Research on Multi-Resolution Modeling of Intercity Railway Train Control System

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***Abstract*—the intercity railway train control system is a new system that extends the automatic train operation (ATO) function on the basis of the traditional train control system and has been successfully applied on the Guanhui Line. Early establishment of a simulation system platform with wide applicability for the system can play an important role in shortening system development time, testing system operation, and training field workers. Multi-resolution modeling can describe the system from different levels and different angles. The modeling results can be combined with distributed simulation to establish a corresponding simulation application platform. Based on the different levels of detail in information interaction, this paper adopts multi-resolution modeling method and selects the operation scenes of train automatic operation and precise stop at the station to establish the train section status model, train pulling in model, and ATO control realizing model to perform the system from low, medium, and high resolution levels. In addition, choose the formal method based on the DEVS-based MRME to formally describe the model, verify the rationality of the model, and lay a theoretical foundation for the subsequent model research and simulation platform establishment.**

Keywords—Intercity Railway Train control System, ATO, Multi-resolution modeling, MRME

I. INTRODUCTION

The train control system is a key equipment for ensuring the safe operation of railways and improving the operating efficiency. The system testing work runs through the entire life cycle of the system. The test work for the train control system is generally dangerous and accidental, and it is difficult to implement it on the railway; on the part of the work that can be performed on the railway site, there will be huge amounts of work, too much manpower and material resources and can not be repeated. Therefore, to establish a system simulation platform based on the train control system structure, which can realize its main functions and reproduce the railway operation scenario, is of great significance both for system development, on-site staff training and system testing.

The intercity railway train operation control system is based on the train control system and extends the automatic train driving (ATO) function. It has a new type of automatic operation related to section automatic operation and the precise stop at the station, and automatic reentry, etc. Currently, it has been operationally applied on the GuanHui Line. For this system, establishing a corresponding simulation platform as early as possible and modeling and simulating each module of the system can not only reduce the burden on the railway field experiment, shorten the development cycle, reduce the research and development costs, but also promote the application of the system, training of railway employees, and improving system functions.

As the intercity railway train control system adds the ATO function to the original system, the structure of the system is more complex and has many functions, involving many details of the level of information exchange. In the process of system modeling and development, if blind pursuit of the performance at the level of detail, rather than a reasonable optimization and abstraction of the model, then it will bring about the problem of increased computational complexity, longer development time, higher construction costs. For the model application, different practitioners in the railway system have different understanding of the system from the perspective of the system. From the macro perspective, railway dispatchers mainly use the railway operation network as the basis to deploy the line operation plan from the system level and monitor the running status of the train; the railway field maintenance personnel pay more attention to the operating status of the system equipment and carry out routine maintenance from the equipment level. And railway R & D personnel need to carry out in-depth study of the system's logic processing, function algorithms, and its more concerned with the system logic level information. Therefore, according to the variety of simulation requirements, the train control system simulation platform should be based on a reasonable optimization of the system structure. It can demonstrate the functions of the train control system from multiple levels and different perspectives, and improve the simulation efficiency and ability to solve problems.

This paper takes the intercity railway train control system as the research object, selects the operation scenarios of section automatic operation and precise stopping at the station. Using the multi-resolution modeling method, the train operation model was established from different levels to provide a theoretical basis for the establishment of the next system simulation platform.

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II. MULTI-RESOLUTION MODELING

In multi-resolution modeling, the model resolution represents the level of detail of the system described. The definition of resolution in this paper is as follows: during the modeling process of the intercity railway train operation control system, the details and levels of information exchange are used as the basis for the classification, different stages and levels of models are used to describe the stages and functions of the train operation process. These details and levels are called Resolution in Multiresolution Modeling of intercity railway train control system. In the development of multi-resolution modeling, researchers have successively proposed a series of modeling methods, among which the representative methods are: Aggregation and Disaggregation, Selective Viewing, Multiple Resolution Entities and IHVR(Integrated Hierarchical Variable Resolution Modeling), etc.[4] This paper uses the Aggregation and Disaggregation method to study the modeling of the train control system in the intercity railway.

Aggregation and disaggregation approach in the realization of object-oriented modeling ideas, has been widely used in multi-resolution modeling. The core idea is to obtain low-resolution models for high-resolution model aggregation and high-resolution models for low-resolution models disaggregation.[5]In the simulation run, the low-resolution model is run first. When more details are needed, trigger the disaggregation to execute the high-resolution model. When the details are no longer needed, trigger the aggregation and continue to execute the low-resolution model. In this way, the two sides of the interaction are always maintained at the same resolution level.[6]

III. MULTI-RESOLUTION MODELING OF INTERCITY RAILWAY TRAIN CONTROL SYSTEM

Intercity railway train control system (referred to as: intercity railway train control system) based on the traditional train control system, adding on-board ATO equipment, expanding the automatic operation function of the train, and increasing the feature of section automatic operation, automatic folding, door, platform door linkage and other functions in the original system.[6] This paper selects the operation scenes of the section automatic operation and the precise stop at the station. The ATO control train model is the main research content, and the multi-resolution modeling of the train control system of the intercity railway is studied.

A. *Intercity Railway Train Control System Structure*

The intercity railway train control system consists of vehicle equipment and ground equipment. The ground equipment includes communication control servers (CCS), temporary speed restrictions servers (TSRS), train control centers (TCC), track circuits, and balises. Vehicle equipment consists of ATP and ATO, among which ATP includes vehicle security computer (VC), track circuit receiving unit (TCR), balise transmission module (BTM), GSM-R wireless transmission unit , driver-machine interface (DMI) etc.[7]The intercity railway train control system structure is shown in Fig. 2.1.

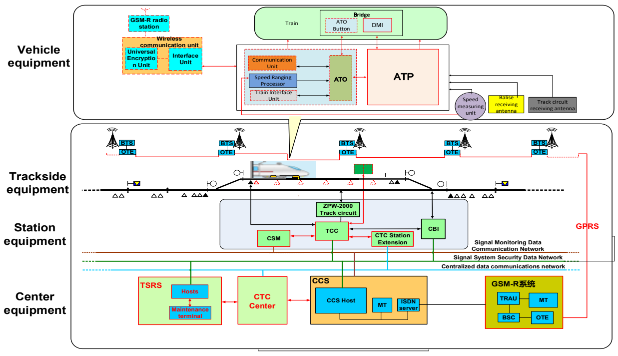

Fig. 2.1 The intercity railway train control system structure

B. *Classification of Resolution of Automatic Train Operation Model*

According to the different levels of information interaction details in the automatic operation scenes, the entire process is divided into three resolutions: low, medium, and high. The resolution division basis is shown in Fig. 2.2.

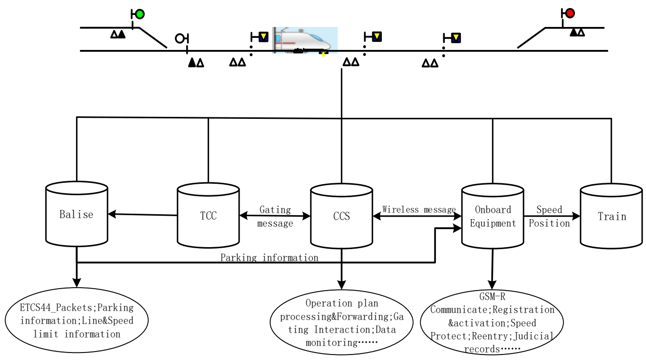

Fig.2.2 Intercity Railway Train Control System Resolution Division

The train section operation information in the figure reflects the low-resolution information of the system. At this time, the train is considered as a whole, and the train is described in the running state. From this model, macro information such as the position and speed of the train can be obtained.

Medium-resolution information during the operation is the process of information transmitted between devices in different operating scenarios. The high-resolution information of the model reflects that different devices obtain sufficient information and then execute disaggregation to complete logic functions and reflect the internal information processing process of the device.

C. *Train Automatic Operation Model Design*

This paper selects a representative train section automatic operation and precise stop at the station, according to the above resolution basis, analyze the train automatic operation model from three levels:

1) *Train section driving state model*

Low-resolution models reflect system-level information. The macro state of the train during autonomous driving can be obtained, and the current position and speed information of the train can be obtained, which can be used by railway decision makers to make train operation management decisions.

2) *Train pulling in model:*

Medium-resolution model that reflects device-level information. This model describes that when the train approaching the station, in order to obtain the information of the train stop position, the train disaggregate the balise transmission unit, obtains related information, and the process of the information is conveyed between various devices. The model can be used for system equipment communication detection, railway field personnel to detect the system.

3) ATO control realizing model:

High-resolution model, reflecting the logic layer information. This model describes the realization of the functions of vehicle equipment further disaggregate, logic information processing, train control realizing, including the ATO accurately controlling the stop train and the inter-station operation function after the train obtains the inbound related information. The R&D personnel of the railway system can design and maintain the system function according to this model, and realize the device control algorithm and logic processing functions.

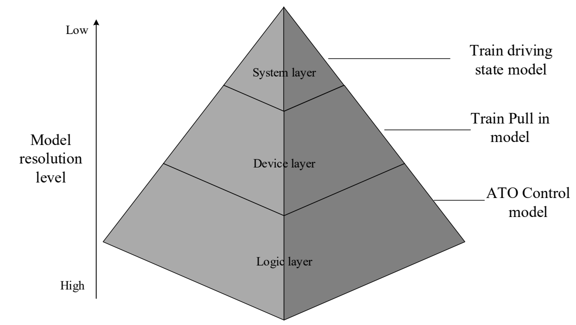

Fig.2.3 Multi-resolution model design

D. Information transfer between multi-resolution models

In multi-resolution modeling, information needs to be transferred between different resolution models. In order to ensure that both parties of the interaction are always in the same resolution level, the low-resolution model information is less precise and more macroscopic, when interacting with the high-resolution model, It is necessary to perform disaggregate first. High-resolution models have higher information accuracy. In some cases, their output information can be directly used as input information of low-resolution models to interact.

In the train automatic operation model, the information exchange between modules is shown in Fig. 2.4.

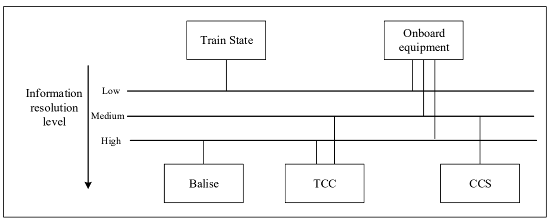

Fig. 2.4 Train automatic operation model information interaction diagram

The train operation status as system-level low-resolution information can directly obtain train speed and position information from equipment-level vehicle equipment; The equipment-level vehicle devices, CCS, and TCC can directly interact with each other because they are in the same resolution level.

IV. THE PROCESS OF DISAGGREGATION AND AGGREGATION ABOUTTRAIN AUTOMATIC OPERATION MODEL

A. Formal description definition of train automatic operation model

In order to ensure the rationality of the established model, this paper uses the MRME method to verify the established model. The MRMS method is improved by Liu BH on the basis of the traditional formal method DEVS. The MRME method has closed coupling and can be described by the traditional DEVS method.[8]

The traditional DEVS method uses a number pair (s,e) to represent the state of the system, where s is the state of the system and e represents the duration of the system in the state.[9]

Based on this, this paper defines the MRME description method of the intercity railway train control system as follows:

$$MRMS =< X_I, Y_O, \kappa, \{M_k\}, \chi, M_\chi > .$$

Where:

κ : the collection of entities in the system;

M_k : a subset of multi-resolution models of entity k ;

$$M_k =< \tau_k, \{M_R^k\}, \{R_{i,j}^k\} > \subseteq MF$$

Where:

MF : Multi-resolution model complete set of entity k;

τ_k : the resolution set of entity k;

M_R^k : model of entity k with resolution R;

$R_{i,j}^k : Y_R^i \to X_R^j$: relation between different resolution models;

χ : model resolution controller;

M_χ : controller model;

Where is called the model resolution controller, its status information includes model resolution information and resolution control information. The conversion of the model resolution is determined by the state of M_χ and the input of the system. π is a mapping function that maps the resolution of the model into the model's resolution mode.

When the resolution model of the model at time t is $\phi(t)$, the operating structure of the system is:

$$M_\phi =< Q_\phi, \{I_{\phi,q}\}, \{C_{\phi,q}\}, \{Z_{\phi,q}\}, \{R_{\phi,q}\} >$$

Where:

Q_ϕ is the collection of all modules in the system;

$I_{\phi,q}$ is the collection of modules that affect the module in the system;

$C_{\phi,q}$ is the collection of modules that need to be maintained consistency with module;

$Z_{\phi,q}$ is the connections within the module;

$R_{\phi,q}$ is the connections between modules with different resolutions;

δ_{χ} is the state transfer function of χ ;

$C_{\phi,d}$ output function of χ ;

According to the above variable description, the entity $\kappa = \{S,T\}$ is defined in the automatic train operation model, where S is the station entity and T is the train entity.

The train entity model $M_T = \{\tau_T, \{M_r^T\}, R_{i,j}^T\}$ has a resolution set $\tau_T = \{\tau_H, \tau_L\}$. Station entity model M_S , train high resolution model M_H^T , train low resolution model M_L^T are all traditional DEVS models.

B. *The MRME Description of Train section operation Model*

In the train section, the system resolution model diagram is shown in Fig. 4.1.

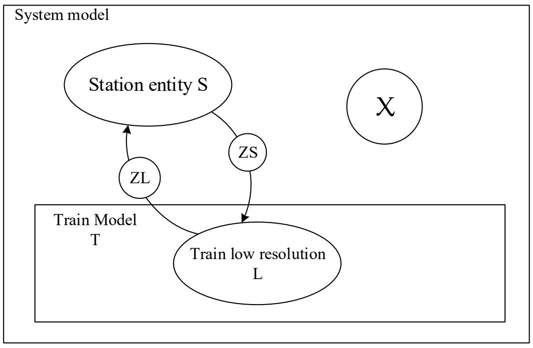

Fig. 4.1 Train section driving resolution

At this time, the model resolution mode is $\phi = \{\tau_S, \tau_L\}$ and the MRME of the system structure is described as:

$M_\phi =< Q_\phi, \{I_{\phi,q}\}, \{C_{\phi,q}\}, \{Z_{\phi,q}\}, \{R_{\phi,q}\} >$

$Q_\phi =< S, L >$

$I_{\phi,S} = \{L\}$, $I_{\phi,L} = \{S\}$, $I_{\phi,\chi} = \varnothing$

$C_{\phi,S} = \varnothing$, $C_{\phi,L} = \varnothing$

$Z_{\phi,S} = Y_L \to X_S$, $Z_{\phi,L} = Y_S \to X_L$

$R_{\phi,S} = \varnothing$, $R_{\phi,L} = \varnothing$

In the system, the train exists in a low-resolution model, and interacting with the station entity model. Therefore, the module entity in the system is S,L . Since there is no aggregation and disaggregation at this time, the model controller does not need to interact with other modules.

C. *Train pulling in Model MRME Description*

When the train approaches the station, it interacts with the station equipment. At this time, the train is disaggregated and the low-resolution part of the train converts to a high resolution model. The system model diagram is as follows:

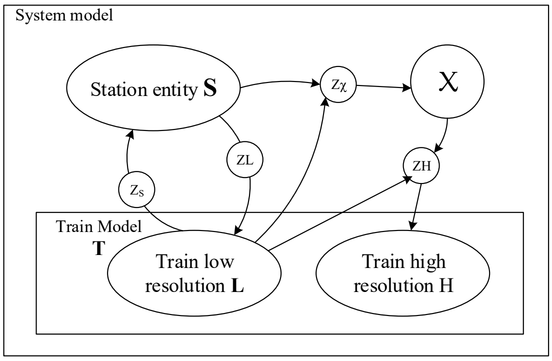

Fig. 4.2 Train pulling in resolution diagram

At this time, the model resolution mode is $\phi = \{\tau_S, \tau_L, \tau_H\}$ and the MRME of the system structure is described as:

$M_\phi =< Q_\phi, \{I_{\phi,q}\}, \{C_{\phi,q}\}, \{Z_{\phi,q}\}, \{R_{\phi,q}\} >$,

$Q_\phi =< S, L, H >$,

$I_{\phi,S} = \{L\}$, $I_{\phi,L} = \{S\}$, $I_{\phi,\chi} = \{S, L\}$,

$C_{\phi,S} = \varnothing$, $C_{\phi,L} = \varnothing$, $C_{\phi,H} = \{L\}$,

$Z_{\phi,S} = Y_L \to X_S$ $Z_{\phi,L} = Y_S \to X_L$,

$Z_{\phi,H} = Y_L \times Y_\chi \to X_H$,

$Z_{\phi,\chi} = Y_L \times Y_S \to X_\chi$,

$R_{\phi,S} = \varnothing$, $R_{\phi,L} = \varnothing$, $R_{\phi,H} = Y_L \to X_H$;

In the process of disaggregation, the train model exists at the same time in the form of low resolution and high resolution, so the model consistency problem $C_{\phi,H} = \{L\}$, needs to be considered.

D. *ATO control realizing model MRME description*

In this model, the train stops according to the stopping information in the balise, and executes the station operation . At this time, the train exists completely in high resolution. The system model diagram is as follows:

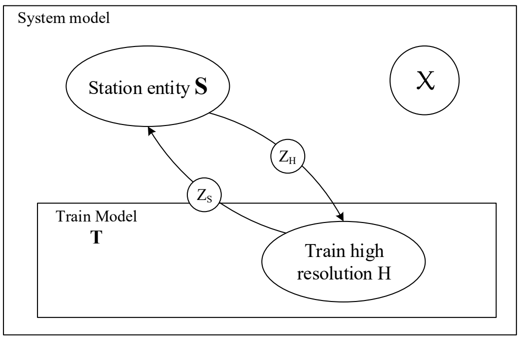

Fig. 4.3 ATO control realizing resolution

At this time, the model resolution mode is $\phi = \{\tau_S, \tau_H\}$ and the MRME of the system structure is described as:

$M_\phi =< Q_\phi, \{I_{\phi,q}\}, \{C_{\phi,q}\}, \{Z_{\phi,q}\}, \{R_{\phi,q}\} >$

$Q_\phi =< S, H >$

$I_{\phi,S} = \{H\}$, $I_{\phi,H} = \{S\}$, $I_{\phi,\chi} = \varnothing$

$C_{\phi,S} = \varnothing$, $C_{\phi,H} = \varnothing$

$Z_{\phi,S} = Y_H \rightarrow X_S$

$Z_{\phi,H} = Y_S \rightarrow X_H$

$R_{\phi,S} = \varnothing$, $R_{\phi,H} = \varnothing$

Since the disaggregation process has been completed at this time, the model controller χ does not need to interact with other models. After the operation between the train stations is completed, the reverse process of the inbound aggregation may be carried out, and the high-resolution model is aggregated to continue the interval operation of the low-resolution model, which will not be repeated here.

V. CONCLUSION

In this paper, according to the different levels of information interaction in the train control system, it is divided into three levels of low, medium, and high resolution information mode, corresponding to the information level of the system control, device, and logic layers. Based on this, the operation scenes of train automatic operation and precise stop at the station are selected, and establishing the train section status model, train pulling in model, and ATO control realizing model to describe the system. To prove the rationality of the model division, the MRME method based on the DEVS was chosen to analyze the process of aggregation and disaggregation of the scenes, and the state transition of the different stages of the model was described by the formal method, which laid a theoretical foundation for the follow-up study.

In the next research, the different resolution models established in this paper will be further studied, such as the design of consistency maintenance algorithms between the models, the interaction between the models across the resolution, etc., and according to the model the simulation system is implemented, and the simulation platform is built.

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