Data Flow and Data Structure Design for Computer Interlocking Applied in Medium-Low Speed Maglev

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Abstract—**Computer interlocking (CI) is serving as a core part of operation and control system (OCS) in rail transit, with no exception in medium-low speed maglev transportation system which has almost the same strategy as urban rail transit in train control. Important as it is, the data structure and data flow in CI have to be analyzed in detail just in the system design stage, so as to ensure that it can not only meet the safety-critical technical requirements, but be easier for system upgrade and function expansion as well. Till now, most related research on CI are not based on the medium-low speed maglev application background, moreover, discussion on data flow as well as data structure in CI can also be hardly found. In this paper, data flow and data structure in CI has been analyzed exhaustively according to the specific static and dynamic data transmission and exchanging requirements in medium-low speed maglev, the data structure in signal has also been set as a case with its design in detail also be discussed.**

Keywords-medium-low speed maglev; interlocking system; data structure; data flow; static data; dynamic data

I. Introduction

It is of no doubt that the operation and control system (OCS) serves as the neural nerve of the whole rail transit system, for it realizes train dispatching with high efficiency under the safety-critical criteria defined by IEEE and EN standards series [1-2]. And computer interlocking (CI), which is even the core part of OCS, burdens key functions including train shunting, switch status changing, route arrangement etc. in station areas [3]. Medium-low speed maglev, which has almost the same train operation and control strategy as urban rail transit in its OCS, has experienced a fast development process in not only related techniques, but also rail transit market; major cities such as Changsha, Beijing ... have already employing medium-low speed maglev as a way of urban rail transit system connects suburban areas with medium passenger capacity, and also as a new name card of the city which represents high technology and low pollution [1-2]. It can be inferred that the core part CI in OCS applied in medium-low speed maglev has its own technical requirements in data flow and data structure design, and such problem have to be analyzed in detail just in the system design stage, so as to ensure that the data flow and data structure can not only meet the safety-critical technical requirements, but be easier for system upgrade and function expansion as well [4].

Many scholars has taken interlocking system in rail transit into consideration to study its reliability in various aspects, even since the electromechanical interlocking (EI) period. In late 1970s, A. H. Cribbens et al. (1978) was trying to replace traditional EI by microprocessor-based CI, and put emphasis on the outstanding safety and reliability signalling technology which must be satisfied by interlocking [5]; during 1980s, A. H. Cribbens and his research group (1987, 1989) realized successful development of solid-state computer interlocking, long-distance interlocking data transmission terminal, and all-electronic signalling system based on that, and the software and data structure which could help ensure system safety, and had been employed in data communication between interlocking and trackside equipments, had been discussed [6-7]. As CI related techniques developed quickly, in recent years, researchers paid most attention on functional reliability analysis for CI. G. Hong et al. (2011) and N. Jing et al. (2013) focused on the hardware redundancy design in the so-called iLOCK CI system which had been applied in Chinese High Speed Rail (HSR), and pointed out that the 2 out of 2 × 2 (2 oo 2 × 2) design can help enhancing the reliability of CI evidently [8-9]; X. Hei et al. (2013) utilized the unified modeling language (UML) to define the whole function of CI with time constraints, which could clearly describe and define the time factors in real-time safety-critical function analysis and could greatly improve the credibility and usability of CI model [10]; J.

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Mocki et al. (2016) defined the concept of safety cost, and had analyzed the core function of CI in railway junction area as well as built the junction signalling system reliability function cost chart [11]; while A. Fantechi, et al. (2017) set CI as a typical distributed system with many key safety-critical functions, studied the modeling method for such distributed system, and proposed a system design method which could ensure safety restrictions be satisfied in each stages of system design, however [12].

From the literature review above, it can be seen that the safety-critical function for CI is undoubtedly important, and many efforts have been made to ensure its reliability and safety in system design employing hardware redundancy analysis, or partial function analysis, etc. However, even if some of those reports have taken data transmission in CI into consideration, the work they did, have only focused on the data transmission between CI and other sub-systems in the signalling system [7], or on the data flow in a single component [9]; and till now, most related research on CI are not based on the medium-low speed maglev application background. Thus, in this paper, data flow and data structure in CI has been analyzed exhaustively according to the specific static and dynamic data transmission and exchanging requirements in medium-low speed maglev, the data structure in signal has also been set as a case with its design in detail also be discussed.

II. Basic Theory of Computer Interlocking in Medium-Low Speed Maglev

The core technique of CI is based on computer technique, also, communication, fault-tolerant, and "fail-safe" techniques are supplemented as auxiliary ones to help CI realize real-time control for station area in railway system [13]. The CI applied in medium-low speed maglev has no exception to that technical basis. Making a discussion of basic theory of CI in medium-low speed maglev, and an analysis of data flow based on the hardware as well as software design, can be valuable in mastering the system function and performance in detail.

A. Hardware Part

Different from the general computer based control system, CI has very high requirements on reliability and safety design. On the station site, CI is operating uninterruptedly, and no system fault is tolerant, for serious accident may happen caused by CI fault. As mentioned in literature [8-9], for hardware part in CI, 2 out of 3 (2 oo 3) and 2 oo 2 × 2 structures have now been widely used, especially the latter one. From the functional view, CI is comprised by a master computer and several slave computers, to be specific, master computer is in the human-machine interface (HMI) layer, and is serving as the interaction face between operation personnel and CI itself, while slave computers are in the interlocking layer, and are serving as interlocking function command executors with data exchanging with outdoor equipments. Both of these 2 types of computer have 2 sets of equipments, thus the redundancy design can be achieved, as shown in Fig. 1. Generally, master computers are industrial personal computers (IPCs), slave computers are typical measurement and control computers with compressed real-time protocol (CRTP) bus. Thus, the whole CI can be ensured to be working with high efficiency.

B. Software Part and Data Flow

As far as software part of CI is considered, 2 layers corresponds to HMI and interlocking layer in hardware part are set. Software in HMI layer realizes operation, representing, and maintenance information processing; while software in interlocking layer realizes basic interlocking control, execution control, and diagnosis function, etc.

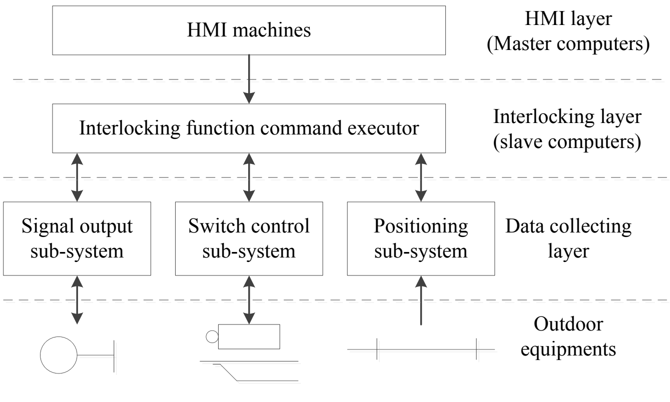

Figure 1. Layer structure of CI.

To be specific, the control execution in interlocking layer includes command execution, route processing, status input, information output and command output modules. In HMI layer, many operation commands are generated and sent to interlocking layer, thus in the interlocking layer, many program modules are corresponding to those commands, and the working flow as well as data flow are shown in Fig. 2, where i is the route number in operation, m is the total routes can be managed, L_i is the current number of route sheet; if the execution result is the same as the object suspected, the corresponding command will be deleted from the route sheet, otherwise, information will be given to the operation personnel to let them give the correct action. Fig. 2 tells that there are also program modules in route processing part and decides the data flow direction. After route searching, data of route nodes which have been searched out will be sent into route processing program, such program includes consistency check, switch manipulation, control command formation, route locking, signal opening, signal open keeping and route unlocking modules. The control command will be finally sent to information output module and command output module, the status of all the command related trackside equipments will be changed and the corresponding information will be sent to HMI for representing.

C. Basic Interlocking Content in Medium-Low Speed Maglev

In medium-low speed maglev transit system, interlocking is a kind of interacting pairwise relationship between signals, switches and routes, such relationship can help to ensure train operation safety. The basic interlocking content in medium-low speed maglev can be described as:

1) Routes and switches: generally a switch has 2 status: direct position and reverse position, the status of switch decides the route related to it, different status of switch correspond to different object points in different routes; thus, the route managing process must include switch status checking steps, only if the switch is in its correct position can the corresponding route be locked.

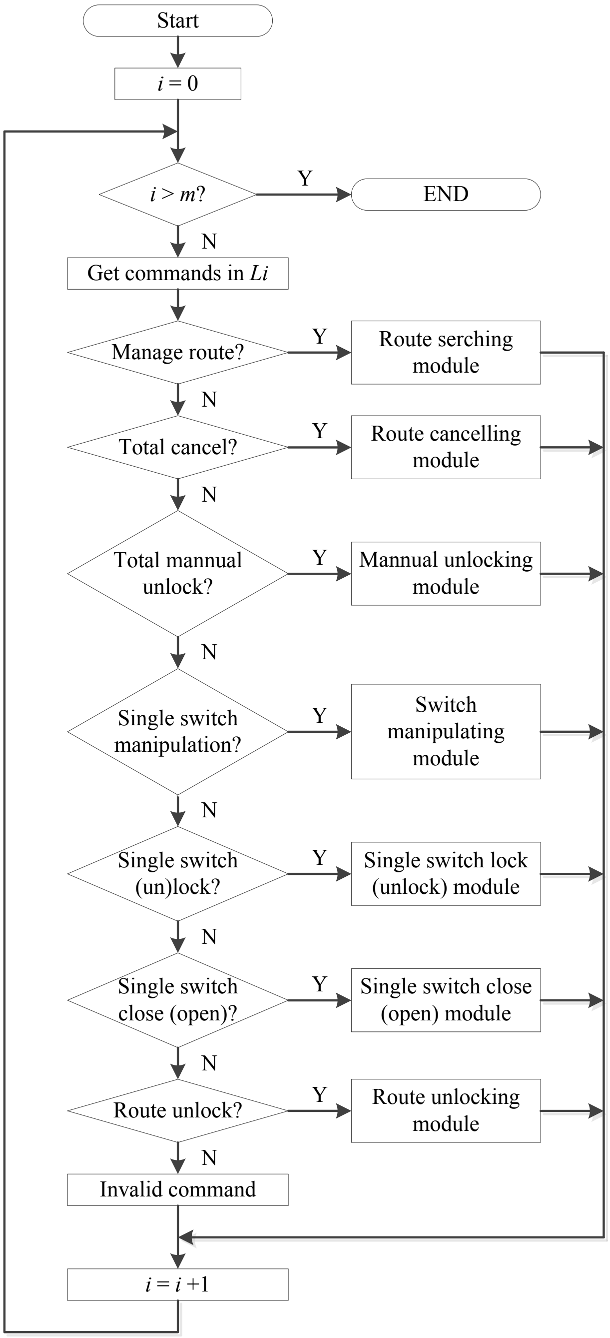

Figure 2. Working flow and data flow in interlocking layer of CI.

2) Signals and switches: signals are applied to protect certain routes, the interlocking relationship between these 2 types of items are almost the same as the one just mentioned above; it should be pointed out that, in abnormal situation, switches may be trailed or incomplete closing, the corresponding signal must be closed.

3) Routes and signals: the prerequisite of signal open permission is all the sections in the route protected by such signal is idle, moreover, the status of switch must be correct with no conflict routes, and the route must be locked.

4) Routes and routes: there are usually 2 types of relationship between different routes: contradict and conflict. Contradict route means that 2 routes pass different position of a single switch, it can be distinguished by the status of switch; while conflict route means that 2 routes has overlapping zones, it cannot be simply distinguished by the status of switch. Thus, when a route is in managing process, its conflict route must be locked as the status of "cannot be managed".

5) Signals and signals: likewise, the corresponding signals indicating of conflict routes also must be locked as "cannot be opened" so as to ensure operation safety.

III. Data Structure Analysis of Computer Interlocking in Medium-Low Speed Maglev

Interlocking data is all of the data which appears in the interlocking calculation process in the CIs in medium-low speed maglev system. And data structure is just the way of organization in memorizers of these data [13]. Generally, these data can be divided into 2 types, static data and dynamic data, namely constants and variables, and the corresponding data structures are static and dynamic structure.

A. Static Data Analysis

Static data in CI is the data expression of static characteristics of equipments in station area during the software design stage, static constants which includes route properties, related signals, related switches and their status, checking requirements of home section and starting section, can be set in read-only memorizers (ROMs) of computers. For the whole software in CI, static data are important for accurate and reliable execution of commands. Thus, proper data structure design is necessary for CI software.

Usually, there are 2 ways in organizing static data, one is the form of total route table, which means data can be stored in static databases; the other is the station data structure, which means data can be stored item by item according to the on-site conditions. Static data organized in former way is based on routes, the calculation efficiency may be quite low if the station area is very complex, and may not be suitable for station reconstruction; while static data organized in latter way is based on station condition, route managing process can be realized by only set a route searching algorithm, which is more flexible. In this section, the latter way is adopted to organize static data in CI in medium-low speed maglev.

Here the signal is set as an example in organizing static data. In design stage of CI for medium-low speed maglev, a data class of signals can be set, and each signal can be seen as a specific object in such class. Static data includes number, name, characteristics, position, neighbor nodes. In order to discriminate different signals, an integral binary number can be employed to describe the character of each signal, as shown in Table I. As it can be seen there are still many idle bit in such integral binary number, functional expansion can be achieved in the future, and all the characteristics can be described in detail just via such number.

TABLE I. STATIC DATA TABLE OF SIGNAL

Bit	Meaning of "1" in such bit	Meaning of "0" in such bit
0	Is the terminal signal	Is NOT the terminal signal
1	Is the shunting signal	Is NOT the shunting signal
2	Is the home signal	Is NOT the home signal
3	Is the outgoing & shunting signal	Is NOT the outgoing & shunting signal
4	Is the single signal	Is NOT the single signal
6	The protected route is from right hand side to the left	The protected route is from left hand side to the right
7	Is high signal	Is NOT high signal

B. Dynamic Data Analysis

As mentioned above, dynamic data in CI is those variables which appears in interlocking calculation, dynamic data includes manual input, status input, representing output, control output, and intermediate variables, where manual input variables are generated by manipulations given by operation personnel, status input variables are from all the equipments monitored by CI, representing output variables are information transmitted to HMI, control output variables are ones for switch and signal control, while intermediate variables are those generated just in the interlocking calculation.

Back to the example in section III-A, the dynamic data of switches may include signal opening sign, status of electric relays, etc. Consider that there might be different data descriptions for different types of signal, in data structure design for CI in medium-low speed maglev, dynamic binary data is designed separately for home signal, outgoing signal, and outgoing & shunting signal, the meaning of designed dynamic data of signal can be seen in Table II.

TABLE II. MEANING OF DYNAMIC DATA OF SIGNAL

Type	7	6	5	4	3	2	1	0
Home signal	LXJ	ZXJ	YXJ	TXJ	LUXJ	YAJ		
Outgoing signal	LXJ	DXJ						
Outgoing & shunting signal	LXJ	DXJ						

It should be pointed out that the blank cells in Table II are reserved, the default value of blank cell is "0". For electric relays, "1" represents energized, while "0" represents down. As objects of the signal class mentioned above, their initialization can be realized by constructed function in such class.

IV. CONCLUSIONS

In this paper, the reliability of CI in medium-low speed maglev has been underlined, to ensure system reliability in the design stage, data flow as well as data structure in CI has been analyzed in detail according to the specific data transmission and exchanging requirements of medium-low speed maglev. The data flow analysis and the concept of data structure design discussed in this paper may serve as a valuable reference in CI as well as OCS design in future medium-low speed maglev project.

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REFERENCES

[1] X. Jiang, W. Nai, A. Yilixiati, Y. Yu, S. Wang, and D. Dong, "A train positioning mechanism for medium-low speed maglev train based on parity check cross coding inductive loop wire," 3rd International Conference on Control Science and Systems Engineering (ICCSSE), 2017, pp. 269-272.

[2] W. Nai, Y. Yu, T. Zhang, W. Ye, S. Wang, D. Dong, "Reliability Enhancing Mechanism for Train Positioning Based on Cyclic Check Cross Coding Inductive Loop Wire for Medium-Low Speed Maglev," 3rd International Conference on Control Science and Systems Engineering (ICCSSE), 2017, pp. 273-276.

[3] W. Zheng, W. Nai, D. Dong, S. Chen, and W. Yang, "Design of turnout points interlocking control system in switchback station for Shanghai Metrol Line 16 based on fail-safe principle," Proc. International Conference on Systems and Informatics (ICSAI), 2012, pp. 404-408.

[4] J. W. Palmer, and A. C. Renfrew, "Issues raised in development of a large knowledge-based system for the design of railway signalling shemes," Proc. 1st International Conference on Intelligent Systems Engineering, 1992, pp. 316-323.

[5] A. H. Cribbens, M. J. Furniss, and H. A. Ryland, "A experimental application of microprocessors to railway signalling," Electronics and Power, vol. 24, no. 3, 1978, pp. 209-214.

[6] A. H. Cribbens, "Solid-state interlocking (SSI): an integrated electronic signalling system for mainline railways," IEE Proceedings B - Electric Power Applications, vol. 134, no. 3, 1987, pp. 148-158.

[7] A. H. Cribbens, and R. C. Waterman, "Long distance data transmission of safety information for the solid state interlocking," Proc. International Conference on Main Line Railway Electrification, 1989, pp. 322-326.

[8] G. Hong, and X. Yuan, "Control strategy and reliability study of iLOCK high-speed railway interlocking system," Proc. International Conference on Remote Sensing, Environment and Transportation Engineering, 2011, pp. 3950-3953.

[9] N. Jing, and B. Han. "The study of TYJL-ADX interlocking system based computer," Proc. 25th Chinese Control and Decision Conference (CCDC), 2013, pp. 4205-4208.

[10] X. Hei, K. Zhao, W. Ma, G. Xie, and L. Wang, "A real-time model of railway interlocking system based on UML extension mechanism," Proc. IEEE 4th International Conference on Software Engineering and Service Science (ICSESS), 2013, pp. 19-22.

[11] J. Mocki, and L. Vlacic, "Performance evaluation of railway junction signalling and interlocking," Proc. 35th Chinese Control Conference (CCC), 2016, pp. 9712-9717.

[12] A. Fantechi, A. E. Haxthausen, and M. B. R. Nielsen, "Model checking geographically distributed interlocking systems using UMC," Proc. Euromicro International Conference on Parallel, Distributed and Network-based Processing (PDP), 2017, pp. 278-286.

[13] Ministry of Railways of the People's Republic of China, "Technical requirements of computer interlocking," 2002, TB3027-2002. (In Chinese)