Pilot System of CARAT on the Sanyo Shinkansen Line

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The Computer- and Radio-Aided Train (CARAT) control system is a new train control system being developed by the Railway Technical Research Institute of Japan. Since 1987, the institute has examined individual, basic factors essential to this system, such as the quality of radio transmission, the accuracy of train positioning, and the control algorithm of trains. Next, the institute developed a pilot system for the purpose of confirming the synthesized performance under a more realistic environment. This system has been installed on the Sanyo Shinkansen between Shin-Iwakuni and Tokuyama. The pilot test began in March 1991. The test train uses an on-board system made up of three subsystems for (a) train position detection, (b) calculation of train target speed based on the control command received from the ground systems, and (c) radio transmission. On the ground, there are three sets of systems, each made up of three subsystems (a) the radio transmission subsystem, (b) a train tracking-controlling subsystem, and (c) a system simulating the movement of trains (except for the train equipped with the on-board system). The radio data are transmitted via leaky coaxial cable.

In Japan, train operation density of a commuter line in a big city must be increased and the interurban train speed raised. It is not economical to make these improvements by adjusting the current practice, because a large amount of work will be involved whenever the system is modified and, even then, traffic efficiency will not be improved that much. Besides, varying needs must be met flexibly and quickly. This has been a problem for train control systems that must be solved without increased cost or a deterioration of safety.

Against this background, the Railway Technical Research Institute (RTRI) of Japan has developed a new train control system, called the Computer- and Radio-Aided Train (CARAT) control system, under a subsidy from the Ministry of Transport. CARAT is equipped with a microcomputer, train position detection function, and driving-control function on-board, in which position information, interval control information, and so on are exchanged by radio between the on-board unit and the ground unit at a control center (1,2). Introduction of CARAT would realize a higher train operation density and an improvement in efficiency and economy at a stroke.

Figure 1 shows the development process. RTRI has worked on CARAT since 1987, and has carried out individual examinations of basic factors essential to the system, such as the quality of radio transmission, the accuracy of train posi-

tioning, and the control algorithm of trains. RTRI has achieved good results in putting theory into practical use. The next step was a pilot system that performs all these examinations at the same time. Installed on the Sanyo Shinkansen between Shin-Iwakuni and Tokuyama, the pilot system testing began in March 1991.

In this pilot system, one train is equipped with an on-board system made up of three subsystems that serve respectively for train position detection, train control, and radio transmission. On the ground, there are three sets of systems, each of them made up of three subsystems that serve for the radio transmission, the train tracking-controlling, and the train movement simulation. Radio transmission data are exchanged via leaky coaxial (LCX) cable. RTRI expects that this system will be able to confirm the performance of CARAT under a more realistic environment.

OUTLINE OF CARAT

System Concept

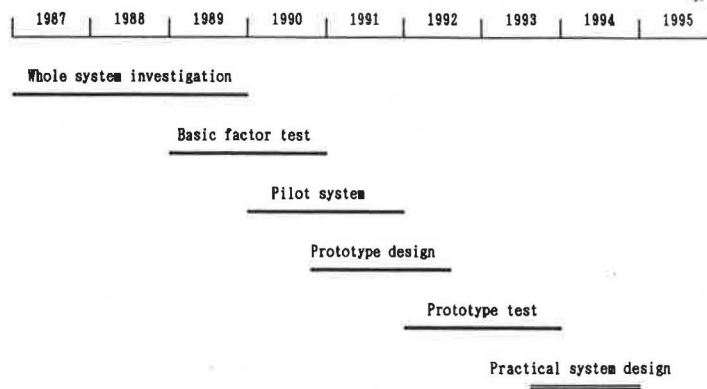The following three points constitute the basic concept of CARAT:

1. Train position is usually detected on board; train interval and points are controlled on the ground according to position information transmitted from on board.
2. The on-board system determines the speed that guarantees safe train runs and controls the timing of the ground system with the train runs.
3. The information is transmitted between ground and on-board systems by a radio communication system covering one unit of the former to N units of the latter.
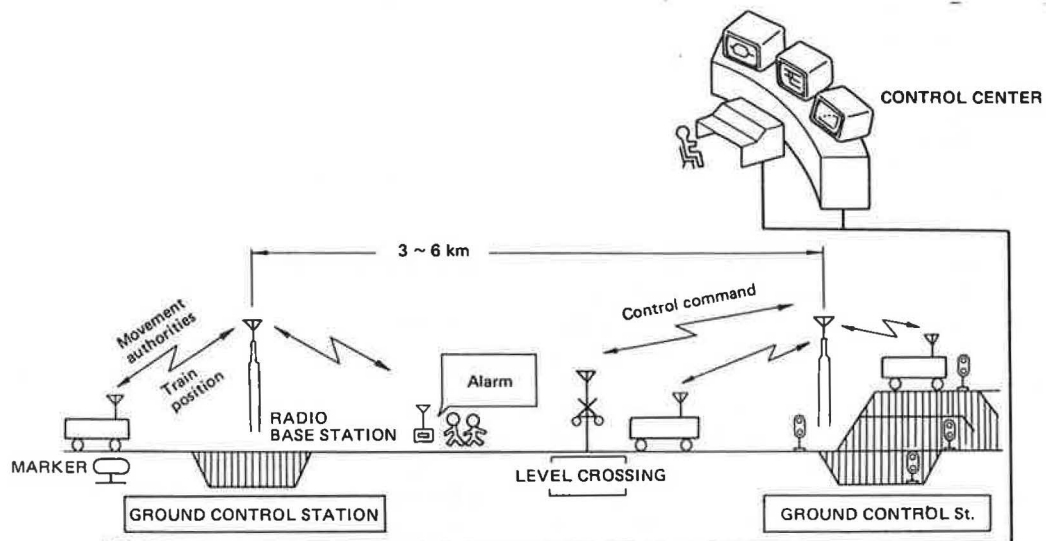
Figure 2 illustrates the system concept.

System Configuration

Figure 3 shows an example of the system configuration. The CARAT consists of ground systems, on-board systems, and radio transmission systems that exchange information between the train and the ground. The ground system is made up of a central system, control station systems, wayside systems, and a ground transmission system that connects the other systems. Table 1 illustrates the configuration of each system and their main functions.
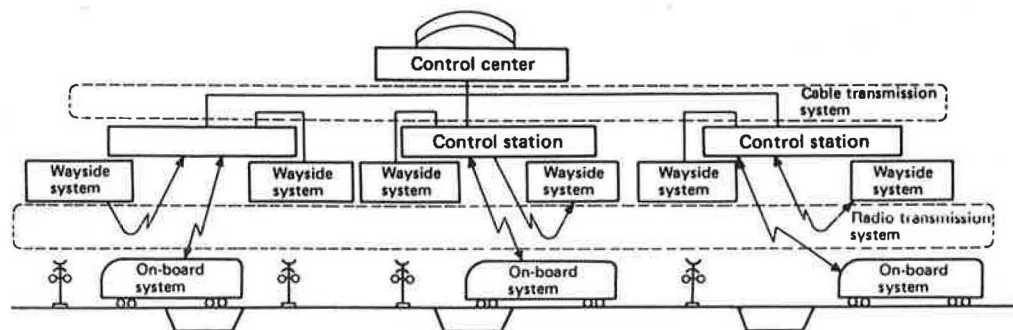
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| 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |

Whole system investigation

Basic factor test

Pilot system

Prototype design

Prototype test

Practical system design

FIGURE 1 Development process.

FIGURE 2 System concepts.

FIGURE 3 An example of system configuration.

TABLE 1 ARRANGEMENT AND FUNCTIONS OF EACH SYSTEM.

		Arrangement	Functions
Ground	Central system	Center	Information exchange medium between control stations Monitoring of whole system
	Control station system	Base station units	Ground functions of train interval control, station compound safety control and route control
	Wayside system	Level crossing units Work units	Level crossing control Train approach warning
	Ground transmission system		Transmission between ground systems (This system may be used in transmission between control station system and wayside one.)
Onboard		Train units	Onboard functions of position detection, train interval control, station compound safety, level crossing control and route control
Radio		Each system unit of control system, wayside and onboard	Information transmission between control station system and onboard one and between the former and wayside system

Examinations of Basic Factors

Radio Transmission

RTRI has measured electric field strength and bit error rate, and grasped characteristics of transmission quality and transmission distance about both LCX and space wave (quasi-microwave). Also, RTRI has established that in a tunnel it is possible to transmit—without taking special steps—over a distance of 4 km, because quasi-microwave propagates comparatively well in tunnels (3,4).

Position Detection

With two commuter trains, RTRI has tested the method in which running distance is calculated by rotation of axles. It has been found that it is necessary to sense rotation of two axles at least in order to limit errors under 20 m in slip and racing of wheels. For higher precision, rotation must be counted on three or more axles or software must be used to correct the count. But in this case, it is assumed that the spot coil of the ATS-S is located every 400 or 500 m (5).

Control Algorithm

RTRI has checked the basic algorithm using a laboratory prototype system. In this system, personal computers are allocated for processing units and a local area network (LAN) simulates the transmission between the ground and on-board units (6). RTRI has also finished the first examination of train interval control and level crossing control with this system in which some trains run on the imaginary railroad. Moreover, RTRI has compared the performance of a real-time operating system; the test results are reflected in this pilot system.

Calculation Unit for Safety Control

RTRI's purpose now is to check the algorithm using personal computers, but finally the software that deals with safety must be executed using a fail-safe processor. The processor for safety now used in Japan is 8 bits, which is insufficient for CARAT. Therefore, RTRI has been developing a 32-bit processor for safety (7). The basic hardware has been produced and its performance is being tested in the pilot project.

PILOT SYSTEM

System Configuration

Figure 4 shows the whole system configuration.

Test Purpose

The objective of the pilot system is to accumulate system performance estimation data and take error records in preparation for implementing a prototype. RTRI sees this pilot system as a means for an overall examination, including all basic factors except the calculation unit for safety control. Therefore, RTRI is relying on personal computers, except in the cases of the radio transmission system and the position detection system. RTRI operates the system (complete with the functions that have been developed in the laboratory prototype system over a long time in a more realistic environment), examining the communication of radio transmission data, train interval control, and position detection.

Examination Place

The system is installed on the Sanyo Shinkansen about 900 km from the starting point between Shin-Iwakuni and Tokuyama. LCX is laid in three zones over a distance of 5.7 km, and a shed for testing is built 897 km from the starting point to house ground system equipment. The train carrying the on-board system runs twice or three times a day between Shin-Osaka and Hakata, and communicates traffic control information via LCX with the ground system on the testing section. Position detection is tested over the whole section.
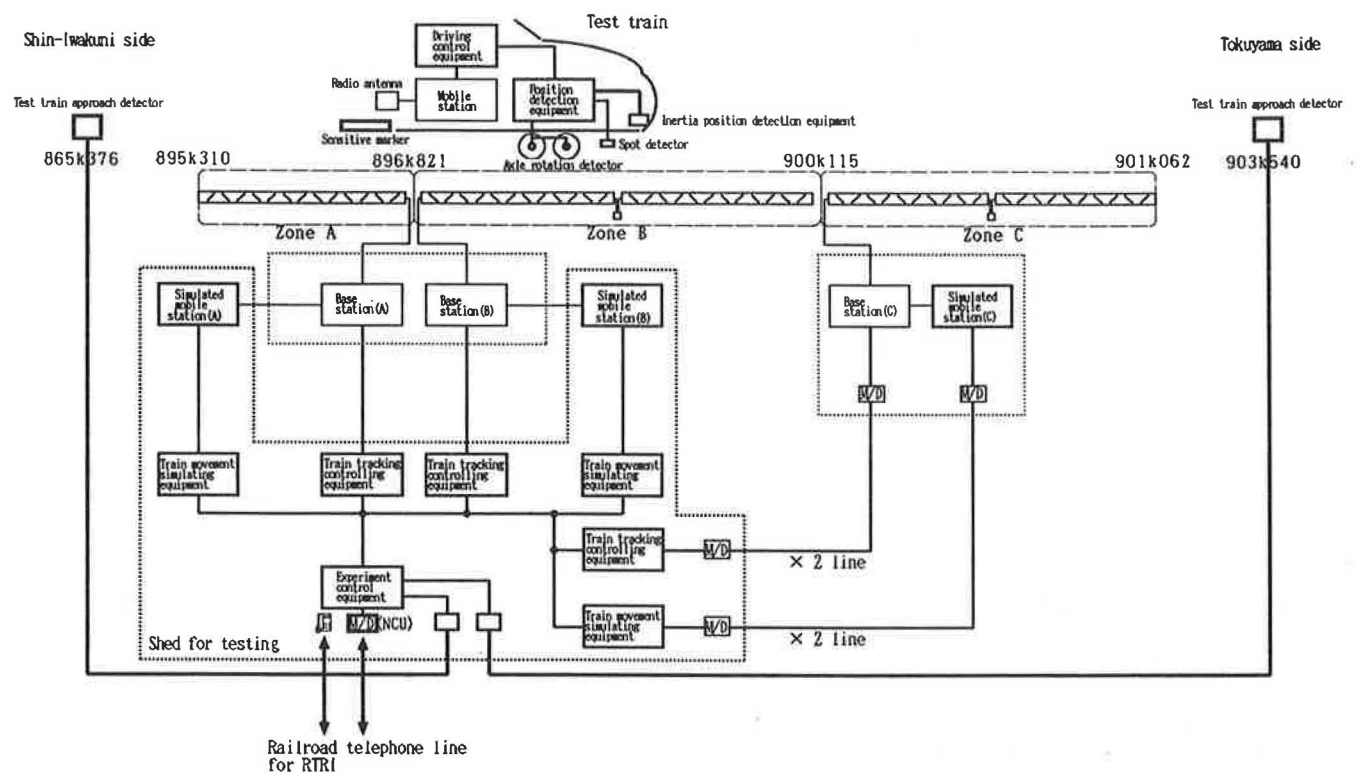
FIGURE 4 **Whole equipment configuration.**

Equipment Configuration

On the ground there are three sets of systems, each of them made up of a base station connected to LCX, train tracking-controlling equipment, a simulated mobile station, and train movement-simulating equipment. Experiment control equipment connects the train tracking-controlling equipment and the train movement-simulating equipment by LAN. On-board are position detection equipment, driving-control equipment, and an on-board station with a radio antenna. The pilot system uses personal computers except in the equipment related to radio and the driving-control equipment, and uses a real-time multitasking operating system. Application programs are described in C-language.

Testing Method

The pilot system is basically designed so that the ground system makes an experiment in interval control of a test train when the train runs on the test section installed with LCX. First, on the ground, each subsystem finishes its initial processing, because an approaching test train detector installed at both stations of Shin-Iwakuni and Tokuyama senses the arrival of the test train. And, as the test train comes into the test section, a train position message is transmitted from on-board to the ground and an interval control message is transmitted from ground to the train by radio.

Because the test section is only 5.7 km long and there is only one test train, the train movement-simulating equipment simulates trains ahead of and behind the test train. On the

ground, RTRI confirms the functions of position tracking and interval controlling for each train. In on-board drive control, RTRI confirms the function of drive controlling and on-board signaling indication while running on the test section.

In this pilot system, radio communication data transmitted in the testing section are recorded by the train tracking-controlling equipment on the ground and by the driving-control equipment on board. The former also records the checking results of received train position messages. The detection error data between Shin-Osaka and Hakata are recorded by the position detection equipment on board. The data obtained on the ground are transferred from the train tracking-controlling equipment to the experiment control equipment, and transmitted to RTRI via telephone line. The data obtained on board, however, must be retrieved by a worker.

Subsystem Functions

Figure 5 shows the subsystem configuration and main exchange data. The following describes details of each subsystem.

Train Tracking-Controlling Subsystem

This subsystem does train tracking, route control simulation, interval control, train position indication, and logging. Each train tracking-controlling equipment covers the test section divided as shown in Figure 4.
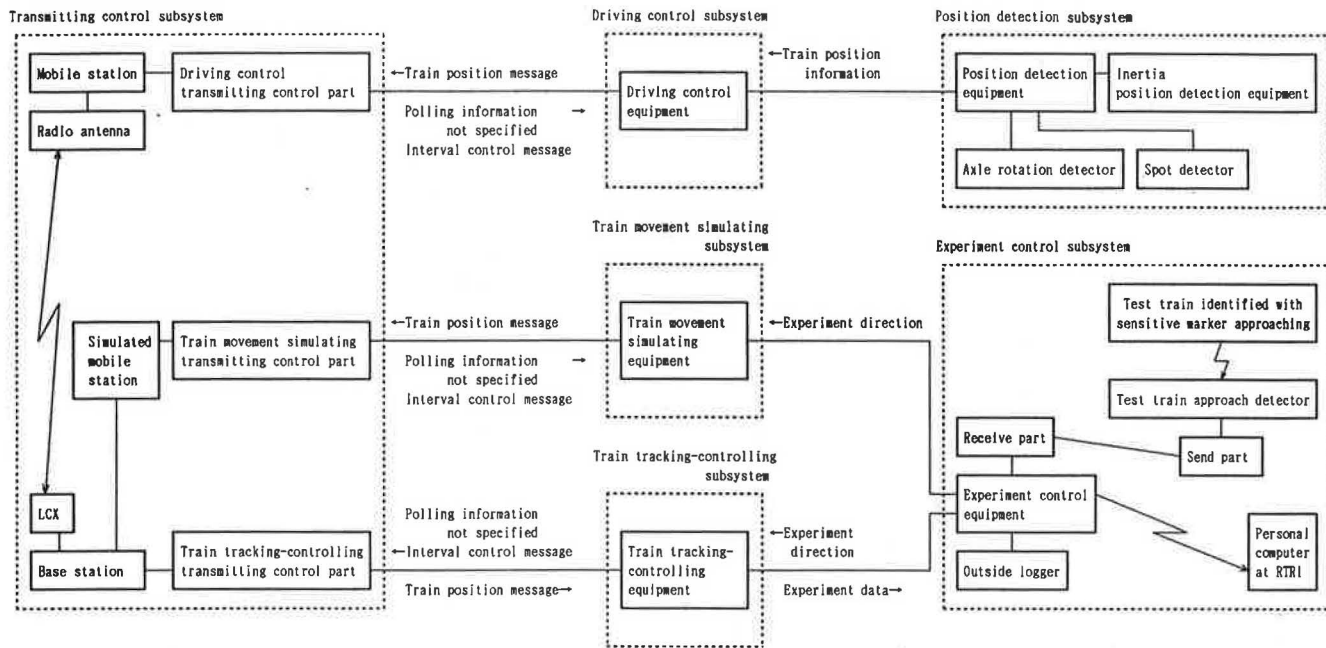
FIGURE 5   Subsystem configuration and main exchange data.

Train Position Tracking   Train tracking-controlling equipment receives some train position data periodically from the on-board system and train movement-simulating subsystem, and then updates the train position data. Position data obtained here are provided to the functions of interval control, route control simulation, and so on. Position on the track is determined by train tracking and controlling section number, tracking block number, and distance from the starting point in the block, because test sections are divided by the so-called tracking block in the data. This equipment tracks trains by referring to a train table that grasps positions of each train and to a tracking block table that grasps trains that exist in each tracking block. Received train position data are checked for their contents.

Route Control Simulation   In this system, a route is set up at the boundary of every tracking block, and the entrance into the tracking block is permitted via this route. The trains request route control in case the route within a certain distance is not being controlled. On a submain line, when trains start the route, they request route control at a fixed time after arriving at a given platform. Alternatively, route control simulation can be done by hand, and if all of the following conditions are satisfied, the route is controlled: the relevant route or a competitive one is not yet controlled; unlocking is not prohibited; there is no train in the clear section of the competitive route; and control request timing of the relevant route comes earlier than that of the competitive route. The route is restored when the train head comes into that route.

Interval Control   To prevent a collision of trains or trains coming into an uncontrolled route, conditions ahead of each train are checked, and stopping target points are transmitted to each train. There are four kinds of stopping targets: the tail position of a train running ahead, the origin of a route not yet controlled, a railroad end position, and the position ahead at a certain distance set when the former three stopping targets do not exist.

Train Position Indication   Position, number, velocity, route condition, and so on of each train running in the tracking-control section are indicated on the railroad diagram format.

Logging Process   The radio communication data and checking results of received train position messages are logged.

Train Movement-Simulating Subsystem

Train movement-simulating equipment is installed at each radio station. It simulates train movement within the communication section.

The simulated trains are controlled with a deceleration control, which holds the train under a safe speed calculated by the driving-control function inside the equipment, and with an acceleration control, which acts when the difference between the current speed and the safe speed exceeds a certain value.

Safe speed is calculated from conditions such as current position, stopping position, restricted speed between those two positions, gradient, and so on. The train position update is calculated by averaging the speed from the last retrieved position to the current one. Stopping point is set at 10 m ahead of the stopping target.

Because more than one train is simulated, the current speed, stopping target, restricted speed, permissible speed curve, and

so on of a designated train can be indicated. Train movement conditions in the simulated section can be indicated also on the train diagram format.

Position Detection Subsystem

The position detection subsystem is basically designed so that it can determine the train position from rotation counts of axles and by detection of the spot coil. Apart from this, there is position detection equipment that uses the inertial method, and RTRI is investigating its precision and performance for making revisions when wheels slip or race.

The rotation sensor is an eddy current system that can count rotations exactly from low speed to stopping. As a countermeasure for slipping and racing of wheels, RTRI has adopted a method that uses software to process inputs from two detectors. In this processing, the slipping and racing are detected every second and the distance run in the meantime is revised using the limit value of acceleration and deceleration, and the operation control signal of the vehicles.

Four kinds of spot coils are used for special speed signal, train radio frequency switching control, open-close control of the train ventilation damper at the gateway to the tunnel, and so on. One spot coil is located every 700 m on the average. The computer for position detection is equipped with a table of kinds and intervals of all spot coils between Shin-Osaka and Hakata. It determines the train position automatically by consulting this table from detected data on kind and interval from whatever station the train starts. With the position thus determined, the train is revised referring to the position table every time a spot coil is detected.

The position detection equipment that uses the inertial method has three sets each of fiber-optic gyros and acceleration sensors. Because an error in this method tends to grow with the passage of time, this equipment—receiving speed data and position from the position detection equipment by wheel rotation—cancels error accumulations. The two position detectors log the distance-run into each logger every time the spot coil is detected. RTRI analyzes the characteristics by comparing both sets of logged data.

Driving Control Subsystem

The driving control subsystem consists of driving control equipment and an indicator that uses a liquid crystal display. The indicator is connected to the position detection subsystem in GPIB interface. While running in the test section, this subsystem exchanges control data between the train and the ground, handles safety control, cab signal indication, and the logging of data communicated by radio.

The permissible speed is calculated based on the interval control information received from train tracking-controlling equipment on the ground, train position input from the position detection subsystem, and wayside stored data. The results of this calculation guarantee safe driving up to a target point, but are not reflected in the actual train driving. Cab signaling indicates train position, wayside data, permissible speed curve, and so on. Radio communication data for the ground are logged into the equipment's logger.

Experiment Control Subsystem

The experiment control subsystem consists of the experiment control equipment connected to each subsystem on the ground, test-train-approaching detectors and their send-receive parts, an outside logger, and a personal computer connected to the experiment control equipment via telephone line at RTRI for data collection. The operator inputs experimental conditions here. At the start of the experiment (timed to the arrival of the test train), the conditions are transmitted to each subsystem. When the experiment is over, data logged in the train tracking-controlling subsystem are transferred to its outside logger; if a personal computer at RTRI requests the data, this subsystem transmits them. This subsystem monitors all the other subsystems on the ground throughout the experiment.

Transmitting Control Subsystem

The size of one input-output message from each control equipment is 160 bits, and a message converted to HDLC format of about 200 bits is transmitted to the radio system. The data-transmit speed is 4.8 kbps. An encoder of the radio system divides the data into 132-bit segments, appends a 40-bit flag sequence and 48-bit BHC marks to each data, and then transmits them to the radio station. At the radio station, data-transmit speed is 8 kbps by digital modulation system. A polling method with a period of 200 ms for the transmitting control uses one 12.5 kHz channel each for sending and receiving between ground and train systems.

Some polling information specifies a train and some does not. A train entering a radio zone first answers the polling information that does not specify the answering train, and requests a registration of the train for the train tracking-controlling subsystem. The train tracking-controlling equipment is already in receipt of a notice on the incoming train from the neighboring equipment and begins to send polling information that specifies the train after checking the train number and a train number received by radio.

Outline of System Processing on Test Train Runs

Having detected the approaching test train at the station, the train movement-simulating subsystem produces a simulated test train. The simulated test train answers the polling information that does not specify the train, and sends a train position message. After this, the subsystem simulates a train run exchanging the train position message and the interval control message. Upon coming into the test section, the test train receives polling information that does not specify the train, and answers with a train position message.

Then the train tracking-controlling subsystem switches train tracking from the simulated test train to the test train. After this, the subsystem sends an interval control message and receives a train position message for the test train. When the test train comes into the next section, the same communication sequence is repeated in the new zone. In the former zone, the tracking ends upon receiving the incoming information on the test train.

When the test train leaves the test section, the train movement-simulating subsystem recreates the simulated test train, and the train tracking-controlling subsystem switches the tracking train. Finally, when the simulated test train leaves the tracking section, both the tracking and the train movement simulation end.

The simulated trains that run ahead or behind of the test train are produced together with generation of a simulated test train. There is no switching of tracking for these simulated trains. At the boundary of train tracking-controlling sections, these trains are switched between neighbor train movement-simulating subsystems via LAN.

FUTURE CHALLENGES

Functions Buildup

Inputting the point detection information installed on the ground of Shinkansen, RTRI can grasp the detection position error of the test train real-time. RTRI also intends to implement an on-board point control function.

Addition of Test Train

By adding test trains equipped with on-board systems, RTRI intends to confirm the tracking performance of any test trains in the test section.

Development of Exclusive Equipment

RTRI would like to make a trial product that is closer to the real equipment than the personal computer. Then RTRI intends to introduce the calculation unit for safe control now being testing for performance, at the point handling the vital data.

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