Development and Deployment of Track Inspection Technique on In-service Rolling Stock

The periodic inspection and maintenance of their infrastructure by railway operators is essential to ensuring safe and comfortable railway transportation. For more than 50 years, Hitachi has been contributing to maintaining the safety of railway transportation through its work on the development and commercialization of inspection devices that use optics and sensors for the measurement of railway infrastructure. Working with the Railway Technical Research Institute as well as railway operators, Hitachi over recent years has developed track geometry (rail) inspection systems that are small enough to mount on the bogies or undersides of rolling stock during normal operation, and also systems for transmitting measurement data to the cloud or other trackside systems for storage in real time. Operation of this technology has already commenced on a large number of railway lines where the fine-grained measurement data so collected is being put to use for track maintenance planning, thereby contributing to improvements in maintenance efficiency in anticipation of a worrying aging of the population and a low birthrate as well as the looming retirement of large numbers of experienced staff. Plans for the future include extending the installation of inspection systems on operating rolling stock beyond track inspection to include, for example, systems for the inspection of overhead wires.

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1. Introduction

The periodic inspection and ongoing maintenance of railway infrastructure is an essential task for railway operators that supports safe and reliable railway transportation. For more than 50 years since the 1960s, Hitachi has been contributing to ensuring the safety of railway transportation through its work on the technical development and commercialization of inspection for track geometry, overhead wires, and the track wayside using sensors and optics technology acquired from a variety of fields, such as lasers and light-emitting diodes (LEDs).

Improving maintenance productivity is an urgent task for the railway industry, where the challenges include what to do about labor shortages due to the aging population and low birthrate, and the retirement of large numbers of experienced staff with expertise in areas like maintenance planning. As is happening in many areas of social infrastructure, parts have been

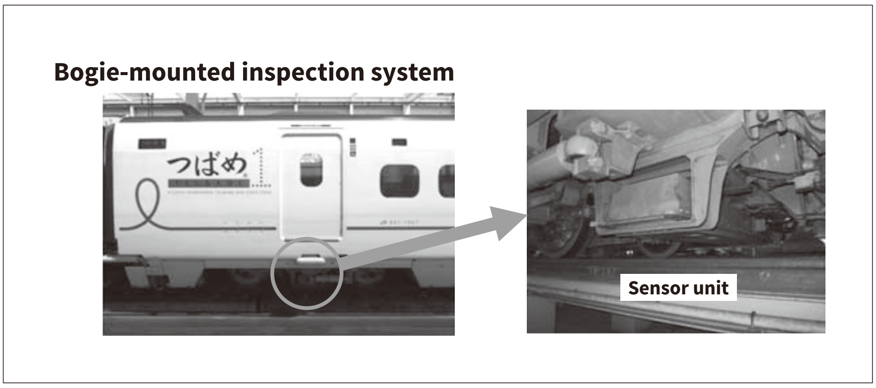


Figure 1 — Onboard Track Inspection System for Kyushu Railway Company

The first onboard track inspection system used the inertial mid-chord offset method and was mounted on in-service Shinkansen rolling stock.

maintained using time-based maintenance (TBM), which includes the replacement of parts based on time intervals, etc. However, currently, a shift toward condition-based maintenance (CBM), which includes diagnosis of the extent of infrastructure deterioration and outcome-based replacement of parts, etc. is under active investigation.

The onboard (able to be mounted on in-service rolling stock) track geometry (rail) inspection system described in this article represents a major change away from past practice for inspection and is contributing to improvements in the efficiency of the sequence of steps in railway infrastructure maintenance that runs from inspection through to the actual maintenance, and to the provision of comfortable railway transportation that is safe and reliable.

This article presents an overview of the onboard track inspection system and describes an Internet of Things (IoT) solution for the management of track geometry measurements as well as future activities.

2. Background and History of System Development

The five parameters that railway operators typically use for measuring and managing track displacement are offset, alignment, gauge, cross-level, and twist. If the measured value of one of these parameters exceeds its limit (with each railway operator setting their own values for these limits), the response is to perform repairs or other maintenance as needed to prevent the problem from affecting operation. The accuracy requirements for track geometry (rail) inspection systems are defined in terms of repeatability (the standard deviation in the values obtained by two separate measurements of the same parameter). Typical repeatability values for offset, alignment, and gauge are 0.5 mm and 0.3 mm (for conventional and Shinkansen railway lines respectively), and similarly for cross-level and twist are 1.0 mm and 0.5 mm.

The past practice for offset and alignment measurement using a dedicated inspection vehicle involved measuring the distance from the carbody to the rails at multiple points and using these values to calculate the deviation. This is called the "differential method," and two such dedicated inspection vehicles that use the technique are the Doctor Yellow used on the Tokaido and Sanyo Shinkansen and the East-i used on the Tohoku Shinkansen and elsewhere.

The differential method requires a dedicated inspection vehicle because of the variety of different inspection equipment used, including measurement sensors of various types located under the vehicle floor, a control unit inside the train for performing data analysis, and recording and display systems. Accordingly, being able to mount the inspection system on an in-service train offers considerable scope for cost savings because it avoids the need to manufacture a dedicated inspection vehicle.

In collaboration with the Railway Technical Research Institute (RTRI), Hitachi in 1995 set about developing a new track geometry measurement technique called the "inertial mid-chord offset method" as an alternative to the differential method. This included field trials on the test track at RTRI and on the lines used by railway operators, with a prototype being completed in 1999. The first onboard track inspection system to enter commercial use was installed on Shinkansen rolling stock operated by Kyushu Railway Company in 2009 (see **Figure 1**).

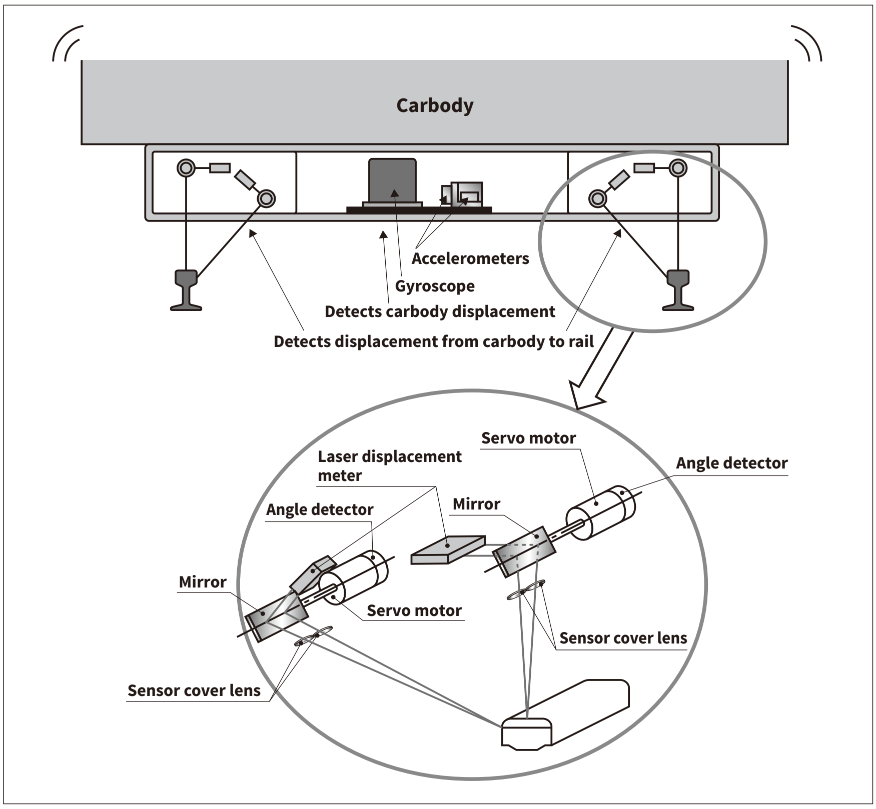


Figure 2 — Diagram of Onboard Track Inspection System
The system components include accelerometers, gyrosensors, and laser displacement meters.

3. System Overview

The onboard track inspection system uses the inertial mid-chord offset method devised by RTRI to measure track displacement. This works on the physics principle that displacement can be calculated by twice-integrating acceleration. As shown in **Figure 2**, the sensors used by the system are limited to those needed for measurement, namely accelerometers, a gyroscope, and laser displacement meters. The track displacement measurement is calculated from the absolute spatial location of the device performing the measurement (obtained using built-in accelerometers and a gyroscope) and the locations of the left and right rails relative to the device (obtained using laser displacement meters).

Measurement using the laser displacement meters of the locations of the rails relative to the device works by using a laser beam to track the predetermined positions of the top and side of the rail, without being influenced by vibration and other interference. This tracking function performs real-time control, including automatically identifying and ignoring objects other than the rails if they intrude into the range being scanned by the laser displacement meter. As this is performed 1,000 times a second, the laser beam is able to continuously track the rail surface even when the train is travelling at high speed.

As the inertial mid-chord offset method keeps track of the absolute spatial location of the device, it establishes a virtual reference line on the rail and can obtain the measurement as if it were calculating using the differential method. Accordingly, unlike the differential method as shown in **Figure 3**, it does not need to measure a number of points simultaneously and can perform track geometry measurement from a single sensor installation. This is what allows the inspection system to be kept small and light. It also means that the inspection equipment can be installed on the bogie or under the vehicle floor without exceeding vehicle or track clearance limits, while still providing the same track displacement measurements as a dedicated inspection vehicle.

Unlike the case when using a dedicated inspection vehicle, however, there is no opportunity for a human operator to be onboard when track inspection is done from in-service rolling stock. Instead, inspection needs to be done without human intervention.

Figure 3 — Differential Method and Inertial Mid-chord Offset Method

The new inertial mid-chord offset method can measure rail displacement using a single sensor unit.

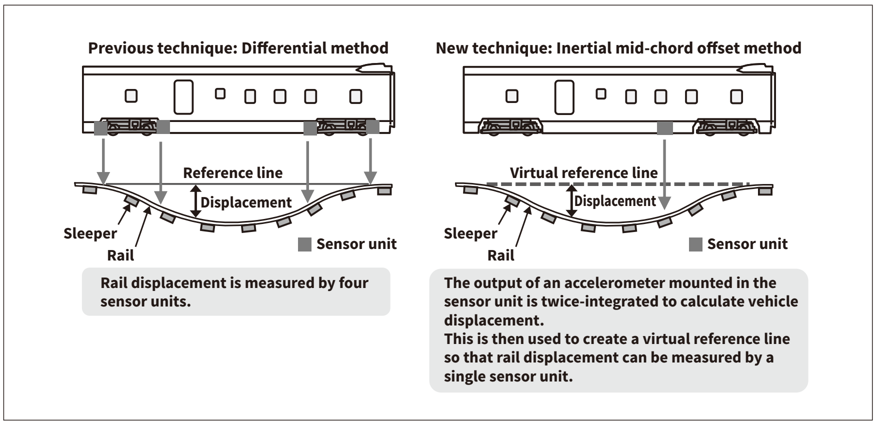
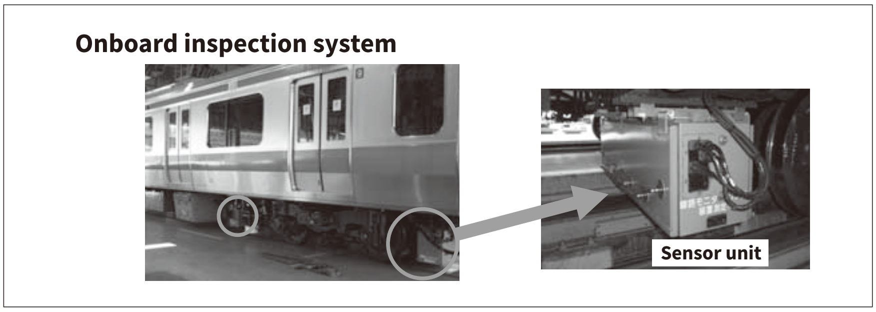


Figure 4 — Onboard Track Inspection System for East Japan Railway Company

The system is currently in use on a number of lines.



Accordingly, Hitachi looked into three of the challenges that this poses: (1) When to start and stop track geometry measurement, (2) Deciding where to perform measurements, and (3) Transmission to the data center system for track geometry measurements.

To determine when to start and stop track geometry measurement, it was decided to use the data depots (devices on the track wayside) that provide track location information. East Japan Railway Company installed data depots that recorded the locations of where it wanted measurement to start and end. The system was then implemented such that track geometry measurement was able to start or stop automatically when the train passed over a data depot. To determine where to perform measurements, the data depots that were already installed on most of the track for the dedicated inspection vehicles were used.

Meanwhile, a public data network was used for wireless transmission of track geometry measurements made by the onboard system to the data center system. This provides the ability to transmit track geometry measurements to designated servers in real time, facilitating maintenance in ways that include remote operation of the onboard system or installation of software updates, and the sending of automatic notifications to the people concerned when measured values exceed the limits. Along with the monitoring of track condition in real time, these functions reduce the number of times staff have to go out into the field and provide ways of dealing efficiently with any problems that arise.

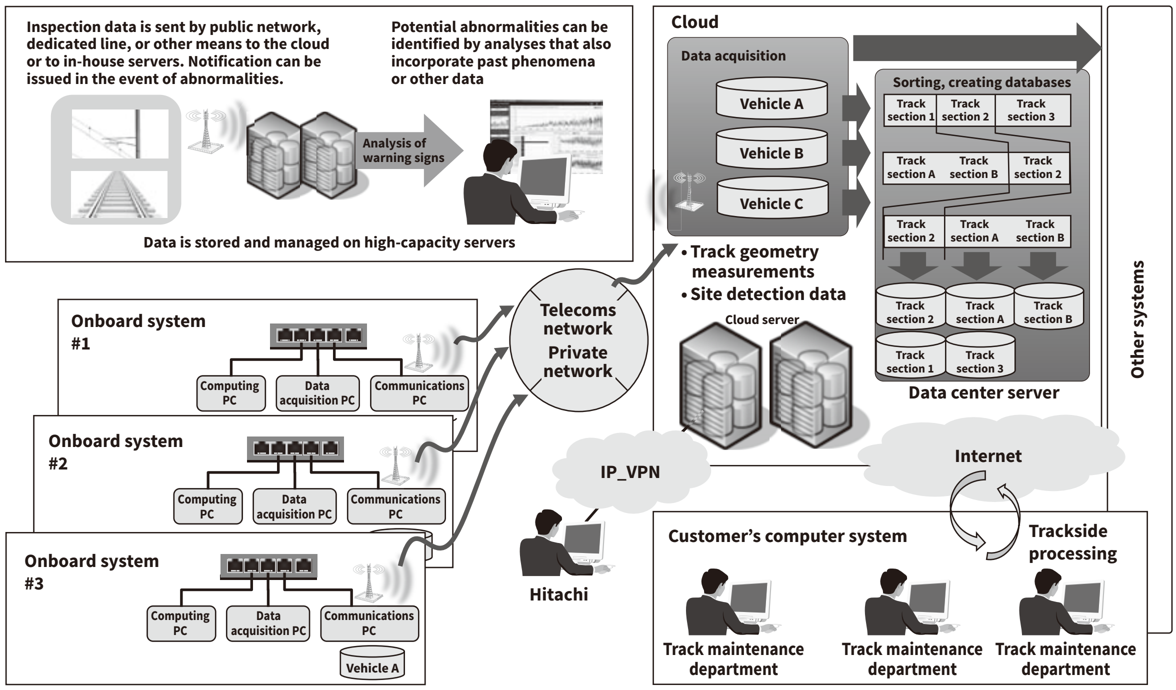
East Japan Railway Company embarked on the large-scale rollout of onboard track inspection systems on its major lines in 2015 and is using the systems in its routine operations. Hitachi has also been striving to make ongoing improvements, taking on issues that have arisen as the systems have been adopted for a variety of different railways and on a variety of different rolling stock, including accuracy at low speeds, individual measurement error, system diagnostics, robustness, and operator-less measurement.

Figure 4 shows an onboard track inspection system in use by East Japan Railway Company.

4. IoT Solution for Management of Track Geometry Measurements

A number of issues arise from the greater number of onboard track inspection systems in use, namely the data center system for each device, the higher volume

Figure 5 — Management System for Track Geometry Measurements
The system utilizes an IoT solution.



IoT: Internet of Things PC: personal computer IP: internet protocol VPN: virtual private network

of data, and the increasing complexity of device operation. Hitachi has responded by coming up with two IoT solutions.

The first is a cloud solution that combines the data center systems. The solution is already in use supporting data management and analysis, providing a system for storing data on a private cloud and making it available for viewing, extraction, and analysis. **Figure 5** shows a diagram of the system. The track geometry measurements sent by each inspection device in real time are stored on the receiving servers in the cloud in an integrated database that in turn provides users with access to track condition information for each section of the railway line. Similarly, analysis of the fine-grained data collected by the system can provide a detailed view of changes in track condition, thereby enabling the formulation of more efficient track maintenance work plans.

The second solution is a service that performs continuous monitoring of the inspection system and its components. It connects to existing maintenance communication links and performs continuous condition monitoring as well as remote system operation, checking, and upgrading. Along with the monitoring and analysis of inspection data, this also provides users with efficient maintenance of the inspection system itself, with potential for reducing maintenance workloads. **Figure 6** shows a system diagram of the cloud service currently used by East Japan Railway Company.

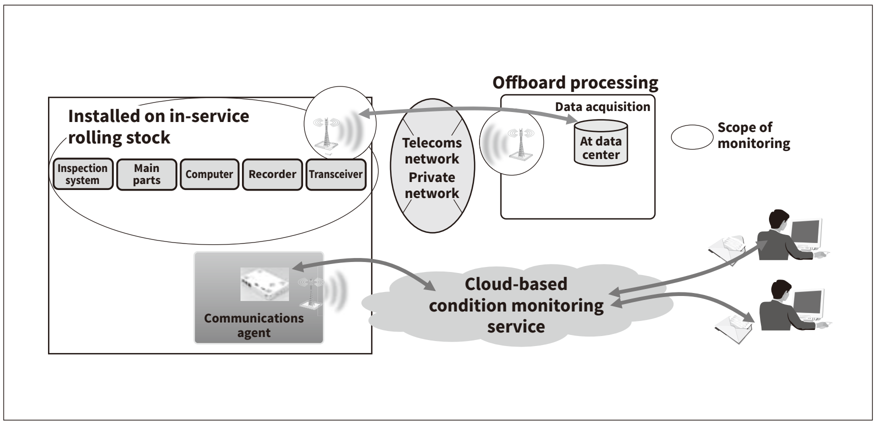
Hitachi is currently working on a maintenance planning support service that will help prepare maintenance plans for maintaining the systems in an efficient and waste-free manner, utilizing the latest techniques such as the use of big data analytics for warning sign and trend detection. Hitachi also intends to develop cloud plug-in functions, with its objective being a data lake that is able to integrate all of the different types of measurement it is working on.

5. Future Developments

Along with use of the onboard track inspection system described in this article for track displacement monitoring, other inspection and maintenance

Figure 6 — Management System for Onboard Track Inspection System

The capabilities of the system include equipment condition monitoring and remote operation, inspection, and system upgrades.



work essential to the safety of railway transportation includes that for overhead wires and other electrical infrastructure, track infrastructure and materials, and potential obstacles such as structures or trees located close to the track. As most of this work is handled using traditional TBM, there is a need to switch to outcome-based maintenance. Hitachi's plans include drawing on experience gained from the development of the onboard track inspection system to install other such systems (such as those for overhead wires) on in-service rolling stock.

6. Conclusions

This article has presented an overview of the history of system development for onboard track inspection at Hitachi, the technologies used, and how the new IoT is used for system operation. Hitachi intends, by supplying better and more innovative products, to contribute to the progress not only of railways but of all forms of social infrastructure by helping achieve efficient maintenance and comfortable railway transportation that is also safe and reliable.

Acknowledgments

The authors would also like to take this opportunity to express their deep thanks to everyone who offered their advice and assistance to this work.

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