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The Research of Key Technologies for Data Interactions Between Real-Time Simulation Systems

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Abstract. This paper aims at the data interaction problem in the interconnection of real-time simulation systems for autonomous driving. First the complex data interactions between strong and weak real-time simulation systems are analyzed with emphasis. Then an interface adaptation technology that ensures high transmission rates, low latency, and low bit error rates during data exchanges among multiple systems is proposed, which can further enable the realization of the real-time interaction and information fusion between multiple simulation systems. The proposed approach can also be applied to construct the real-time distributed simulation interconnection application systems.

Keywords: Real-time simulation systems; Data interaction issues; System interconnection; Interface adaptation technology; Reflective memory.

1. Introduction

Data interaction among simulation systems is the foundation of multi-simulation system interconnection where the real-time simulation systems have more stringent requirements for data transmissions. In the process of real-time data interaction, it is essential to ensure low latency and low error rate in data transmission, which can maintain the temporal and spatial consistency between multiple systems and ensure the stability and reliability of the entire simulation system. Here, the problem of time synchronization needs to be resolved first, where several mature engineering solutions and technical studies can be found through literature searches.

In the process of interconnecting multiple real-time simulation systems, there will be an interconnection between different types of network simulation systems, such as the connection between reflective memory networks and Ethernet and there will also be technical difficulties such as different data structures between different systems and different simulation frame rates. Thus during data interactions, it is also necessary to solve the problems of data format conversion and simulation frame synchronization. Therefore, an interface adaptation technology that ensures high-speed, low-latency, and low bit error rate in data transmissions between multiple systems is proposed in this paper, which can solve or improve the aforementioned technical difficulties.

2. Interconnection Between Strong and Weak Real-Time Simulation Systems

In real-time simulation systems, a hierarchical hybrid synchronization method combining BDS (Beidou Navigation Satellite System)/GPS time synchronization and simulation data-driven approaches is adopted. With the method of integrating hardware and time synchronization software, the timing server provides high-precision, high-resolution unified clock signals to each simulation subsystem on the platform. This coordinates the time advancement methods of various simulation systems, and ensures the logicality of events related to time in simulation nodes with different real-time constraints. Thus this approach can solve the time synchronization issues in the interconnection of strong-weak real-time simulation systems. The strong real-time simulation system module joins the HLA/RTI federation of the weak real-time simulation system through an HLA/RTI interface member to facilitate data interactions between the two layers of simulation systems, where HLA/RTI means High Level Architecture and Run Time Infrastructure. Considering that strong real-time simulation systems interact directly with devices and have more stringent time constraints compared to weak real-time simulation systems, it is essential to ensure

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that the strong real-time simulation system is not affected by the time advancement of the weak real-time simulation system. In the HLA/RTI system, this can be achieved by designing an interface with a "time constraint" characteristic, which means that the time advancement of the weak real-time layer is constrained by the strong real-time layer unidirectionally.

During system simulation, the BDS/GPS clock server outputs timing signals using UTC time. These timing signals are primarily used in the following two aspects:

1) Timestamp information: Due to the synchronization error between simulation nodes and network transmission delay, when simulating information exchange between subsystems, the sequence output by the Beidou/GPS clock server is used as timestamp information to mark the moment of sending simulation information. The lowest bit of the timestamp is specifically used as a time synchronization flag, where The lowest bit being 1 indicates that the time is already synchronized and the timestamp in this situation is referred to as an absolute timestamp. Otherwise, it is called a relative timestamp.

2) To drive the real-time simulation system engine: Due to the high precision of the timing signals output by the Beidou/GPS clock server, where the timing accuracy is lower than 1μs, NTP time synchronization accuracy is lower than 0.5ms, and B-code output accuracy is lower than 200ns, these signals can be used directly to drive the simulation engine of the real-time simulation system for autonomous driving. Furthermore, by employing a reflective memory network to transmit the timing signals, network transmission delays can be reduced to the hundreds of nanoseconds level, which can significantly enhance the real-time performance of data processing. For the millisecond-level simulation frame step of the autonomous driving Hardware-In-the-Loop (HLA) simulation, the impact of network transmission delay on the simulation operation can be ignored.

3. Interface Adaptation Technology

The network setup of the real-time simulation system generally adopts VMIC real-time reflective memory networks. In this paper, a dedicated interface adapter for the reflective memory network is designed, which can achieve real-time information interaction between multiple simulation systems. The interface adapter between multiple simulation systems reads the data from one simulation system network and converts the received data packets into the required interaction data format for another simulation system, and thus achieves the interconnection between multiple simulation systems.

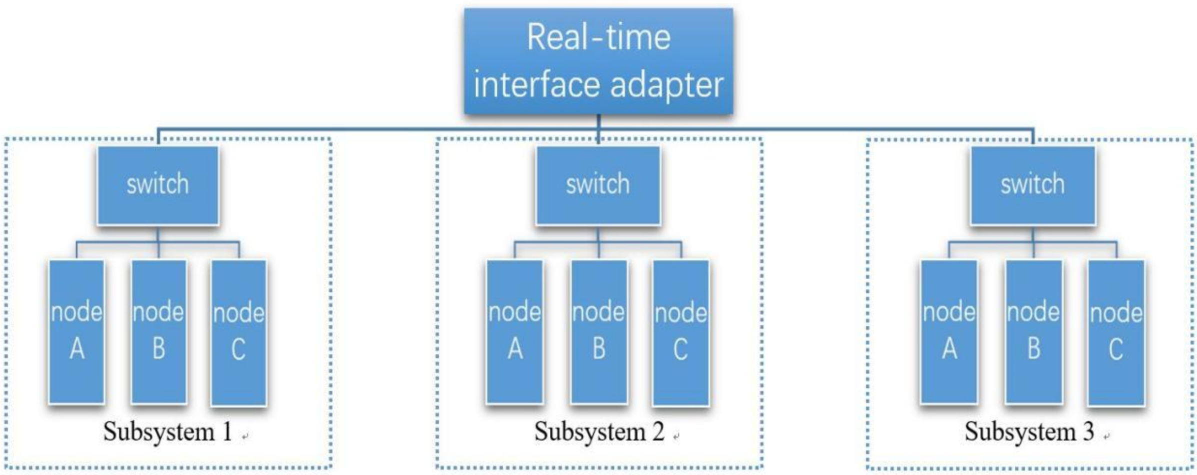

Fig. 1 Real-time Interface Adaptation Diagram

To ensure the real-time performance and the communication speed of the real-time simulation system, a fiber optic network for communication is generally utilized where different simulation nodes forms a network through a switch. In the initial stage of construction, the current simulation

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systems considered the requirements for generalization and modularization, where the reflective memory cards that perform the same function in each simulation system are assigned with the same node number, as well as the same data storage address and space. During the interconnection process of multiple real-time simulation systems, if the systems are simply interconnected through a switch, issues such as data storage address and node number conflicts may arise. Furthermore, the interrupts of the master control computer will be responded to by all connected terminals, which cannot meet the operational requirements for multi-system interconnections. If the node numbers and data storage spaces of different systems are reassigned, the simulation system will lose its universality and the workload would be significant. Additionally, in the process of Building the network of a large systems, if relying solely on switches for connectivity, the system will not only be constrained by the number of nodes but also encounter data interaction issues between different types of real-time simulation systems with varying structures (such as reflective memory and Ethernet). To solve this problem, a real-time interface adapter is proposed to be used in the real-time simulation platform for isolating control commands and data between various real-time simulation systems, as well as for data interaction between subsystems and the master simulation controller.

The device first identifies the interrupt data received by the online subsystem. To reduce system resource consumption and ensure data transmission rate, it processes the received data first, filtering out data that does not need to be forwarded. Based on the data forwarding flag, it selects and processes the data that needs to be forwarded. It then determines whether the frame data should be broadcast to all other systems or sent point-to-point to a target system based on the received target system flag. The software then checks if the data format of this frame matches that of the target system. If the data format is the same, the data is directly forwarded through the corresponding system's communication card. If the data format is different, the data format is converted according to the communication protocol before being transmitted through the target system's communication card. To ensure the real-time performance of the simulation system and prevent data lag, errors, or frame loss, high requirements are placed on the data processing and transmission performance of the device. To balance both system real-time performance and bandwidth utilization, DMA (Direct Memory Access) technology can be used for data packets with large volumes during the data interaction between the data transmission card and the real-time data interaction device. This reduces CPU resource consumption while increasing bus bandwidth utilization and enhancing data transmission speed. For data with smaller volumes and higher real-time requirements, such as control signals, direct use of the onboard FIFO for high-priority real-time transmission can achieve the goal of instant forwarding. Through the above methods, the forwarding time of each frame of data is controlled within microseconds to ensure the real-time nature of the simulation system.

4. Application Scenarios and Values

This technology is currently applied to the information fusion of cross-system vehicle carrier equipment and can also be used in high-precision distributed real-time simulation systems. Furthermore, it can establish an advanced automotive control system design and development framework, as well as hardware-in-the-loop testing and system implementation technologies, meeting the development and testing needs of users with multiple sensors, various vehicle models, and different OEMs. For example, it may support worst-case analysis and timing-accurate simulation of heterogeneous communication architectures consisting of interconnected CAN, switched Ethernet, AFDX, FlexRay, LIN, and ARINC429 buses through a gateway. During the data fusion process, it is crucial to ensure low latency and avoid any frame loss or errors, as these can lead to incorrect calculations by the onboard computer, causing system failures, delayed or even error commands that could lead to fatal traffic accidents. Therefore, in autonomous driving real-time simulation systems where data processing speed requirements are stringent, how to quickly and accurately complete the data fusion and interaction between multiple sensor subsystems

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is a technical challenge. By utilizing the interface adaptation technology proposed in this paper, it is possible to ensure high-speed data transmission with low latency and low bit error rates between multiple systems, guaranteeing the temporal and spatial consistency across multiple systems and the stability and reliability of the entire simulation system.

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