Integration Research of Communication Based Train Control and Computer Interlocking in Urban Rail Transit

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Abstract. By analyzing the interface information of CBTC and computer interlocking, the process of train control was abstracted as a closed-loop control model based on communication mode of train-to-train. Considering the whole fail-safe of the integrated signal system, designed four operating modes that would have strong compatibility. Through software simulation, the model tested its the validation and the integration proved its feasibility. The results indicate that this kind of integration can be available in the signal system of urban rail transit.

Introduction

Integration of CBTC (Communication Based Train Control) and CI (Computer Interlocking) is becoming the tendency of signalling system in urban mass transit\cite{1,2}. The researches of the integration in signalling system can be divided into three parts. One is equipment integration that is integrating the wayside signal equipments from their functions\cite{3}. One is control mode that is unifying the interfaces inner and outside of signalling system, adopting the same train-to-wayside communication protocols, and unifying the engineering design standard at different railways\cite{4}. The other is control synthesis that is synthesizing a signalling subsystem to enlarge its control range\cite{5}.

This paper proposes an integration model of CBTC and regional CI based on the train-to-train communication from the points of equipment integration and control synthesis, and simulates and tests its function.

Interface Analysis of CBTC and CI

Because of the existing complex interfaces for wired connections between the regional CI and ZC (Zone Controller), generally, the serial interface and cross-linking are adopted in engineering to meet the requirement of real-time control and intercommunication of the signal system\cite{6}.

The interface information transferred from the regional CI to the ZC are axle section state (occupied / idle), switch position and signal state including releasing state, interlocking protection state and route delay state of manually cancelling route, platform automatic reversal button state, platform emergency stop button to activate, platform screen door to alarm, admission passage cancellation request (for parking ensure), platform area request for deducting train and platform area request for ahead of the train departure.

The interface information transmitted from ZC to the regional CI are CBTC train approaching signal (approach locking signal), signal degradation command, guarantee for parking in front of signal (delay signal of manual cancellation), occupation of ZC section (any section of the train is idle), the train having crossed the signal and pushed into the next section (signal of automatically cancelling route).
The regional CI transmits only status information to ZC, but ZC sends control commands to the regional CI. Therefore, ZC can be regarded as an upper controller, and the regional CI is an executive machine. So there exists the possibility of their integration and optimization.

**Inference**

In order to ensure the stability and effectiveness of safe control of the whole signal system, there are two closed loop control processes in the traditional signal system. One is among ATS (Automatic Train Supervision), ZC and regional CI. Another is between ZC and VOBC (Vehicle On-Board Controller). These two closed-loop control processes ensure the safe, real-time and efficient operation of the train, and are indispensable.

Restricted by train-to-wayside communication and mobile security, VOBC requires ZC to calculate the safe distance of the front and rear trains. But ZC uses the traditional colliding-hard-wall theory [6], which assumes that the front train is at stop and the consecutive train is moving, to calculate the interval distance. This calculating method under this assumption is inherently limited, because the safety distance is often too long. It does not conform to the characteristics of the front train moving in real time, and is unfavorable to shorten train operation distance, and also is unable to further improve the utilization of line.

Thus, whether it is for the sake of ensuring the stability of the integrated system, or for the optimization of the closed-loop control link, through the model of closed loop control information flow, it is necessary and feasible to develop the integrated system of CBTC and regional CI in urban rail transit.

**Integrated Model Based on Train-to-train Communication**

The integration model of CBTC and regional CI focuses on the closed-loop control link between VOBC and ZC. The wireless communication is adopted between trains. ATS releases dispatching order to VOBC. According to the order, VOBC sent route request to the area integrated controller, and the wayside equipment is controlled by the area integrated controller, then the route is prepared and fed back to VOBC, and then VOBC continues to extend its LMA (Limit Movement Authority), as shown in Figure 1.

At this point, the area integrated controller is the real integrated machine. In the internal logic, the original regional interlocking machine’s function module is retained, and the part of the functional modules of original ZC is added. That is, there are still interlocking module and drive acquisition module, and the interlocking operation module is a double 2-vote-2 redundant structure, which ensures the interlocking operation safety and reliability. Considering the signal system’s degradation mode, the functional modules of the original ZC are retained, that is to say, the transponder message module and the LMA calculation module are retained. It consists of two sets of high-performance industrial control computer systems (master and standby area controller), and each set of industrial control computer system is composed of main and slave computer.

![Figure 1. Integration model based on train to train communication.](image-url)
Integrated Model Information Flow

In the integration model, the area integrated controller is no longer reading data from the line database. VOBC reads the line information on its own, and there is no LMA control between the area integrated controller and VOBC. The real-time wireless communication is adopted between the front and the rear train to acquire the train location in VOBC. According to the ATS dispatching order, route application is sent out to the area integrated controller by VOBC of each train. Then, the LMA is automatically calculated by VOBC according to the line information and the route state information returned from the area integrated controller. The dispatching order is directly issued to VOBC by ATS, so the radio train dispatch is really realized. Thus, the train can optimize traffic flow only by using the track resources it needs. In addition, the train can obtain the train location information more quickly through communicating with other trains. The train interval control will be more accurate [7,8] and the distance will be shortened between the front and back train, thus greatly improving the performance of the system.

In summary, the logic work flow of the area integrated controller and VOBC under the condition of train to train communication is shown in Figure 2.

Simulation

In order to verify the feasibility of the integrated system scheme, referencing the verification method of train control system and interlocking system[9-11], on the simulation platform of the rail traffic signal system with the existing interlocking system, the software has been used to simulate the control function of the area integrated controller, and the concrete control process is carried out as shown in Figure 3.
The experimental interface is developed by VC++6.0 program, as shown in Figure 4, and urban rail transit main track signal layout is selected as the reference computer simulation design. The certain regional CI area of main track is used as an experimental object to set up three stations, respectively marked as Z01, Z02, Z03, where Z03 is the centralized station for placing the area integrated controller to control the signal S0101 (uplink), X0101 (downlink), Platform Screen Door(PSD), and Emergency Stop Button(ESB) at the station of Z01 and Z02, and switches P0201/P0202, P0301/0302 and P0303/P0304 in this region. The free state of the route is shown in yellow light band, and the white band represents the route locking, and the red band represents the route occupied. The axle-counting equipment is used as the dividing point of each track section. Four control modes of the signal system are selected on the menu to realize fail-safe train control modes. For security, the integrated system can operate the devices only in manual mode and detection mode, as shown in Figure 4 (a). When working in automatic mode, the train route is automatically arranged, automatically released. When the train is rolling into the route section, it automatically turns into a red light belt. With the train advancing, the route, which has been free, will automatically release and show in yellow light band, as shown in Figure 4 (b). In the backup mode, the train route is manually arranged and unlocked automatically.

The above simulation experiments have basically realized the interlocking function of automatic train running and signal equipment linkage under the two communication modes. Through menu manipulating, four modes of signal control, such as automatic mode, backup mode, manual mode and detection mode, are freely switched. In the interlocking area, the integrated controller function is basically realized.

![Figure 4. Experimental interface of integration system.](image)

**Conclusion**

The Integrated system of CBTC and regional CI, proposed in the design, is based on CBTC standard framework of IEEE1474.1 to realize integrated signal control function[12], whose main fail-safe modules adopt double 2-vote-2 redundant structure. So the safety and reliability of the integration system is guaranteed. The closed loop control of the integrated system is analyzed by using the information flow model, and the stability of the control function of the integrated system is guaranteed, and the control function of the original signal system is also fully represented.

When designing the signal integration system interface, the plane diagram of urban rail transit signal system is chosen as reference, so that the simulation system is closer to the real working conditions. When the software is designed, the functions of automatically searching, selecting and locking the route are realized by the interlocking operation module in the integrated system. The function of analog automatic operation and route setting of the single-row train has realized.
feasibility of the integrated system is proved by experimental simulation. At present, the software hierarchy and hardware feature need to be further improved.

As the simulation is completed under the assumption of reliable train-to-train communication and train-ground communication, the optimization effect of the scheme needs further testing in practice.

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References

[1] Liu Jian, Li Zhong-lei, Hou Lei. LTE-M Based CBTC Signal System of Interoperability for Urban Rail Transit. Proceedings of the 2015 International Conference on Electrical and Information Technologies for Rail Transportation.Zhuzhou:Scientific Research Publishing, (2015)66-72.

[2] Lin Hai-xiang, Zeng Xiao-qing, Shen Tuo. Interlocking Technology in High Speed Railway. China Railway, 2016(4): 38-43.

[3] He Qing, Wu Wei. Integrated Research on Computer Interlocking System and FZ-CTC Station Subsystem. Journal of Lanzhou Jiaotong University, 2010, 29(6): 129-132.

[4] Peter Gurník. Next Generation Train Control (NGTC): more effective railways through the convergence of main-line and urban train control systems.Transportation Research Procedia(14). Netherland: Elsevier B.V., 2016: 1855-1864.

[5] Gao Jian-guo, Chen Guang-wu. Research and simulation on integration of station and section of railway. Railway Computer Application, 2011, 20(1): 20-22.

[6] Lin Hai-xiang. Research on Computer Interlocking and Train Control System Integration in Urban Rail Transit. Lan Zhou: GSSTD, 2016.

[7] Su H., Wen J. Reliability and safety analysis on railway signal regional computer interlocking system. International journal of safety and security engineering, 2014, 4(4): 315-328.

[8] Cao Yuan, Tang Tao, Xu Tian-hua. Application of formal methods in train control system. Journal of Traffic and Transportation Engineering, 2010, 10(1): 112-126.

[9] A. Bonacchi et al..Validation process for railway interlocking systems. Science of Computer Programming, 2016(4): 1-20.

[10] M.J. Morley. Safety-level communication in railway interlockings. Science of Computer Programming, 1997(29): 147-170.

[11] Piotr Kawalec, Marcin Rzysko. Modern methods in railway interlocking algorithms design. Microprocessors and Microsystems, 2016(44): 38-46.

[12] IEEE Std 1474.1 TM: 2004, IEEE standard for communications based train control(CBTC) performance and functional requirements.