structure association, The strong consistency among multiple behavior models is analyzed by parameter constraint Association.

III. Design and Verification of Typical Electromechanical Management System

Taking the landing gear brake system as an example, the architecture of the landing gear airborne integrated management system is shown in Figure 5. The information unit is composed of a dual redundancy aircraft system processor, a 4 redundancy remote interface unit, and a control interface unit. The physical unit is composed of a cabin door, a prop, a wheel, a hydraulic / pneumatic system, and a landing gear retractor.

According to the landing gear architecture, the elements of the landing gear system can be abstracted into 4 levels. The calculation system provides the man-machine interface for landing gear normal retraction and release, emergency release, reset after emergency release and ground maintenance control, as well as the landing gear status display and data recording functions.

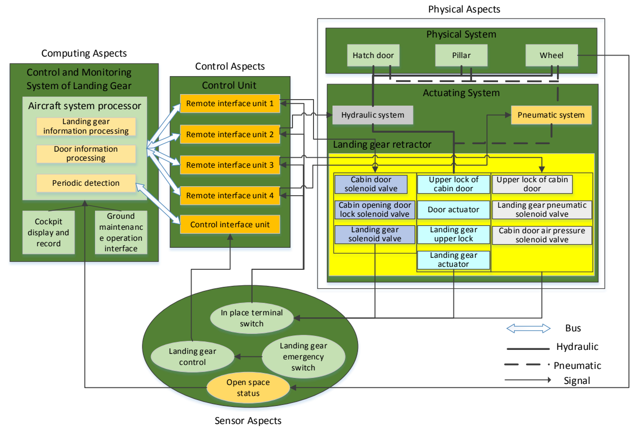

Fig. 5 The system diagram of landing gear system

The sensing system mainly collects the external signals and commands, and transmits them to the operation interface unit of the control system for information transmission. The landing gear control command is sampled in the control system. According to the landing gear retraction and release status, the cabin door, landing gear solenoid valve, unlocking solenoid valve, cabin door and landing gear air pressure solenoid valve are controlled according to the operation process to realize the retraction and release operation of the landing gear. At the same time, the working condition of the landing gear is monitored, and the fault and status information is sent to the cockpit for display and record. The physical entity part provides energy, actuator and electrical control interface for the retraction and extension of the landing gear, which is used to perform the retraction and extension operation of the landing gear, and provides the sampling interface for the retraction and extension working state of the landing gear.

The landing gear system model is established in AADL, and the components in the landing gear system are described according to the semantics of AADL. The interaction between components and systems is carried out through port connection and component access connection. At the same time, the processor and memory are bound to the components in the system, and the data flow between components, components and systems, and between systems is realized. Adding time attribute to the process attribute of the system can analyze the schedulability of the system.

IV. Conclusion

Electromechanical CPS system is the multi-scale integration of computing and physics, the time-space interaction of system environment and state, the uncertainty of system dynamic behavior, which makes the model driven design and verification method of electromechanical CPS not only more important in the design of electromechanical CPS application system, but also facing new technical challenges. This paper describes the interaction and integration of computing process and physical process from the level of electromechanical CPS system. The modeling method focuses on the mapping and support of the logic design and physical implementation of electromechanical CPS system. In order to solve the problem of semantic diversity of spatiotemporal data and semantic consistency of various models in the simulation of electromechanical CPS system, spatiotemporal hybrid automata modeling method for electromechanical CPS system and scene driven dynamic behavior modeling method are proposed.

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