Trends and Topics of Research and Development Related to the Sophistication of Signalling and Telecommunication Systems

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Following recent developments in information and communication technology (ICT), various research and development projects are ongoing around the world to propose new train control technology for safer and more stable transportation services. In particular, 5th generation mobile communication network systems (5G) which will be partially available in 2019 are expected to be used for critical roles in various safety-related systems in the future, such as for automatic driving systems for road vehicles and train control systems. This paper outlines recent trends in basic studies for utilizing various communication network techniques including content centric network techniques and 5G systems to sophisticate signalling systems and train control systems. This paper also introduces a future plan for the challenges of the developing autonomous train operation and control system to realize safer, more stable and low-cost train operation services.

Keywords: radio train control, ICT, information network, fifth-generation mobile communications system, autonomous

1. Introduction

Significant leaps in the processing performance of processors and the availability of higher-capacity, lower-priced storage devices have made it possible to process large volumes of data at high speeds, with even small-sized devices now capable of performing sophisticated information processing, which was difficult in the past. When fifth-generation mobile communications systems (5G), which was partially available from FY2019, become fully deployed, sensors embedded in a range of smart ‘things’ will be able to communicate with computers on the network, sending large volumes of digitized data about physical phenomena around us for sharing and utilization across different industry segments [1]. 5G also offers potential for applications that are directly related to safety such as autonomous road vehicles and train control systems. Research and development is underway across the globe on the application of the latest information and communications technology for safer and more reliable transport services.

This paper presents RTRI’s research and development programs on the utilization of information network technology including 5G for further sophistication of train operation and control. This paper also presents the concept of an autonomous train operation and control system that is being studied for safer, more reliable and lower-cost train operation and control.

2. Utilization of information network technology

2.1 Research and development of an information combination network for train operation

Currently, information required for train operation is transmitted on separate networks belonging specific to different ‘sectors’: vehicles, signalling systems and operations, each using different data formats and transmission methods. In this system, if a user wants to access information, they first need to select the correct source in the appropriate sector before sending the information request. This hinders data sharing. Given the above, efforts are being made to develop a communication protocol that enables integrated data sharing among the sectors [2].

The protocol is being developed with the concepts of Information Centric Network (ICN) and Content Centric Network (CCN) in mind. With ICN (or CCN), a user can access the required information simply by indicating it without the need to know its location. The information combination network for train operation being developed by RTRI couples the concept of ICN/CCN with QoS (Quality of Service), which is designed to control the flow of data according to the priorities of the data over the network, to enable applications to access the information required for train operation without paying attention to transmission paths or information locations.

Studies are being conducted on security features and also data transmission methods capable of enabling continued train operation while maintaining safety in emergencies, both required for the information combination network for train operation to have, by referring to IEC 62280, the international standard on safety-related communication, and the IEC 27000 and IEC 62443 series of international standards on information security.

By the end of FY2016, the basic data format and communication protocol were defined as RITP (Railway Information Transfer Protocol) and simulation verified that certain functions operated as designed (Fig. 1). Plans for FY2019 include installing into a prototypical network a function that automatically measures transmission media and selects the appropriate path and some of the security check functions, building the prototype on the test track at RTRI and verifying the functions. From FY2020 onwards, the prototype will be used on the test track in actual day-to-day operations to verify its practicality for commercial use while a proposal will be made for the standardization of the protocol.
2.2 Utilization of the fifth-generation mobile communications system

The information network based on the RITP described above requires a transmission medium, or a communication system, to receive and send information. To fulfill the requirement, general-purpose mobile telecommunications technology, which has been making rapid advances in reliability and transmission rate, would be considered for possible adoption in addition to the existing communication networks railway operators have built.

The fifth-generation mobile communications system (5G), which was partially available from FY2019, is expected to offer a transmission capacity of 10 Gbps, more than 100 times the transmission capacity of the current LTE mobile networks. The concept behind 5G is to connect every smart thing to the network and to change data transmission from one designed to transmit information for people to use, to one designed to transmit information for both people and smart things to use. 5G is expected to accommodate not just applications that transmit large volumes of data but applications that handle small data but use numerous sensors and terminals like those for the IoT.

For the railway sector, 5G is expected to offer high-capacity transmission of images and other data between the ground facilities and vehicles and low-delay transmission of control data, and enable the use of monitoring systems with many field devices and sensors (Fig. 2). Upon 5G becoming available, research and development efforts will be launched for methods to build an information network based on the RITP described earlier, complete with security features required for railways.

RTRI has been pursuing research and development of a high-capacity, highly reliable radio communication network for railway applications that has seamless links between a number of radio communication media (Fig. 3). The use of millimeter radio waves is planned for the 5G segment of the network. For this, RTRI is planning to use achievements from past studies, such as communication line design techniques for a ground-to-train communication system using millimeter radio waves and related measurement and evaluation of radio wave propagation and simulation techniques.

2.3 Use of millimeter waves and other radio frequency ranges

One of the key challenges in advancing the utilization of ICT for railways is how to secure radio frequencies, which can be considered to be a resource, for transmitting information. Data exchange between running trains and ground facilities requires not just conventional low-capacity, highly reliable transmission but increasingly transmission capable of handling large volumes of data such as images and sensing data. Currently, of the radio spectrum, railway operators mostly use radio waves in the UHF frequency range (300 MHz to 3 GHz). However, the UHF frequency range is also used for many other purposes such as mobile telephony, wireless LAN, radio communication for businesses, broadcasting and other applications, making the frequency band extremely congested. As such, the possibility of using the millimeter wave range is being studied, which is wider than the UHF band and offers numerous channels. With the availability of low-cost, high-performance semiconductor elements and the advances in RoF (Radio over Fiber), a technique to transmit electric signals at radio frequencies directly on optical fibers, it is possible to build a low-cost, ground-to-train communication system using millimeter radio waves [3]. A ground-to-train communication system using millimeter radio waves, once available for commercial application, is expected to improve driver task efficiency, passenger services and enable the introduction of new traffic control methods. Furthermore, coupled with 5G and other broadband networks and general-purpose radio communication technology that were mentioned earlier, millimeter radio waves are expected to be actively used as tools and means to realize safer and more reliable train operation. At the same time, however, to successfully send information whenever needed for train operation and control and other purposes that demand high levels of reliability and safety, interference immunity and transmission quality must be maintained.

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3. Autonomous train operation and control

3.1 What is autonomous?

Autonomous train operation and control means that each train controls the relevant points machines and level crossings to set its course, based on information about preceding, following and other trains in the vicinity, wayside and permanent way conditions and the status of points machines, crossings and other facilities, and determines the appropriate target stopping points and running pattern while monitoring the safety of the permanent way, enabling it to run without external control. Once automatic train operations are already in place, control systems on the ground control point machines based on the locations of the trains and send speed signals and other instructions to each train, allowing the trains to run according to the given patterns. Autonomous train operation and control not only has these automatic train operation attributes but also allows each train to control the relevant points machines and level crossings and determines the target stopping points while monitoring safety along the prescribed route.

3.2 Features of the autonomous train operation and control system

To achieve autonomous train operation and control, relevant information needs to be loaded on the train, which also needs to be capable of determining the section and speed that allow safe running. For these reasons, a route database, which includes data about the location of stations, points machines, level crossings and other facilities, and the planning timetable are loaded onto the train. Based on traffic information including the locations of the preceding and following trains and their arrival and departure times at/from the stations and passenger flow data, the train predicts the operation ahead and, if necessary, adjusts the timetable (Fig. 4 (1)). Based on the revised timetable, the train directly controls the points machines and level crossings and sets the route (Fig. 4 (2)). While monitoring the permanent way and its vehicles for any abnormality (Fig. 4 (3)) and based on disaster prevention and maintenance data, the train determines the target stop point (Fig. 4 (4)) and generates the running pattern that enables the train to stop at the target point (Fig. 4 (5)).

If the disaster prevention and/or maintenance data indicate the need to slow down in a certain section, the train generates the appropriate running pattern accordingly.

In autonomous train operation and control, the train repeats steps (1) to (5) in Fig. 4 on a real-time basis while running.

A pillar of the autonomous train operation and control system is the algorithm for determining the target stopping point based on a range of relevant information, which is Step (4) in Fig. 4. The algorithm needs to be designed in such a way that it is capable of resolving possible abnormalities. If, however, an unanticipated event occurs, the system alone cannot resolve it. To deal with such unexpected events, the system may need to include a feature whereby possible solutions are proposed to the controller and crew based on a range of conditions data collected on the train for coordinated man-system corrective actions.

Fig. 4  Autonomous train operation and control system functions and information flows

In a section with many branch lines and train types and consequently complex operation patterns, a deadlock may occur in which trains obstruct each other’s routes or where one train prevents other trains from operating normally. To address these situations, it may be necessary to add an oversight system, which collates a range of information including section-wide train movements and passenger flows, real-time hazard maps and maintenance planned and in progress and provides the train with summarized points to consider when determining its route. (Fig. 5).

Fig. 5  Autonomous system configuration

3.3 Benefits of autonomous train operation and control

The benefits of autonomous train operation and control include: less ground facilities, cables for train control and other components leading to reduction in maintenance and running costs and the risk of failures; reduced workload on controllers and crewmembers contributing to reduced human error; and early resumption of train operation after an abnormality contributing to improved convenience and efficiency. Each train can swiftly detect abnormalities based on detailed data around and confirm safety soon after the abnormality is resolved, enabling an early decision at the site to resume operation. When an abnormality arises where there a number of trains, forcing those trains to slow down or stop, other trains outside the affected section can continue to operate safely. If, for example, a train detects an obstruction on the track and stops, as soon as the obstruction is removed and it is safe to run again, the train can recognize that and resume running while checking for safety.

In the event of a slope failure or other events forcing train services to be suspended for an extended period of
time, the train can collate information and decide to revise the operation plans and return to the previous station accordingly while exchanging information with the following trains, allowing the passengers to quickly leave the train there for safety.

In the autonomous train operation and control system, safety-related functions are concentrated on the train. In the event that a train cannot communicate with the ground facilities, it should still be capable of continuing operation as long as safety is maintained using the onboard functions such as forward monitoring.

The autonomous system should be capable of offering safe and secure transport service by coordinating with the staff involved in train operation. It is believed that the digitization of railway transport services can be achieved in a broader sense if in addition to railway user behavior, their desires and satisfaction levels are also fed back to the system.

3.4 Benefits of autonomous train operation and control

The radio train control system, which is already in place for commercial use, would be used as the basis in the steps for realizing the autonomous system. Currently, RTRI is developing a new train control system, an advanced form of the radio train control system, that combines traffic control with train control via an information network. The new train operation and control system would be the same as the conventional radio train control system in terms of ground-train sharing of functions and data transmission but the control processing for all trains, which is currently performed on the ground, would be transferred to individual trains. A staged development process for the autonomous system has been envisioned where an algorithm to adjust departure and arrival times and target stop points based on data including on disaster prevention, passenger flows and permanent way monitoring would be loaded onto the train (Fig. 6). Permanent way monitoring technology and level crossing monitoring and control technology have been presented in the relevant issues of RTRI REPORT. Those techniques could be further refined so that they can be used as underlying technologies for autonomous systems.

While keeping in mind the formulation process of the next RTRI master plan for FY2020 onwards, the development plans for the autonomous train operation and control system will be discussed further to make specific proposals including for research and development topics and timelines.

4. Conclusion

ICT, which has been thrown into the spotlight by the rapid advances in information network technology, is not just an essential tool for the railways to remain sustainable, but is also a potential driver for further growth of the railways. That said, ICT cannot be fully utilized by simply adopting the technologies already available. Appropriate technologies must be selected based on what is required for the safety and reliability of railways. The selected technologies often need to be customized to achieve the required functions and performance. Among the issues that lie ahead, criteria and guidelines for selecting appropriate technologies and methods for evaluating the effect of their adoption would need to be established. Information networks must be made secure enough against cyberattacks. This is especially true for control systems that directly affect safety. An appropriate approach to making control systems robust under cyberattacks while maintaining safety must be clarified and specific control methods established.

The concept of autonomous systems has been around for some time. However, there are still difficult technical hurdles to overcome. While rapidly advancing ICT is helping to raise the possibility of realizing autonomous systems, these obstacles include permanent way monitoring, secure transmission of information and methods for coordinated control of ground facilities by trains based on a range of information.

RTRI will continue its research and development efforts with unwavering resolve in cooperation with other railway operators and research institutes with advanced technologies, manufacturers and universities, to achieve outcomes that will contribute to the maintenance and further development of the railways.

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