Development of the Reconnected Metro Train Control and Monitoring System

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Abstract. Train Control and Monitoring System (TCMS) is usually used to monitor the status of train and all the subsystem, to control the train-level functions and vehicle-level functions, including the control of the Propulsion Subsystem, the Braking Subsystem, the Passenger Information Subsystem, and so on. This paper mainly introduces the design of metro train control and monitoring system, including the designs of network structure, Vehicle Control Unit (VCU), Human Machine Interface (HMI) and Portable Maintenance Unit (PTU), and summarizes the advantages of the new network system.

Introduction

CRRC Nanjing Puzhen Co., Ltd (CRRC Puzhen) is one of the earliest R & D domestic train network of vehicle factories independently, the current CRRC Puzhen train network has been fully achieved 100\% autonomy. Independent domestic network technology has been successfully used in dozens of Metro trains, Electric Multiple Units (EMUs), Diesel Multiple Units (DMUs) and other projects at home and abroad. Based on the previous mature projects and train's network design experience, we designed a set of TCMS with more advanced, more reliable and more secure network system in this project, by adopting train network structure, software and hardware in line with modern mainstream design. This paper mainly describes the design of TCMS, including the designs of network structure, VCU, HMI and PTU.

Network Structure and Compositions of TCMS

TCMS control is divided into train control level and vehicle control level. Generally, TCMS basic management functions are the following seven categories: (1) MVB Bus Management; (2) Remote Input/Output Management; (3) Remote Serial Link Management; (4) Time Management; (5) Device Availability Check Management; (6) Fault Management; (7) Software Version Update Management.
Design of Network Structure

A metro train/unit has 4 cars in this project. The metro train can be re-connected referring to the metro company actual passengers flow to reduce the train maintenance costs. Fig.1 is the metro train network structure, and among them: Tc represents Trailer Car with a driver’s Cab, and Mp means Motor Car with Pantograph. Furtherly, this part explains the network structure in three aspects: network hardware, subsystems and network bus.

Network Hardware

(1) GW (Gate Way)
GW is provided as a medium for data transmission between the train-level WTB bus and the vehicle-level MVB bus which is equipped in each Tc Car. GW mainly to achieve three functions: WTB management (train-level), MVB management (vehicle-level) and Logic control.

(2) Rep (Repeater)
In each Mp car, setting up a repeater with redundant function, which used to filter the signal amplification, extend the signal transmission distance, and increase the reliability of the bus.

(3) VCU (Vehicle Control Unit)
VCU is connected to MVB bus to monitor the status and fault information of the train equipment (eg PCE, ACE, BCE, etc.) in real time and control the whole metro train. Meanwhile, VCU sends diagnostic information to HMI, helping drivers to drive. One metro train has two VCU, which divided into strong VCU and weak VCU, two VCU redundant backup each other.

(4) RIOM (Remote Input/Output Module)
In Tc car, two sets of independent RIOM units are configured for train control and monitoring system, the other car with one unit. Each RIOM unit is composed of different types of modules, including processing module, analog input and output module, digital input module, digital input and output module.

(5) HMI (Human Machine Interface)
In this project, each Tc car is equipped with one HMI, which is the interface between TMS and operator man-machine.

(6) Switch (Ethernet Switch)
In each car, setting up an Ethernet switch respectively, which used for network maintenance.

(7) AP (Access Point)
The vehicle is equipped with a wireless router that works in the client mode to achieve getting the vehicle into the barn, connecting to the barn wireless network, downloading vehicle failure information, uploading and downloading train video information.

AP mainly consists of Car Wireless Host and Antenna.

(8) EVR&FDL

Data records are divided into two types, event data recorded in the EVR and fault data recorded in the FDL.

**Subsystem Modules**

From the network structure of Fig. 1, the subsystem includes the following eight parts which complete the corresponding functions: (1) PCE: Propulsion Subsystem (Mp Car); (2) ACE: Auxiliary Subsystem (Tc Car); (3) BCE: Braking Subsystem (Every Car); (4) EDCU: Electronic Door Subsystem (Every Car); (5) HVAC: Heating, Ventilation and Air Subsystem (Every Car); (6) PIS: Passenger Information Subsystem (Tc Car); (7) ATC: Automatic Train Control Subsystem (Tc Car); (8) FAU: Fire Alarm Unit Subsystem (Tc Car).

**Network Bus**

Network bus used in this project includes WTB, MVB, CAN and Ethernet. The relationship among the four data streams is shown in Fig. 2:

![Network Bus Diagram](image)

**Figure 2. Data flow relationships of each bus.**

(1) Wire Train Bus (WTB)

Train bus system consists of a stranded WTB with redundant structure, and WTB uses dedicated shielded twisted pair cable for transmission of process data and message data. WTB has the function of train reconnection, that is, when the configuration of the train changes, WTB can address the vehicles to form a new network topology automatically, which is particularly suitable for dynamic connecting of vehicles.

(2) Multifunction Vehicle Bus (MVB)

Vehicle bus system consists of a MVB with redundant structure. MVB bus of each vehicle is connected by a highly reliable car terminal connector. They provide redundancy for the critical areas concerned, that is, a single point of failure in the multifunction vehicle bus does not cause the bus system to fail or affect the normal operation of the train.

(3) CAN Internal Network Bus

CAN (Controller Area Network) is a serial data communication protocol, especially suitable for distributed control or real-time control. In this project CAN is mainly used as BCE, FAU and EDCU maintenance network. CAN bus on the form of the interface in two forms: CAN interface devices are connected to the MVB online directly and I/O signals are connected to the MVB via RIOM.

(4) Ethernet Bus
Ethernet bus runs through the entire train, connecting each vehicle's important network equipment (VCU, DDU, RIOM, etc.) and the subsystems (PCE, BCE, etc.) for Ethernet maintenance. Through Ethernet Bus, it shall be possible to access all the processors of propulsion & control equipment within the whole train using a standard laptop from one point provided in the Drivers Cab. Such access is required for uploading of firmware/application program, visualization of process parameters and also force or record the same and downloading the diagnostic data.

Software Development of VCU

Master VCU control system is TCMS main control unit system, VCU software program development using IEC61131 standard format language.

Software Application Structure of TCMS

Software of VCU is designed to use a dedicated design tool in this project, software development framework contains hardware interface PLC_Config, procedures and data sets (DUT).

Hardware interface implements the data exchange between the local variables and other MVB devices. First, hardware interface maps the local variables to the packets of the corresponding protocol, and then sends the data packets to the MVB bus through the MVB protocol. The program obtains the data from the hardware interface related logic operations.

Procedure is a collection of subroutines (POUs) which used to create logical relationships, including logical operations, MVB communication control and data logging.

Data set (DUT) is the transit point of the data in the application. Any data is sent, received and stored all through the data set which used to define various variables.

Software Structure of VCU

VCU consists of processor module, MVB communication module and power input module, while the different modules are connected through the bus at the top of the module.

VCU control unit software structure consists of three parts: hardware interface PLC_Config, data input and output modules, logic diagnostic modules (state diagnosis, control management and fault diagnosis). Software structure is shown in Fig.4.

(1) Hardware Interface PLC_Config

The main control unit of TCMS is VCU. It is necessary to establish a link to MVB communication between VCU and other nodes. The type of the hardware interface PLC_Config is decided by the type of the process data. The type of the process data with different communication protocol is independent. Only the MVB process data type is used in the software structure of the whole system.

(2) Data Input and Output Modules

The data input and output modules are divided referring to the Subsystem. Each Subsystem corresponds to two programs for data copying, one for input and the other for output. The input is to copy the data of the hardware interface port to the data set (DUT), while the output is the opposite. The symbolic names of the data input and output program of the braking subsystem, for example, P_IL_BCE: the input of the braking subsystem; P_IO_BCE: the output of the braking subsystem.

(3) Logic Diagnostic Modules

The logic diagnosis consists of three parts, each of which is divided into different programs referring to these functions: Diagnostic State (S); Control and Management (C); Diagnostic Fault (F).

The logic diagnostics in this project are partly shown in the following examples.

P_PROS: Propulsion subsystem status detection; P_DRVC: Driving subsystem control detection; P_BRKF: Braking subsystem fault detection.

Definition of DUT

The purpose of DUT is to aggregate the variables corresponding to the same node or function into a structure. One DUT consists of basic data types and also contains variables of different data types. In
this project, DUTs can be used as: Train information, Hardware input and output variables (RIOM), Diagnostic variables, Intermediate variables and MVB node status.

DUT is used to transfer data from one POU to another or multiple POUs. While programming, the DUT structure in the corresponding variable group of the POU is defined with the number of variables to be defined in the POU reducing. For each node, one or more DUTs are created including input and output variables for the corresponding subsystem.

**Design of HMI**

The metro train status information, process data and fault information are sent by the VCU to the HMI. The instructions issued by the HMI (e.g., HVAC temperature setting, time setting, etc.) are transmitted from HMI to VCU. With regard to the design of HMI display, standard Chinese/English Languages are both served. Not only texts and numbers, but also some simple graphics are used for information display.

**Environment of HMI Software Development**

The HMI development environment is described as, Development language: C#; Application development tools: Qt Creator; Graphics library that used: Qt-Linux-Commercial; Software platform of application runs: Linux Operating System.

**Design of HMI Software Flow**

HMI’s application procedure is actually composed of two threads, MVB threads and GUI threads. MVB thread performs MVB communication function mainly; GUI thread is used to create HMI graphical interfaces and providing some control logic primarily. The communication between MVB thread and GUI thread using the method of global variable. HMI software structure is shown in Fig. 5.

**Screen Design and Display**

On the train, the Main Screen displays operation parameters, status and failures primary to facilitate the driver controlling the train. Fig. 6 is HMI basic operation flow. The middle area is the Important Information Bar, above it is the Status Bar (Fig.7) and below it is the Navigation Bar (Fig.8).

1) Status Bar

Status bar is shown in Fig.7, which includes the following information: Driving Mode; Train Speed; Emergency Braking State (EB); Event and Fault Status; High Voltage of Catenary Pantograph; Next Station and Destination; Date and Time.

2) Important Information Bar
In the Main Screen of the train shows the status of vehicles, important values, major parts states and other important related information. In the network screen, the green represents normal, the yellow represents a warning fault, and the red represents a major failure. In Important Information Bar, including: Status of Driver’s Cab; Direction of Train Running; State of Pantograph; State of Door; Percentage of Traction Handle; Main Wind Cylinder’s Pressure; Brake Air Cylinder’s Pressure.

(3) Navigation Bar

Navigation bar is located at the bottom of the Main Screen (Fig.8), to achieve the switch between different screens. In this project, there are navigation touch keys as: MAIN Screen; PCE Screen; BRK Screen; ACE Screen; PIS Screen; History Screen; Maintenance Screen.

Metro Train Network Maintenance

Portable Maintenance Tools (PTU)

PTU is used of applications downloading, software updating, online monitoring, maintenance and debugging procedures, fault data downloading, offline data analyzing, parameters setting and other functions. PTU is applied for field maintenance personnel. Maintenance personnel can operate the PTU to monitor TCMS systems and sub-device status. The relationship between PTU and TCMS is shown in Fig. 9.

PTU is used for fault analysis which has the following characteristics: (1) Diagnostic data is displayed in an easy-to-understand chart or graphic; (2) Each faulty can be described in detail; (3) Fault data gives statistics for each component; (4) Data can be archived; (5) System sets up multiple filtering modes; (6) Charts can be printed out.

Cables for Maintenance

When using PTU for TCMS network maintenance, it would use different hardware cables because of the difference of interface type or equipment type. The main cables using of in this project are shown in Fig.10: RJ 45 to M12-A Ethernet connecting cable (Fig.10a); USB-A to USB-M12 connecting cable (Fig. 10b); RS232-DB9 to USB-A connecting cable (Fig.10c); RS232-RJ45 to RS232-DB9 to USB-A Serial cable (Fig.10d).

Conclusion

Based on one practical project of TCMS, this paper introduces the designs of principle and flow of metro train TCMS in detail. TCMS software ideas are consistent with the mainstream software design thoughts of current network. Engineers have carried on the optimized design in the aspect of monitor of metro train running state, operation habit of driver, realization of control function, train operation parameters and so on.
In addition, the main innovations/characteristics of this TCMS are:

1. Designed WTB, referring to the passenger flow, re-organizing the train;
2. Set Ethernet maintenance network/switch, to improve maintenance efficiency;
3. Set AP for data wireless transmission;
4. Adopted modular approach for VCU software programming, to ensure the correctness of the program;
5. HMI development of high integration, information and interface design reasonable and comprehensive;
6. Network structure is in line with modern mainstream, more secure and reliable.

References

