Research on Train Control System Based on Train to Train Communication

Yu Liu
National Engineering Research Center Of Rail Transportation Operation And Control System
Beijing Jiaotong University
Beijing, China
Email: yuliu@bjtu.edu.cn

Lei Yuan
State Key Laboratory of Rail Traffic Control and Safety
Beijing Jiaotong University
Beijing, China
Email: lyuan@bjtu.edu.cn

***Abstract*—With the developing of wireless communicate technology and the emergence of new demand, it is of great significance introducing Internet of Vehicles into train control system. This paper introduces the background and significance of train control system based on train to train communication researching, it also suggests an implementation of a train control system based on train to train communication. By changing the traditional function allocation method between train and ground, the ability of subsequent trains to obtain the position information of the preceding trains status is added, and the active protection capability and intelligence of the train are enhanced. In this paper, for the key function modules train management and moving authority generation, this paper uses MATLAB/Simulink as a tool to model and simulate them based on the theory of time-use security state machine. According to the output of each module, the correctness of the system scheme is verified, and it provides theoretical basis for the real system building.**

Keywords—Train to train communication，Timed Safe State Machine，Train Control System，simulation

I. Introduction

With the advancement of control and communication technology, the standard system of the train control system in China has been continuously consolidated and improved. Especially in the urban rail transit, the mature application of CBTC shows the important position of communication in the train control system, and also proves that the Moving Blocking system will be the development trend of the train control system. However, with people's preference for urban rail transit, the operational efficiency of urban lines is facing higher demand; at the same time, due to the intertwining of urban lines, the number of railway wayside equipment is increasing, so the installation cost and maintenance difficulty and security risks will become problems [1]. In order to meet these challenges, it is imperative to study a new generation of train control system based on train to train communication.

In this paper will propose a basic scheme of train control system based on train-train communication, and simulate and analyze its train management and movement authority function modules to illustrate the rationality and advantages of this basic scheme.

II. The Basic Design Scheme of Train Control System Based on Train to Train Communication

A. *Definition of train control system based on train to train communication*

The train control system based on train to train communication, is to extend the existing train-ground wireless communication system to trains, track trains back and forth, and directly exchange data, and transfers part of the functions realized by the ground equipment to the onboard equipment and realizes the function redistribution of train control system, thereby reducing the ground equipment and optimizing the system structure; through the train-to-train communication, the train autonomously recognizes the positional relationship of the train before and after and autonomously determines the movement authority.

B. *Basic structure of train control system based on train to train communication*

The train to train communication of train control system proposed in this paper is still composed of onboard equipment and ground equipment. The specific structure and information control flow are shown in Figure 1.

Ground equipment includes automatic train supervision (ATS), train management module (TMM), object control unit (OCU), wayside signal infrastructure equipment (signaling machines, turnouts, etc.). The TMM is a newly introduced concept .It takes part of the safety functions of the original regional control center --- train registration and cancellation, train information storage and forwarding, etc.. TMM does not have complex control calculation logic. OCU is a newly introduced concept, It is responsible for acquiring the status of basic signal devices such as semaphores and switches, as well as communicating motion commands. As a sensor, it also does not have complex logic.

Onboard equipment is divided into digital map module, interlock logic, and train control modules. Among them, the digital map will combine multiple train positioning technologies for functions such as train location acquisition and route planning; the interlocking module will inherit all the functions of the traditional interlocking, and achieve higher automation, such as automatic handling of routes, automatic reentry, etc.. The train control module includes three basic functions: train management, movement authority generation, and train speed control. The first two items are quite different from the traditional system, which is the focus of research.

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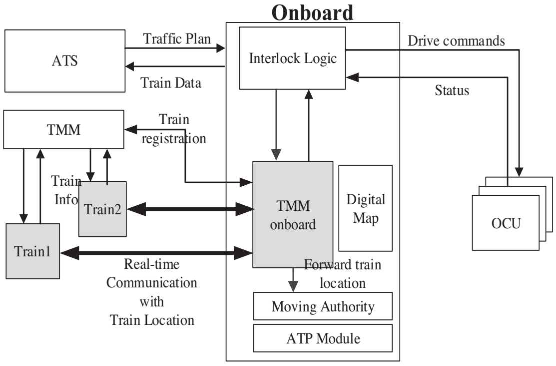

Fig. 1. structure of train control system based on train to train communication

C. *Working principle of train to train communication system*

The basic workflow of train to train communication of train control system is: 1. ATS sends the route plan to the train that is about to enter the main line; 2. The train applies to the TMM for registration. If the login conditions are met, the TMM allows the train to log in; 3. The TMM acquires and stores the status information of all trains during each communication cycle and forwards them to each train on the line. 4. The train autonomously judges the communication train ahead according to the position and status of the trains sent by the TMM; 5. The train establishes a communication link with the train in front to obtain its position and status information; 6. The train obtains the OCU message, and analyzes to determine the status of the forward signal. 7. The on-board safety computer completes the calculation of movement authority according to the end of the route, the condition of the line obstacles, and the position of the train ahead. 8. the train generates a speed monitoring curve to control the speed of the train.

III. MODELING OF TRAIN TO TRAIN COMMUNICATION OF TRAIN CONTROL SYSTEM

A. *Theory and tools of Timed safe state machine*

This paper adopts the theory of timed safe state machine to model the train management and movement authority module of train-train communication of train control system. The Safe State Machine (SSM)[6] is an extension of the finite state machine based on the Esterel synchronization language and is suitable for analyzing reactive systems [7]. The Timed Safe State Machine [TSSM][8] adds time attributes to the general safe state machine to increase the description of the system time [8]. Because the train management and movement authority functions in the train control system are based on discrete time logic processing, and are related to the train cycle and communication cycle, and to a certain extent ignore the minute time of packet analysis and data processing, so it is very suitable for the modeling and analysis of timed safe state machine theory.

- the basic semantics of timed safe state machine

The timed safe state machine is a seven-tuple:

$$M ::= (S, \Sigma, \Delta, I, T_{tr}, S_0, S_f) \quad (1)$$

Among them, S represents a finite state set, Σ is a set of finite flags, Δ is a set of finite clocks, I is a clock constraint, T_{tr} is a transition set, S_0 is an initial state, and S_f is an abort state.

TSSM is based on the assumption of synchronization. Different devices of the system can have their own clocks and are independent of each other, but all clocks use the same time sequence as the logic time basis. TSSM's state and output dependencies are:

$$\left.\begin{aligned} S_t &= F(S_{t-1}, I_t, t_{ct}), \\ O_t &= O(S_t, I_t, t_{ct}). \end{aligned}\right\} \quad (2)$$

Among them, S_t represents system state at time t, S_{t-1} represents system state at time t-1, F represents state transition relationship, I_t represents system input, t_{ct} is excitation time; O_t is system output at time t, O indicates the relationship between system state and output at a certain moment.

- the characteristics of timed safe state machine

The three characteristics of the safe state machine are: hierarchical structure, concurrency control, and priority control.

The meaning of the hierarchical structure is that the system is composed of a set of states, and the state is divided into a macro state and a simple state, and the macro state can be nested in a simple state with no upper limit in depth. The layered state is executed from the outside to the inside and executed layer by layer.

The meaning of concurrency control is that multiple signals occur one after another. Only when the last one occurs, an output signal is generated. For example, in a train control system based on train to train communication, the train receives the preceding train information, receives the OCU information, and receives the TMM information. And only after receiving all, it generates a movement authority.

The meaning of priority control is: when the state is faced with a variety of situations, there is a transfer order. Priority control can be done by nesting structures and setting transfer types, such as forced abort transfer> weak abort transfer> normal abort transfer.

- Stateflow

The modeling and simulation tool chosen in this paper is Simulink/Stateflow in Matlab14.0, which uses a safe state machine to give time characteristics to simulate a discrete event system.

B. *Train Management Modeling*

According to the needs and principles of train management, a timed safe state machine model for train management as shown in Figure 2 is established.

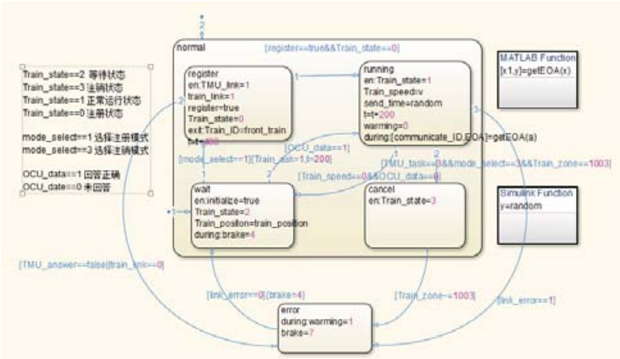

Fig. 2. Train Management Model

The initial state of the train is "waiting". In this state, the following trains should complete the functions of initialization, device power-on and self-check, anti-slip, etc.. When they receive the mode selection "Login" command, they establish a communication link with the TMM and send them. Establish a connection request and enter the "Login" status. During the login process, the train should complete the train data acquisition and communication before the completion of the train. When the login is completed, the train enters the main line. In the normal operation process, the train management should obtain its own position, speed, status and other information during each train cycle, and receive the TMM information and the data of the communication train ahead When the train leaves the line, it applies to the TMM for cancellation at the designated position. The process is similar to the login.

During the entire operation of the train, if TMM, leading train or OCU packet cannot be obtained due to a communication failure, it will lead to a “failed” state. In this macro state, the train should maintain the maximum common brake until parking and give alert notice.

Since the train control system requires high real-time performance, the concept of time must be increased. A train cycle is 200ms. After it sends a TMM link request, it must wait for the next train cycle to perform other communication tasks. Similarly, Similarly, after the TMM sends the "Allow Logon" command, it must wait for the next TMM communication cycle to send additional messages. The TMM- trains clock is different from trains-trains, so it is necessary to consider a certain range of errors and randomness. Figure 3 shows the principle of modeling assignment for train management method 2. Among them, "13-26ms" is the one-way information transmission time between the train and the TMM, "26-50ms" is the one-way information transmission time between the train and the train, the TMM communication cycle is 500ms, and the train communication cycle is 200ms.

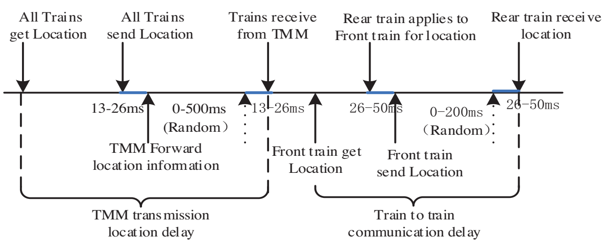

Fig. 3. Model timing principle

C. *Movement Authority Modeling*

After the train completes MA initialization, all obstacle information is processed, including fixed obstacle traversal and moving obstacle traversal. Through electronic map mapping, the train derives the signal and the turnout location from the OCU. Combined with its status, we can get the fixed obstacle position closest to the current train and use it as the fixed EOA end point to complete the fixed obstacle traversal. Through train-train communicates, the train receives the real-time position of the train in front, and uses it as the moving EOA endpoint to complete the moving obstacle traversal. Figure 4 shows the moving obstacle traversal model. At this stage, it does not involve the communication between the train and the outside. According to the reactive system principle, the time length is zero at this stage.

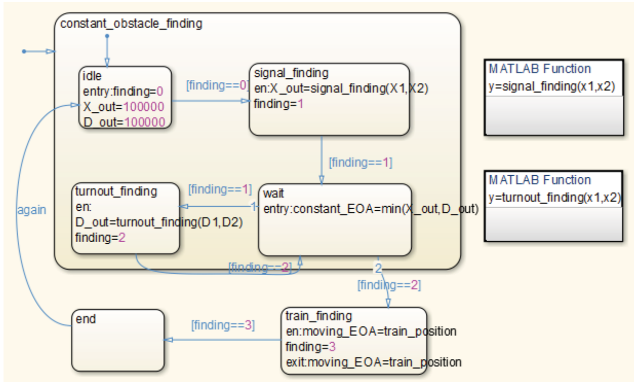

Fig. 4. Movement authority traversing obstacle model

Due to the fact that the EOA end point is divided into the zones and the stations, trains and no trains, it cannot directly be the minimum value of moving EOA and fixed EOA. Figure 5 shows the MA calculation model, which includes four macro states: initialization, presence of the leading train, absence of the leading train, and failure. First, the train should initialize the EOA end point as the route end point, and then determine whether there is a leading train according to the train management results. If there is no leading train, the final EOA focuses on the fixed EOA end point minus the safety distance; if there is a vehicle ahead, it is necessary to determine whether the vehicle's position is in a zone or a station by an electronic map mapping. If it is at the station, the home signal is used as the EOA end point. If it is in the zone, subtract the safety distance from the position of the leading train tail as the EOA end point.

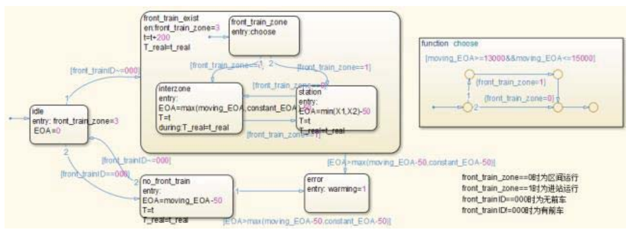

Fig. 5. Movement Authority EOA Calculation Model

IV. SIMULATION RESULTS AND ANALYSIS

The overall model of train management and movement authority for train-train communication of train control system is shown in Figure 6. The input of the model is the train number, position information, the mode selection command, the status of each communication link, and the route plan of three trains. The output of the train management section is the current train speed, position, brake level, fault and front vehicle communication ID, and delay from the TMM information. The output of the movement authority section is the EOA end point, train-train communication delay, and so on.

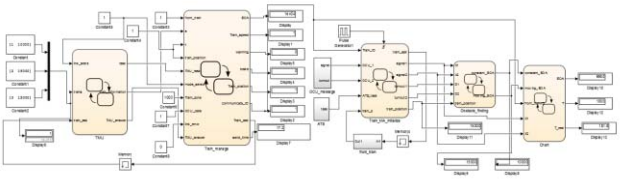

Fig. 6. Overall model of Train Management and Movement authority of Train Control System based on train to train communication

A. Communication delay simulation and analysis

The train communicates with the whole line train in real time and directly determines the position of the train in front of it; the train first uses the TMM to obtain the position of the whole line train to determine the associated vehicle ahead, and then communicates with the associated train to obtain its precise position. The simulation results of 100 delays for the different trains are shown in Figure 8. Among them, "*" indicates the delay of 50 trains at the same time, the average is 373.7ms; "o" indicates the delay of 100 trains at the same time, the average is 569.6ms; "+" indicates the delay of simultaneous communication of 150 trains, with an average of 782.1ms.

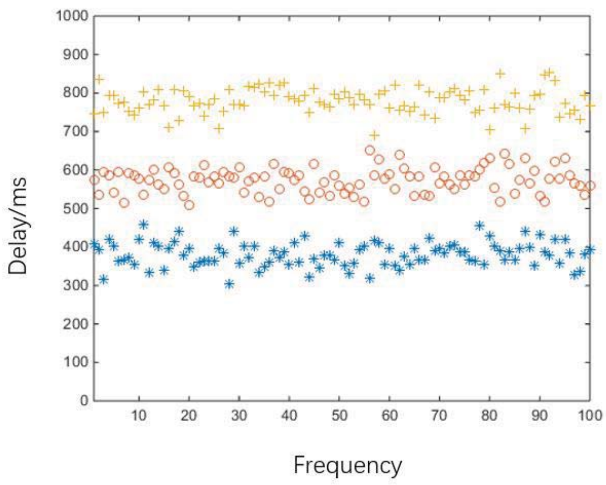

Fig. 7. Different number of train communication delay

B. functional verification

For the train management function, no matter how many trains are set on the line, through the simulation operation model, the train ID in the output result of the train management module is always the closest train ID from itself, so the function of determining the associated leading train is correct.

For the determination of the EOA end point of the movement authority function, the simulation results are shown in the figure. The three sloping lines indicate the position of the leading train changes over time. The horizontal solid line is the end of the train route, and the bottom line is the EOA end point of the train. Regardless of the line fault condition, when the train is running within the approach range, the EOA end point is the associated leading train position minus the safety distance; when the front t train exceeds the end of the train's route, the train's EOA end point becomes the route signal's position minus the safety distance. The simulation results are in accordance with the principle of EOA generation and the movement authority function is normal. The output of EOA in the figure is zigzag. This is because train management and movement authority generation are discrete processes. The sampling time is the communication delay described in the previous section.

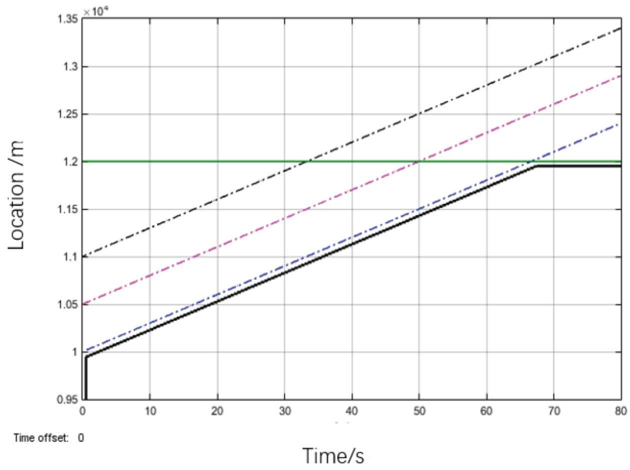

Fig. 8. EOA point simulation results

V. CONCLUSION

Through the delay analysis of key information in train-train communication and the modeling and simulation results of key functions, it can be seen that the train control system based on train to train communication proposed in this paper is basically reasonable in structure, the key functions of the system are correct, and the delay is within an acceptable range. This kind of train control system has certain feasibility. With the development of communication technologies and control methods, the introduction of train to train communication into the train control system has great development prospects. The next step can further analyze the system safety and reliability, and provide more theories for real system implementation and recommendations.

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REFERENCES

[1] European Commission within the Seven Framework Programme, Next generation of train control systems project[R],2013, WEB: http://www.NGTC.eu.

[2] Brosseau, J., Moore Ede, B. (June 2009) “Development of an Adaptive Predictive Braking Enforcement Algorithm,” DOT-FRA-ORD-09/13, U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development, Washington, D.C.

[3] Hartenstein H, Bochow B, Ebner A, et al. Position-aware ad hoc wireless networks for inter-vehicle communications: the Fleetnet project[C]//Proceedings of the 2nd ACM international symposium on Mobile ad hoc networking & computing. ACM, 2001: 259-262.

[4] Yasuyuki Nakamura, Overview of the Next-generation Railway Operation System in the Tokyo Metropolitan Area, JR East Technical Review No. 20(2011): 03–06.

[5] Mayumi Korekoda, Hiroshi Kawasaki, Yasuhiro Tanaka, Considerations for a Next-generation Railway System in the Tokyo Metropolitan Area, JR East Technical Review No. 20(2011): 16–19.

[6] Alstom Transport, Lille metro RS and Urbalis Fluence - Case Study[R]. WEB: http://www.alstom.com/transport.

[7] Jikang Xu, Train-train communication based CBTC system analysis, Railway Signalling & Communication, 2014 50(6):78-80.

[8] Su Jing, Wang Dong, Zhang Fei-fei. Review of vehicle networking technology application [J]. Intelligent Processing and Application, 2014, 06: 69-12.

[9] Wang Zhe. A study on performance analysis of wireless inter- vehicle communication system in traffic streams [D]. Hefei: USTC, 2009.

[10] García C R, Lehner A, Strang T, et al. Channel model for train to train communication using the 400 MHz band[C]//Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE. IEEE, 2008: 3082-3086.

[11] Liu P, Ai B, Zhong Z, et al. A Novel Train-to-Train Communication Model Design Based on Multihop in High-Speed Railway[J]. International Journal of Antennas and Propagation, 2012.

[12] Chen Qi-xiang. Research on Train to train direct communication based on ultra-short wave [D]. Lanzhou: Lanzhou Jiao Tong University. 2014.

[13] Ning Bin, Tang Tao, et al. High-speed train control system [M]. Beijing: Beijing Publishing House,2012.

[14] Wang Zhao-ran, Xie Xian-zhong, Zhao Ding-xin. Key technique of vehicular Ad Hoc Network [J]. Science Technology. 2011, 27(1): 44-51.

[15] Yang Qiong, Shen Lian-feng. System architecture and communication protocols in vehicular Ad Hoc networks [J]. ZTE Communications. 2011, 03:8-11.

[16] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[17] K. Elissa, “Title of paper if known,” unpublished.

[18] R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.

[19] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[20] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.