A Novel Railway Signal Control System Based on the Internet and Assurance Technologies*

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SUMMARY We have developed a novel railway signal control system that operates as a distributed system. It consists of a central control unit (called LC) and terminal devices (called FC) that are distributed at the railroad wayside and operate signal devices. The Internet technologies and optical LAN technologies have been used as communication methods between the LC and the FCs. While handling enormous amount of electric cables may cause human errors, the system is expected to reduce troubles of the current signal system at construction works thanks to the Internet technologies. The FC is a distributed terminal device that has its own processor and placed at the railroad wayside to control the field signal devices. The LC is a centralized computer device that has software arranged by the function of the field devices. An optical network system and multiple communication paths between the LC and the FCs realize durable transmissions. Moreover, the assure performance of controls and transmissions have been investigated, and the autonomous distributed signal control system is also discussed as the next steps of the system.

key words: network technology, train signal control, internet protocol, optical transmission, assurance technology

1. Introduction

Railway signal systems have significant roles in the safe and stable train operations. These systems are still developing to satisfy a lot of demands such as changes of transportation capacity or revisions of train schedules.

Ordinary railway signal systems mainly consist of logics by relay circuits, which need specific electric wirings. Manual works of the wiring tasks built up the relay circuits that are individually designed, but the works may cause human errors which result in significant transportation disorders. Moreover, demands for high operating rate require a duplex structure of the systems, but it is difficult to complete the duplex system by the relay logics.

Recently, computer technologies are much progressed.

We have applied the technology to the railway signal devices to overcome these issues. For example, an electric interlocking system, which is a computerized interlocking system, has computerized logics and achieves duplex structures (ATOS is an example [2]). Other signal devices, such as a train detector system, an automatic-train-stop (ATS) system, have been computerized and installed. Signal devices located not only in station yard area but midway between stations are also computerized to achieve high reliability of the system. Usually they are installed in a room like the computer room of a station, the railway control system forms a centralized system. Figure 1 schematically illustrates a typical setup of the railway signal control system. In addition, Assurance technologies are applied in various fields recently [3], [4], [6], the same is true on railway system [1], [7]. New railway system such as ATOS and D-ATC has developed with heterogeneity and adaptability [5], [8], [9].

In this paper, firstly we describe issues of the present computerized signal devices. Secondly, we introduce a novel system as a distributed signal system. Finally we discuss the assurance techniques of our system and an autonomous distributed signal system.

2. Issues of the Computerized Signal Devices

The signal control systems are dramatically developed, mainly because of the computer technologies. Nevertheless, they have some issues. First, as shown in Fig. 1, since the control logic is usually settled in the computer room of a station and the operational part is at the rail-side area, electric wires from the central area to the rail-side are still needed.
When the system needs enormous number of cables, the construction cost, in which cable-laying cost is dominant, is very high. Moreover, the wiring tasks of enormous numbers of cables are heavy works, because we have to install or rearrange the cables with great care. Unfortunate human errors in wiring tasks sometimes occur, the errors which may cause serious transport disorders. Second, since the transmission path of the current system is a simplex structure, they also cause serious transport disorders if a damage accident of cables happens. Therefore, the duplex structure of the control system for field devices is required. For example, an interlocking device directly controls signal devices by applying electric voltage to copper wires through relay circuits. Enormous amount of wirings are required because an interlocking device controls a number of signal devices. When the transport capacity increases, or an interlocking device deteriorates, the interlocking device will be improved or replaced where large number of wirings are needed. It requires much time and is a manual work that may cause human errors. The error results will make a big transport disorder. Moreover, a system change as adding a new color signal device needs all signal devices to be rearranged or restructured. Since the all signal devices are individually settled, and they have different software and independently operate, we have to handle all devices one by one and pay great attention to avoid causing harmful influence each other.

3. Distributed Signal Control System Based on the Internet Technology

3.1 Overview of the Distributed Signal Control System

In order to solve those issues, we have developed a distributed signal control system. We employed an optical LAN and the Internet technologies to the transmission between the control devices and the field devices. The optical LAN drastically changes the control method of the field devices [11]-[14]. Figure 2 schematically illustrates the system. The system consists of a central control unit (Logical Controller: LC) and many terminal devices (Field Controller: FC). Optical fibers connect these unit and terminal devices.

The system has two approaches. One is a software approach, in which software logics in the central controller is rearranged according to the tasks of field devices. The other is a hardware approach, in which we realize a distributed signal control system by using the Internet technology and optical LAN technology.

The software approach is as follows. Since current signal devices have to operate independently, they sometimes have same logics inside. Then, we break down the sequence of the signal device and rearrange them according to the field device in order to eliminate the overlap operations. Figure 3 explains the current software architecture of the signal systems and that realized by our system.

On the other hand, the hardware approach is using the field terminal devices (FC) as distributed processors to intellectually control the signal devices, as shown in Fig. 2. The FC translates internet protocol commands into electric power signal (direct voltage for LED bulbs, relay devices and so on). Figure 4 illustrates two methods of signal devices controlling. One is the conventional method where a central control device feeds electric power directly to the signal devices via individual cables. The other one is our...
Fig. 4  Direct control by individual cables and the control by using data-flow.

Fig. 5  The Field Controller (FC).

The former FC needs specific signal equipment and can control only one device, but it is very durable to external disturbance because the FC terminal and the signal device is closely located in the same box. The latter FC can handle several conventional signal devices. In this case, construction cost is low because we need not replace present signal devices to the specific ones. Since we have to use copper wires from the FC to the signal devices, protection for the external disturbance should be completed.

The optical transmitting system is realized by using a Passive Optical Network (PON) system (Fig. 6). Since a branch of the PON system is a passive device, it does not need electric power and is very robust. Therefore the PON system is suitable for our system. One optical line is divided into more than 30 lines by using the branch devices. When we use 10 optical lines, we can control more than 300 devices with a PON system, which means that one LC can control more than 300 FC via the PON system. We use a duplex transmission path by arranging two optical fibers for one path in order to avoid communication breaks caused by cable-damage accidents.

A monitoring and remote controlling setup is indispensable for daily operation of our system, which has many complicated devices such as LC and FC. We have employed the client-server architecture (Fig. 7) as the monitoring/controlling setup. It consists of four types of method where the Internet protocol and optical cables provide the data to operate the signal devices.

The LC is a central control unit that has control commands for field devices. The LC translates the commands into the Internet protocol data, which are transmitted through optical fibers. The FC is a terminal device that receives the Internet data and translates it into actual signal that controls field devices. We have two types of FC; one is the FC inside in the signal device itself (Fig. 5 (1) is one example. An FC is inside in a color light signal device). In this case we have to set new signal devices that include the FCs inside instead of ordinal ones at the signal construction works. The other one is the FC that can control several devices at once. It is installed in a special container, as shown in Fig. 5 (2).

Thanks to the internet technologies, we can achieve multiplex transmission instead of the direct power transmission by copper wires. By using the multiplex transmission technique, we can reduce number of cables. Moreover, by applying optical LAN technologies, the duplex structure is realized in data transmission.

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Fig. 7 Client and sever architecture as a for Monitoring/controlling setup.

Fig. 8 Four transmitting paths between LC and FC.

Fig. 9 Schematic illustration of the "Out-of-time flag".

Computer terminals, a system-monitoring server, a control server, a client, and a maintenance terminal (PC) for initial setups or maintenance tasks of the LC/FC.

3.2 Techniques to Achieve Assure and Reliable Performance

Since our system is based on multiplex communication realized by the normal internet technologies, an assurance communicating method by using the internet protocol is a significant issue. We have achieved the high-reliable communication as follows. Firstly, signal lines from the central units to the terminal devices are completely duplicated. Since the LC and the FC are duplex devices, we have four number of transmission paths. When the LC consists of LC1, LC2, and the FC consists of FC1, FC2, we have four transmission paths shown in Fig. 8. They independently throw signal commands and receive feedback answers at the same time at every cycle of 200 ms. The LC1 and LC2 exchange the information each other, and the FC (FC1, FC2) is a kind of a hot stand-by system. Then the four commands/feedbacks have same contents as long as the LC and the FC are at normal state. Since one command/feedback has enough information to control the LC or FC, these four paths per a command built up redundant transmissions. Therefore reliability of the communications of our system is expected to be high enough to use for railway control.

Secondly we have developed a novel data transport protocol by using the Internet technology. The protocol is formed from following four techniques. 1) All commands and corresponding feedbacks have their own sequence numbers. The LC confirms that the number of its output is exactly same as that of its feedback. By using the sequence number, we can detect a communication error such as a transmission disorder. 2) The LC and FC always watch intervals of the data flowing. If the interval is too long, the LC/FC recognizes that transmission delays occur. 3) In addition to the normal IP (Internet Protocol) addresses, all commands and feedbacks have identification labels that indicate their destinations. The labels have 4-bit-hamming-distance in order to avoid a bit error during transmissions. The identification label is set into every signal device, and IP address determines the FC. Error of the IP address misunderstanding and that of the identification labels may hardly occur at the same time. 4) Cyclic Redundancy Check (CRC) method and bit-inverting data are used in the communications to find errors of packets. In case of transmission error, the LC/FC operates the corresponding field device to the safe-side status.

Since large latency time between the operation of the central device and that of the terminal device courses confusion of the train operations, we should keep the data flow without delay. To minimize the latency time, we adopt the UDP (User Datagram Protocol), which is widely used for fast communications. Unfortunately, the UDP does not ensure the perfect transmission because it does not have retransmission processing. Then in order to avoid missing of the commands in the data flow process, we have developed a special indicator to detect troubles of the transmission paths immediately (Fig. 9). The indicator, named "out-of-time flag" is located in the data flow format.

The error of transmission paths are caused by the disorder of the sequence numbers, the transmission delays, incorrect deliveries of the commands, or errors of the CRC in the LC/FC. In case the data flows from an LC to an FC incorrectly, the LC sets the out-of-time flag to the next command for the FC. When the FC receives the out-of-time flag, it
recognizes the data, which is including the flag may be incorrect. On the other hand, in case an FC finds an error in the transmissions, the FC sends no feedback to the LC. Then the LC recognizes that there is some malfunctions in the transmission paths and set the out-of-time flag to the next control commands. Moreover, while the flag is active, the LC and the FC change their states to the irregular states. The train operations will be kept on the safe side if they are at the irregular states. When the transmission path changes in a good state, the LC cancels the flag and the FC recognizes the recovery of the transmission paths. In spite we use the UDP for the communication, the assistance of the out-of-time flag enables us to detect the malfunction of the transmission paths immediately, and operate the LC/FC adequately in case the commands are in bad states.

4. Assurance Technologies Realized by the New Signal Control System

Our system has many assurance technologies to avoid interfering with the train service.

4.1 Replacement of the New Signal Control System

When we replace current signal devices to the new ones, the short construction term is required. Our system has many mechanisms to satisfy the demand. Firstly, since the transmission form the LC to the FCs is based on the Internet technology, cable wiring tasks are dramatically reduced. Secondly, we can install and validate FCs without the LC, because the FCs have their own processors and accept not only commands from the LC but from the maintenance terminal. Therefore we can separately install and validate the LC and the FC to save the construction term. Thirdly, some FCs have the wired-or circuits by which the FCs can operate both from the current input signals through copper wires and the new ones through optical fibers.

Figure 10 shows schematic illustration of the system in the construction term. The LC is connected between the train diagram control and the interlocking device through the interface and also connected between the interlocking device and the wiring bay through it. Until we complete the system construction, the control timing of our system is verified by which the LC retrieves and processes the data of train positions and control instructions from the current system. After sufficient system verification, the FCs are instructed to operate from our system, then the current system is shut down. By using these FCs, immediate changeover of the signal devices can be realized just by switching-off the current system and switching-on the new system at the control center realize.

4.2 Coexistence of the Systems

When novel signal systems may be generated in the future, we have to add it to the current signal devices without huge system changes. Since the software of the LC is designed according to the function of the field devices and has minimum programs inside, we can easily upgrade or add the software.

Figure 11 shows how the function is added to the system. When one of the old exclusive signal devices is removed, the function of that device is added to the LC. The other exclusive signal devices and the LC process the control data and exchange the control data through the interface between them. In this way, introduction of the system function can be managed economically and systematically.

4.3 Maintenance of the Signal Device

The downtime of signal control systems should be as little as possible. The monitoring/controlling setup enables us to obtain detail information and to catch up system faults. The FC has functions of control and maintenance of the signal de-
vice, monitors the status of the signal device, and transmits the monitoring data to the monitoring/controlling setup. The monitoring server watches the status of signal devices and the network and puts out an alert to the client in the event of the unusual system condition.

A high level of safety in controlling the signal device is required because the FC is in the final stage of controlling the signal device. And also a high level of convenience in maintaining the signal device is required to the workers.

For those purposes, the FC has three different modes: normal, stop and maintenance as shown in Fig. 12. These modes are changed by using the maintenance terminal.

When the FC is put in the maintenance mode for the maintenance such as a change in a control program, it stops accepting the control data from the LC. The FC receives only the maintenance data from the maintenance terminal and controls the signal device and then sends the result data back to the maintenance terminal.

In the stop mode, the FC stops controlling the signal device despite receiving the control data and the maintenance data.

In the normal mode, the FC receives the control data from the LC, controls the signal device, and then sends the result data back to the LC.

The FC checks contents of the data in each mode and resolve its behavior.

In the stop or maintenance mode, because transmission between the LC and the FC breaks, the LC controls the related signal devices in a fail-safe way.

5. Install This System and Advantages of the New Signal Control System

5.1 Install the Network Signal Control System

The network signal control system was installed which we describe in this paper to the Musashino Line Ichikawaono station on February 3, 2007 (Fig. 13). We inspected data of seven months in the practical use system to evaluate this system. This network signal control system transmitted and received about 22,000,000 packets, about 3,600,000,000 bytes per day and transmitted and received about 4,700,000,000 packets, 745,500,000,000 bytes in seven months and controlled signal equipments. As a result, the transmission error never occurred, and the application to actual facilities of this network system was confirmed by reliability and safety.

5.2 Further Step for Autonomous Distributed Signal Control System

As shown in Fig. 3, the software of the LC is classified according to the functions of the signal devices. In addition, each function of signal device is self-contained. Nevertheless, the centralized powerful computer is employed as a control device for train operations. Furthermore, the FC has its own processor and operates by itself as a device control machine. Currently, the LC organizes all the conditions of the field devices, calculates the logics and sends the calculation results to the corresponding FCs. The FCs receive the orders and translate them into electric power to control the field devices.

Figure 14 shows our further step. The LC assigns its software that is classified by the function of the signal devices to FCs. Then the FC will calculate the logic of the field device that belongs itself and exchange the result by neighboring FCs to complete the total signal operation. When the self-contained functions are installed in the processors of the FCs, the signal devices can perform as stand-alone devices. They will exchange their calculation result each other by using the transmission method that is based on the Internet.
protocol. The cooperation tasks of the signal devices are investigated to achieve adequate hardware architecture and transmission method, and efficient traffic control of train operations. In this case, the signal system will achieve the cooperation tasks of field signals, and an autonomous signal control system will be realized.

6. Conclusions

We have developed a novel railway signal control system that operates as a distributed system. A central control unit (LC) and terminal devices (FC) are essential devices for the system. The Internet technologies and optical LAN technologies are also essential as communication methods between the LC and the FC. The FC is a distributed terminal device that has its own processor and is placed at the railroad wayside to controls the signal devices. The LC is a centralized computer device that has software arranged by the function of the field devices.

The assurance technologies realized by the system are discussed. It has a high flexibility for the period of the construction and the operation. Moreover, an autonomous distributed signal control systems are discussed as a further step. When the LC assigns its contents to the FCs and the FC will calculate the logic of their field device, the signal system will achieve the cooperation tasks of field signals, and an autonomous signal control system will be realized. High demands for the safety and reliability of train operation services will successively continue. Our system is expected to satisfy these demands and work as an important infrastructure of the signal control in the future.

References