Trend on Research and Development Activities Relating to Signalling and Telecommunication Systems in Railway Fields

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The spread of new coronavirus infections (hereinafter referred to as COVID-19), which began in Japan at the end of 2019, has greatly affected the country’s railways. Railway operators are trying to provide safe and convenient mobility while taking various infection control measures so that customers can enjoy travel with peace of mind. These conditions have increased the urgency of railway operators to reduce fixed costs while responding to changing needs for mobility in a post-COVID-19 society.

Our belief is that it is necessary to speed up R&D on cost reduction and equipment saving, which already forms part of RTRI’s research program, so that railway operators can contribute to future efforts to reduce fixed costs.

This paper introduces R&D for the advancement of automatic operation and expansion to general line sections, and R&D on cost reduction of signal communication equipment by using general-purpose technology and 5G. It also describes the direction and policy of future R&D for railway maintenance and development in a post-COVID-19 society.

1. Introduction

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2. R&D for automation of train operation

2.1 Issues with crew duties and automation of operation

According to Article 11 (on-board business, etc. of the staff who operate the motor vehicle) of the Ministerial Ordinance to Provide Technical Regulatory Standards on Railways, stipulated by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), staff on board trains can be divided into three categories: (1) staff for operating motor vehicles, (2) staff for train protection and those handling operational tasks, and (3) staff for passenger handling operations.

In the case of one-man operation, the driver plays the roles of these three staff categories alone, and in driverless operation, the staff member taking the place of the driver and the automated system play the roles of (1) to (3). Unmanned operation is a type of driverless operation in which no staff is on board the train and the system and ground staff play the roles of (1) to (3).

There are several ways to realize automation of train operation, depending on the division of roles between people and systems. A ‘Grade of Automation’ (GoA) is used to determine the degree of automation in a railway train operation, which is defined by the international standard IEC 62290-1 (JIS E 3802) [1], which defines the requirements for urban railway commands and control systems (Fig. 1).

In Japan, GoA4 unmanned operation is realized on railway routes that have elevated structures without level crossings and have platform doors on the platform of each station, which prevents people accessing the tracks [2].

The MLIT established an Automatic Operation Technology Study Group on Railways (chaired by Prof. Koseki of the University of Tokyo Graduate School) in FY2018. This group is currently identifying technical issues with and examining the requirements for realizing automatic train operation for the grade above that in which a member of staff who is not qualified to operate a train is at the front of a train and tasked with ensuring automatic train operation in general line sections with level crossings (tentatively called GoA2.5 because it is between GoA2 and GoA3) [3]. Specific tech-
2.2 R&D to support drivers and migration to driverless operation

This special issue contains the following four papers concerning the introduction and expansion of automatic operation and R&D to support drivers in one-man operations.

(1) Development of an automatic operation system using ATS-DK
(2) Operation pattern generation technology for automatic acceleration/deceleration control assuming ATS-P
(3) Train front obstacle detection method with a camera and LiDAR sensor integrated
(4) Safety check method using vehicle side-mounted cameras

R&D (3) and (4) above make full use of digital technologies such as image processing and AI. The technology in R&D (3) will be indispensable for developing driverless operation in general line sections in the future. The technology in R&D (4) will be extendable to driverless operation although the goal is to support one-man operation.

The following sections briefly introduce some examples of research that could not be included in this special issue.

2.2.1 Detection of abnormalities inside level crossings using far-infrared images

Regarding the detection of motor vehicles on railroad crossings, in order to detect automobiles, railways have conventionally introduced systems that irradiate the inside of level crossings with a laser beam and those that use laser radar, etc.

These systems, however, have limitations. For example, they can only detect objects above a certain size, or have an undetectable range. Thus, RTRI has been developing a system capable of detecting objects smaller than cars (e.g. humans) in level crossings by processing thermal images taken by far-infrared cameras (Fig. 2) [4]. Initially, machine learning technology was applied, but issues were encountered involving processing volumes and machine learning. Therefore, by developing a technology capable of recognizing an object at high speed from the difference in time and space, a performance has been achieved that enables even the recognition of a person falling on the road. The processing system has been duplicated, and the reliability of the device has been improved by developing a mechanism to check the video output from the camera. The development of a prototype device designed for practical use was completed in the last fiscal year. Detection performance verification tests are currently underway in the field under various meteorological conditions. This method detects targets based on temperature difference: if the temperature of a target is close to the road surface temperature, the system may either not detect it or detect a false positive. We are now trying to quantitatively evaluate false negative detection probability, false-positive rates, etc. in various conditions, with a view to launching this into practical application in FY2022.

2.2.2 Detection of abnormalities inside level crossings using far-infrared images

Obstruction warning signals are devices which emit light in conjunction with an emergency button, etc. at a level crossing to notify the driver of an anomaly along the railway. On many routes, the driver visually sees the light emission and operates the brake to stop the train. We have developed the emission detection method of the flashing obstruction warning signal using an on-board camera so that safety can be further improved by supporting this visual recognition by the driver (Fig. 3) [5].

Our developed method uses an on-board camera equipped with an optical filter to shoot the front of the train and detects only the light emitted by the obstruction warning signal by image processing from the shot video. To separate the emitted light from other red flashing lights such as traffic lights in a short time, this method first quantifies the emission pattern of the obstruction warning signal shown in the video, then realizes detection by collating this with the contents of a database in which the emission pattern of the obstruction warning signal has been registered in advance.

We have experimentally verified that the light can be detected within 1 s after the obstruction warning signal located 600 m ahead emits light.

We are currently developing a device which can be mounted on a vehicle for practical use and could be put into service in FY2023 after conducting monitored runs on actual line sections in FY2022. We are also developing an algorithm applicable to rotary signals.

This method was developed as an element of the forward monitoring technology using a camera. Since the light emission is detected using a camera, the information can be left as a moving image, in addition, it is applicable and expandable to the detection of other objects such as the aspect of a signal.
3. R&D for equipment and cost reduction

To reduce fixed costs related to signal communication equipment, we should reduce the amount of necessary equipment as well as the equipment cost. To show technologies to reduce the equipment cost and the amount of equipment, this section overviews an example of configuring fail-safe devices with general-purpose processors and an example of R&D for applying 5G to security applications.

In FY2020, at an RTRI lecture [6] and in this journal [7], the concept of Autonomous Train Operation was introduced as a topic of R&D for the future of railways. It aims to reduce the amount of security equipment placed on the ground while making driverless operation, detailed in Section 2, even more sophisticated.

3.1 Configuring fail-safe devices with general-purpose processors

In railway signal systems, a basic requirement is to maintain the system in a safe state or ensure fail-safe functions in which the system transitions to a safe state in the event of a system failure. For this reason, even if using a relay, where contacts are dropped in the event of a failure or if using a computer, the system is configured with fail-safe devices that ensure the fail-safe properties of each input, processing, and output with a single device. However, since fail-safe devices are generally expensive, currently, a method has been studied for configuring security devices at a lower cost by using general-purpose processors, whose performance has improved remarkably in recent years.

When applying a general-purpose processor to a railway signal system, there are issues that (i) the device alone is not fail-safe, and (ii) the product life cycle is short, thus maintaining or renewing it is difficult within the life cycle of the entire system.

Therefore, we took the following steps: first, after organizing and defining the requirements for applying a general-purpose processor to safety-related processing, we proposed a flow to configure the system through the phase to perform safety analysis of the entire system and the phase to check safety requirements. Then, we proposed a configuration method that includes the first step of applying a general-purpose processor to the input/output section of a fail-safe device [8]. We also presented a framework for applying cryptographic techniques with fail-safe appliances for ensuring security, which is an issue when using general-purpose computers and public lines. In future, we will go one step further and proceed with R&D on a method for constructing a system using only general-purpose processors without relying on fail-safe devices.

3.2 Using 5G for security control

Regarding the application of 5G to railways, individual railway operators have already conducted demonstration experiments mainly on the improvement of passenger services in cooperation with telecommunications carriers. The provision of new services is about the improvement of passenger services in cooperation with telecommunications carriers. The provision of new services is about the improvement of passenger services in cooperation with telecommunications carriers. The provision of new services is about the improvement of passenger services in cooperation with telecommunications carriers. The provision of new services is about the improvement of passenger services in cooperation with telecommunications carriers. The provision of new services is about the improvement of passenger services in cooperation with telecommunications carriers.

In March 2021, on the RTRI in-house test line, we constructed a non-standalone (NSA) local 5G system using the 28 GHz band (Fig. 4). A standalone LTE system (standalone BWA) in the 2.5 GHz band has been introduced as an anchor for exchanging control signals between the base station and terminals. In addition to local 5G, we have obtained a license for a specific radio station for standalone LTE systems together, thus allowing comparison in transmission characteristics between local 5G and standalone LTE.

In the future, we will quantitatively grasp the 5G transmission characteristics in the railway environment and evaluate the reliability, delay, etc. We will prepare and propose a draft guideline for 5G utilization centered on railway train operation control by the end of FY 2021, taking into (i) the study on the Future Railway Mobile Communication System (FRMCS) being promoted by the International Union of Railways (UIC) and (ii) needs for railway operators in Japan.

4. R&D for a post-COVID-19 society

Since before the COVID-19 pandemic, we have been working on R&D to reduce fixed costs and realize train operation control that can flexibly respond to changing needs. We recognize that these efforts are important for maintaining and developing the railway also in a post-COVID-19 society. In particular, we believe that R&D must be further accelerated for technologies that directly lead to the reduction of fixed costs, such as automation of operation and equipment saving.

First of all, we will aim at reducing load and time related to driver decision-making, and further automation by developing methods which can exploit different types of data, apply latest data processing, and AI. Our research also aims to reduce costs and increase system and device reliability by designing rapid reliability/validity evaluation methods and methods for detecting abnormalities in processing results, which are needed to apply high-speed processor technology (e.g. general-purpose CPU and GPU used to apply AI) and wireless communication networks (e.g. 5th Generation Mobile Communication System (5G)) in safety-critical work.

In addition, R&D will focus on preparing the transition to new systems that can help save labor, equipment, and energy by constructing a cross-sectoral data-sharing platform and achieving autonomous train operation.

Another goal is to share and disseminate research outcomes more rapidly. Currently, findings are often shared when practicality and reliability have been confirmed. However, it is important to disseminate results as soon as possible even when outcomes only
partially meet railway operator needs because they are still in performance. This is especially true for outcomes which involve new uses of digital technology: given that the development and obsolescence of base digital technology itself progresses rapidly, we should deliver developments to railway operators at an early stage to allow them to be sophisticated while being used. Nevertheless, the performance and effectiveness of findings do need to be verified in terms of safety and in relation to passenger satisfaction, which means that some R&D outcomes will still need to meet the traditional high criteria in terms of performance before they can be introduced in practice. This means that not all R&D outcomes will be dealt with uniformly, and only selected items of research will be proposed at an earlier stage in consultation with railway operators.

5. Conclusions

This paper introduced recent R&D that contributes to the automation of train operations and equipment saving. It also described the future direction and principles underpinning RTRI’s approach to R&D aimed at adapting maintenance and development of railways in a post-COVID-19 society.

At present, while there are positive signs that it will be possible to live with COVID-19 with vaccines and treatments, long-term pandemic control measures are still required. As such R&D aims to help railway operators save labor and improve efficiency improvement, to enable them to continue operating trains on time every day against a background of dramatically altered mobility needs in a difficult business environment. It is also important for us to consider what technologies are required to respond to changes in people’s transport and distribution patterns in a post-COVID-19 society and reflect them in future R&D. We will work diligently on R&D in collaboration with Japanese domestic and overseas railway operators and research institutes, manufacturers, and universities with advanced technologies so that we can contribute not only to the maintenance of railways as a social infrastructure, but also to its further development.

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References

[1] IEC 62290-1:2014, “Railway applications - Urban guided transport management and command/control systems - Part 1: System principles and fundamental concepts,” IEC, 2014.
[2] Mizuma, T., “History and Future of the Automatic Train Operation System in Railway field,” Journal of the Society of Instrument and Control Engineers, Vol. 56, No. 2, pp. 93-98, 2017 (in Japanese).
[3] The Ministry of Land, Infrastructure, Transport and Tourism, Automatic Operation Technology Study Group on Railways, https://www.mlit.go.jp/tetudo/tetudo_fr1_000058.html, 2021 (in Japanese).
[4] Ichikawa, T., Nagamine, N., Mukojima, H., “Study on Evaluation Method of Anomaly Detection Algorithm for a Level Crossing,” presented at the Technical Meeting on “Transportation and Electric Railway,” IEE Japan., May 13th, 2021, Paper TER-21-050 (in Japanese).
[5] Mukojima, H., Nagamine, N., Nomura, T., Ichikawa, T., “Blinking Detection for Obstruction Warning Signal using Front Camera,” Quarterly Report of RTRI, Vol. 62, No. 2, pp. 118-123, 2021.
[6] Kawasaki, K., “Overview of Research and Development Activities Relating to Digitalization of Railway Operation Management and Future Outlook,” Quarterly Report of RTRI, Vol. 61, No. 4, pp. 235-239, 2020.
[7] Kawasaki, K., “Outlines and Future Outlook of Research and Development Activities relating to Utilization of Information and Communication Technology for Signalling and Telecommunication Systems,” Quarterly Report of RTRI, Vol. 62, No. 2, pp. 83-87, 2021.
[8] Gion, A., “Structure and Configuration Method for a Fail-Safe System using General Purpose Computers,” the Journal of Japanese Railway Engineers’ Association, Vol. 64, No. 8, pp. 12-15, 2021 (in Japanese).

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