Development of a Train Control System by Using the On-board Interlocking

Takayasu KITANO
Train Control Systems Laboratory, Signalling and Transport Information Technology Division

Tatsuya SASAKI
Train Control Systems Laboratory, Signalling and Transport Information Technology Division (Former)

Yoichi SUGIYAMA
Train Control Systems Laboratory, Signalling and Transport Information Technology Division

This paper investigates a train control system design which can reduce the amount of signalling equipment required in stations, such as wayside signals, interlocking machines and track circuits. In this paper, the authors report on the specifications of the system and on results from receiving tests with the RFID tag.

Keywords: on-board interlocking, RFID tag, route control, on-board position detection

1. Introduction

A new simple train control system for local traffic lines was designed in order to reduce wayside signal equipment [1]. The system was developed assuming a single track with little traffic. So long as there is only one train in a section between two stations, it is possible to manage the block section in which the train is located safely. When a train is occupying a block which has been sectioned off for other trains, then the train itself can switch the turnout towards the direction of the programmed route. This means that the point machine is controlled by a command from the train, which in turn can reduce the amount of required ground equipment. In order for the system to work, it must be necessary to manage block sections exclusively in order to prevent some trains being entered into the same block. Since the trains in the system have no way to exchange messages about the position of other trains, the system should have ground equipment which manages the block section of a train being present.

This paper first describes the basic concepts underlying the developed system. Then, the characteristics of the receiving equipment of the RFID system are presented, hereafter referred to as the on-board train positioning device.

2. Concept of the developed system

2.1 Interlocking logic

(1) Traditional interlocking logic

Traditional interlocking works by the point machine switching to the direction of the route requested by the route controller or through lever operation after which it is locked. Once the point machine is locked, the signal aspect is changed to indicate the advancing signal. Interlocking machines with locking logic such as approach locking and route locking will keep on locking the point machine to the direction of the train’s route, which ensures train safety. In order to constitute a route for the next train, the interlocking machine first unlocks the point machine on detecting the train position by using RFID tags on the sleeper. On-board interlocking equipment helps reduce the amount of signalling equipment required in stations, such as wayside signals, interlocking machines and track circuits. In this paper, the authors report on the specifications of the system and on results from receiving tests with the RFID tag.

(2) Interlocking logic of the developed system

The new interlocking logic of the developed system adheres fundamentally to the basic idea of this traditional logic. However, in this case, the time locking and sticklocking are substituted by on-board train position detection and velocity control, which provide the simple interlocking logic. The concept of the interlocking logic of the system is shown as Fig. 1. Assuming that the developed system is adopted for local lines, initial and maintenance costs can be cut due to reduced need for ground equipment such as track circuits and interlocking machines. Additionally, the system has ATP (Automatic Train Protect) function as a backup system, in order to prevent signals passed at

Fig. 1 Concept of the interlocking logic
danger. Thus, the safety of the system is maintained by the techniques of the exclusion control between trains, the direct control of the point machine by on-board equipment using on-board position and velocity detection, and the on-board velocity control which enables safe stopping.

2.2 Train detection and on-board position detection

In the traditional interlocking system, a track circuit is needed to detect the train position and lock the point machine in such ways as the approach locking and route locking. However, in the developed system, their function is performed by on-board position detection and velocity control. In the system, the on-board equipment of the train controls the route which the train will pass and switches the point machines on the route with the detected position information. Thus, in the system, the reliability of the train detection is an important factor.

2.3 Verification of on-board position detection

In the paper, the authors assume that on-board position detection uses RFID tags as the train detection device. Since RFID tags have no diagnosis function for device failure, therefore other equipment is required to verify their functional status. In this system, central ground equipment whose name is ‘block controllers’ manages the block section and train location. In cases when the block controller obtains no information from the train or the train cannot detect the position with the failed tag, the block section is kept in occupied state, i.e. as if a train was present.

The method for verifying the validity of the on-board position detection system is shown in Fig. 2. The on-board equipment includes a database in which the order of tags is recorded. When the on-board equipment receives tag information, the equipment collates the reception order with the database. If the order of tags does not accord with the database, the on-board equipment stops the train. The block controller unlocks the block only on reception of information from all tags in the block.

(1) Information transmission between wayside and on-board equipment

Wireless transmission is used between the ground equipment and on-board equipment. An open wireless system was employed to curb the acquisition cost of a new frequency band and the development cost of a new radio unit.

(2) Detection of masquerading messages

With an open wireless system there is a risk of eavesdropping and of masquerading messages being sent. If a third party manages to obtain a train control message and signal aspect, they may transmit the wrong message causing a control hazard. The train control equipment must therefore have a function capable of detecting and discarding masquerading messages. To this end cryptographic technology is used. In addition to this the receiving equipment in the system checks whether the received message is from a satisfactory source without corruption and repetition to detect masquerading messages in the transmission process. If equipment gets copied or stolen, then there is also the risk of the copied or stolen equipment being used in an attack to transmit wrong messages. The receiving equipment would not be able to detect such an attack, therefore additional security is needed. To this end a certification process was added to transmission of the messages in the system [2].

3. System development

3.1 Framework

Three types of equipment were developed: on-board equipment, a block controller and a point controller (Fig. 3). The on-board equipment is installed on the vehicle, and the block controller and point controller are set on the ground. Only one block controller is installed for one line.

The on-board equipment has four functions: the on-board interlocking function, the velocity control function which creates velocity control information, the signal assignment function which indicates signal aspect and provides the human interface, the on-board receiver which receives the messages of the position detection from ground coils or RFID tags.

The block controller manages the block condition to determine the presence or absence of a train in a block and locks the block section when a train is present. The point controller operates the electric point machines according to the instructions from the on-board equipment.

Wireless transmission is used between the on-board
equipment and ground equipment; so, the equipment has a wireless transceiver.

3.2 On-board interlocking function

The on-board equipment has interlocking logic and information containing the timetable for every station. The on-board equipment identifies the station where the train exists with the train position information from the tag and issues switch instructions to the point controller and indicates a signal aspect on the cab.

When the point controller receives the switching instruction from the on-board equipment, the point machine is switched to the direction indicated in the instruction. The on-board equipment sets the route in accordance with the block conditions which are stored in the block controller.

3.3 Information for on-board interlocking

(1) Safety control for failure of non-vital devices

When non-vital devices such as RFID tags are used for train detection, the on-board equipment could fail to read a tag, causing the equipment to lose the train’s position. Thus, it is necessary to find a means to preserve safety in a situation where the accurate position of the train is lost. In this situation the block controller will maintain the block in an occupied condition in the system, until they receive a message to unlock the block from the on-board equipment thus preventing the defective train from leaving the block.

(2) Train location establishment

When a train enters the system’s territory, the on-board equipment of the train detects the position and transmits the request to lock the block to the block controller. In order to prevent trains following the same route, the block controller stores the train location along with the block section.

(3) Block state information without real-time update

Wireless transmission can only be used in a limited area for cost reasons. The block state information which has been stored by the block controller shows the train location at the time when the on-board equipment transmitted the message. So, the train location cannot be continuously updated on a real-time basis. In the system, to keep the safety of the system without real-time update, the block controller manages the train locations per block, and a train can only travel in the blocks which have been locked by the train itself.

(4) Information about neighbouring trains

In the system, a train can obtain information about other train locations by requesting the information to the block controller, which can provide information about neighbouring train locations.

4. Train control system using on-board interlocking

4.1 Route control

The on-board equipment requests the locking of the blocks through which the train plans to pass, using position detection information. The point controller switches the turnouts with instructions from the on-board equipment. The on-board equipment requires a block locking request based on the reception of information from the RFID tags which are checked against the on-board database. For the transmission of the block request, there is a possibility of the reception of wrong information in the process of wireless transmission. The system is therefore designed to detect incorrect messages on the following assumption: over-reached tag information which causes bit error is not received because the receivable area of the tag information is small, the sequence of the tags is checked by the on-board equipment, and errors of the tag information can be detected by adding check code such as CRC. Additionally, the on-board equipment transmits a block locking request with tag information, which is specific information unique to and only known by the train in question.

4.2 Blocking system

(1) Definition of block section

In stations where inbound and outbound trains pass each other on a single track, two kinds of blocks which are inter-station block and station block are defined as shown in Fig. 4. The inter-station block indicated by (I) in Fig. 4 is a block section between the protected area of the departure signal and the nearside of the protected area of the entry signal at the next station. The station block indicated by (II) in Fig. 4 is between the protected area of the entry signal at the next station and the nearside of the protected area of the departure signal. The block section is locked by distinguishing between outbound and inbound trains.

(2) Block state

At the station where two trains could pass each other, both the outbound train and inbound train require the next inter-station and station blocks to depart from the station. In the case, they are prevented from proceeding because the next blocks are locked by the other train. In order to prevent this deadlock in such situations therefore, as shown in Fig. 5, the following conditions are assumed:

(a) Block locking

Block locking means that a train locks the block sections where a train is present and/or the train is scheduled to run.

(b) Temporary block unlocking

Temporary block unlocking is a temporary state de-
signed to prevent deadlock. When the train locking a block has arrived at the station, the state of the blocks behind it is shifted to temporary unlocking. Consequently, if a train comes in the opposite direction it can unlock the block.

(c) Block unlocking
When the train has left a block section it is unlocked by the on-board equipment of the train which locked it.

4.3 Route locking and unlocking

(1) Locking
In the system, since the on-board equipment can obtain the information of the detected position and the velocity, the information can be used for control based on the interlocking logic. The procedure of the locking is shown in Fig. 6, and the basic idea of the locking is shown in Fig. 7. The block between the departure point and the arrival point is locked by the on-board equipment. Once the on-board equipment sets a route and the train enters the path, the operation cannot be cancelled. In the system, the point controller is controlled with instructions from the on-board equipment. So, the safety of the route is kept until the train unlocks the block at the arrival point.

(2) Unlocking
In the system, the safety of the train’s route is kept by locking the block. The route locking is unlocked concurrently with the release of the block.

4.4 Other locking

(1) Stick locking
In the system, stick locking is substituted by on-board position detection and block locking. The point controller can detect an approaching train from information collected from the on-board equipment, and the on-board equipment can detect a train approaching a turnout from information from the on-board position detector.

(2) Time locking
The train is protected against overrunning the end of the block section by the velocity control and stop control following the ATP profile.
(3) Indication locking

In traditional interlocking, the indication locking means confirmation of no error occurring. In the developed system, error output and conflict output are collated by checking the indicated conditions of the signal aspect process and feedback from checking of the signal aspect.

4.5 Velocity control

The velocity of the running train is controlled by the ATP profile and position information from the on-board position detector. The stop position of the ATP profile is set at the same position of the stop sign of the entry signal or the departure signal as shown in Fig. 9. The ATP profile is cleared on receiving the message confirming that the point machine has been switched.

4.6 Signal aspect

Cab signalling is used in this system. The cab signal shows the departure aspect when the on-board equipment has obtained both the route locking information and the turnout completion information. A train about to depart locks the block from the departure point to the arrival point at the next station. After locking the block, the point machines in the block can be switched by instructions from the on-board equipment. However, since the point machine at the next station is not in an area with wireless coverage, the point machine is switched at the time when the train approaches the next station. The normal aspect of an entry signal is a stop, so the signal indicates the proceed aspect on reception of the switch completion information.

5. Characteristics of the RFID tag used for detecting the train position

In the developed system, detecting train position is important. This paper assumes that an RFID device is used for on-board train position detection. In order to put the system to practical use, it is necessary to show the characteristics of the magnetic field of the RFID readers and the performance of received frames.

Three types of environment were set for taking measurements: an ideal environment in which little metal is present around the measurement system, an XYZ table environment shown in Fig. 10 and an underfloor environment shown in Fig. 11. In the XYZ table environment, the RFID tag was set in the center, and the antenna connected with the RFID reader was set on the movable XYZ table. The distance between the tag and the antenna was set at 260 mm, 280 mm, and 300 mm. In the underfloor environment, the antenna was mounted under the floor of the test vehicle on the test line at the Railway Technical Research Institute.

(1) Characteristics of magnetic field intensity

Figure 12 shows the magnetic field intensity characteristics. Figure 12 gives the characteristics of the ideal environment in (1), those of the underfloor environment in (2) and those of the XYZ table environment in (3). When the distance between the antenna and the tag was set at 300 mm, the magnetic field intensity in the metal-free environment was 107.95 dBμA/m and that measured on the XYZ stage was 95.85 dBμA/m and that measured in the underfloor environment was 101.95 dBμA/m.

In the underfloor environment, the fixing frame of the on-board antenna made a loop circuit which was a factor leading to the decrement of the magnetic field intensity.

(2) Received frame performance

Figure 12 shows the average reception time of the frame, when the distance between the antenna and the tag was set at 300 mm. The average time when the antenna lay just above the tag was 6.0 ms/frame, and when the antenna was moved to 250 mm was 12.7 ms/frame. These results mean that a train running at 130 km/h can receive 2 or 3 frames.
6. Conclusions

This paper describes a new train control system using on-board interlocking.

(1) The train position and velocity are detected by the on-board equipment, which can simplify the interlocking logic.

(2) The reduction of the ground equipment such as track circuits and interlocking machines is possible.

Acknowledgment

This work was supported by the Ministry of Land, Infrastructure, Transport and Tourism of Japan.

References

[1] Sasaki, T., “Development of Train Control System by Using Information of Train Position with Wireless IC-tag,” RTRI Report, Vol. 25, No. 5, pp. 11-17, 2011 (In Japanese).

[2] Kitano, T., Sasaki, T., and Sugiyama, Y., “A Countermeasure against Illegal Switching Control in On-board Interlocking System,” presented at the IEEJ NATIONAL CONVENTION, Ehime, Japan, March 18-20, 2014 (In Japanese).

Authors

Takayasu KITANO, Ph. D.
Researcher, Train Control Systems Laboratory, Signalling and Transport Information Technology Division
Research Areas: Networking for Train Control System, Train Position Detection, Safety

Yoichi SUGIYAMA
Assistant Senior Researcher, Train Control Systems Laboratory, Signalling and Transport Information Technology Division
Research Areas: Train Position Detection, Safety

Tatsuya SASAKI
Senior Researcher, Train Control Systems Laboratory, Signalling and Transport Information Technology Division (Former)
Research Areas: Train Position Detection, Safety