

Applying New Technologies to Railways

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Takamasa HAYASAKA
General Manager,
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Message from Managing Editor

To ensure railway safety and sustainable development, it is essential to accurately monitor the ever-changing conditions of railway infrastructure and wayside equipment and use the resulting information to support timely decision-making. As countries around the world face common challenges, including increasingly severe weather-related disasters, aging railway infrastructure, and shortages of maintenance personnel, the need for effective monitoring technologies and data utilization has become more pressing than ever.

The latest issue, Ascent No. 19, presents RTRI's research and development efforts under the theme "Monitoring and Visualization Technologies for Railway Infrastructure." This issue features a method for identifying debris-flow-prone mountain streams using high-resolution elevation data; a seismic observation method based on Distributed Acoustic Sensing (DAS), which uses existing telecommunication optical fiber cables installed along railway lines as sensors; and technologies that apply image processing and AI to analyze forward-view images captured by cameras mounted on trains for evaluating the condition of track components and wayside equipment.

These studies share a common objective: to efficiently acquire detailed, high-density data on the condition of railway infrastructure across extensive areas and to apply these data to disaster preparedness and more efficient maintenance planning and management. Another notable feature is their effective use of existing facilities, publicly available data, and commercially available equipment. These approaches are expected to reduce the workload associated with maintenance and contribute to improving the safety and reliability of railway systems.

By introducing these research and development efforts, we hope this issue will deepen readers' understanding of technologies that contribute to further enhancing railway safety and reliability. We also hope that it will provide new insights and foster collaboration to address the challenges facing railways around the world.

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Front cover photo: Autumn leaves in the courtyard of the Railway Technical Research Institute

Extraction of Debris-Flow-Prone Mountain Streams Using High-Resolution Elevation Data



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* Airborne laser scanning

Airborne laser scanning is a method for measuring the distance between an aircraft and the ground surface based on the time required for laser light emitted from a laser scanner mounted on the aircraft to travel to the ground, be reflected, and return to the scanner. By combining this measurement with GNSS (Global Navigation Satellite System) and IMU (Inertial Measurement Unit), which accurately determine the position and attitude of the aircraft, the elevation of the ground surface can be obtained. This enables the creation of accurate, high-resolution DEMs.

Introduction

Railway tracks in Japan cross numerous mountain streams. When debris-flows occur in such streams during or after intense rainfall (e.g., *Figure 1*¹⁾), they can damage or deform tracks and other railway structures and, in some cases, result in prolonged service suspensions during recovery work. Ideally, preventing such damage requires detailed field surveys of individual streams, followed by assessments of the likelihood and potential scale of debris-flow events and, where necessary, the implementation of protective measures. In practice, however, the large number of stream crossings makes it essential to first narrow down and prioritize candidate sites through desk-based screening.

The Geospatial Information Authority of Japan (GSI), an extraordinary organization of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), has made high-resolution elevation data covering Japan publicly available²⁾. These data can be used to generate detailed topographic maps and readily perform analyses to quantitatively evaluate landform characteristics, such as slope gradients and the area of flat ground.

Against this background, RTRI has developed a desk-based method that utilizes high-resolution elevation data provided by GSI to extract mountain streams along railway tracks that are potentially susceptible to debris-flow hazards.

High-resolution elevation data developed by GSI

Elevation data for the ground surface are commonly referred to as a digital elevation model (DEM). In Japan, a DEM with 50-m meshes was first published in 1993³⁾, and nationwide coverage was achieved by 1999. This DEM was generated by extracting elevation values at approximately 50-m intervals from 1:25,000 topographic maps (corresponding to about 2-mm intervals on the maps).

Subsequently, a DEM with 5-m meshes was published in 2003⁴⁾. Development initially focused on urban areas and gradually expanded outward, currently, most areas along railway tracks are covered, except for some mountainous regions. The currently available 5-m mesh DEM has been generated mainly using airborne laser scanning*. Compared with the conventional 50-m mesh DEM, the 5-m mesh DEM offers significantly improved resolution. This higher resolution enables the detection of fine surface features, such as landforms indicative of past debris flows. Taking advantage of this capability, the developed method uses the 5-m mesh DEM.

Method for extracting debris-flow-prone mountain streams

The developed method uses the 5-m mesh DEM published by GSI to identify de-



Figure 1 Debris-flow event that occurred near Ryugamizu Station on the Nippo Main Line in August 1993¹⁾ (trimmed)

bris-flow-prone mountain streams from two perspectives (*Figure 2*): (1) the susceptibility of mountain streams to debris-flow events (hazard level assessment) and (2) the degree of impact on railway tracks in the event of a debris flow (impact level assessment). A key feature of this method is that it relies solely on publicly available

data as inputs, enabling extraction of debris-flow-prone mountain streams without conducting any preliminary field surveys.

Hazard level assessment: susceptibility of mountain streams to debris-flow events

The hazard level assessment (*Figure 3*)

first assesses the susceptibility of mountain streams to debris-flow events by identifying the presence or absence of landforms called alluvial cones on maps generated from the 5-m mesh DEM. An alluvial cone is a fan-shaped landform found at the outlet of a mountain stream and is considered to have formed through past debris flows.

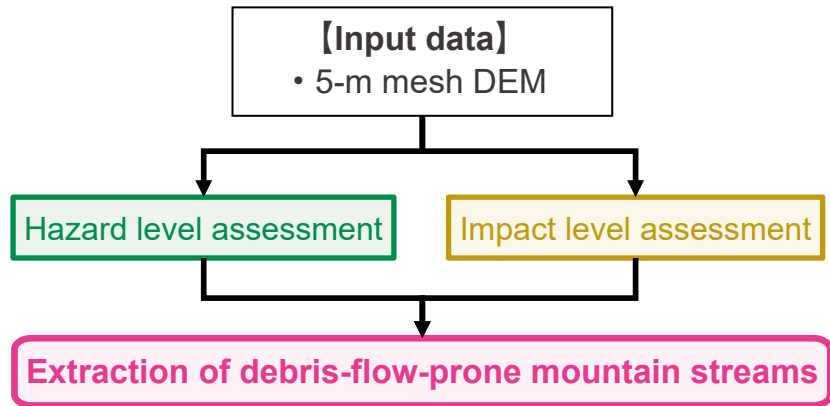


Figure 2 Method for extracting debris-flow-prone mountain streams

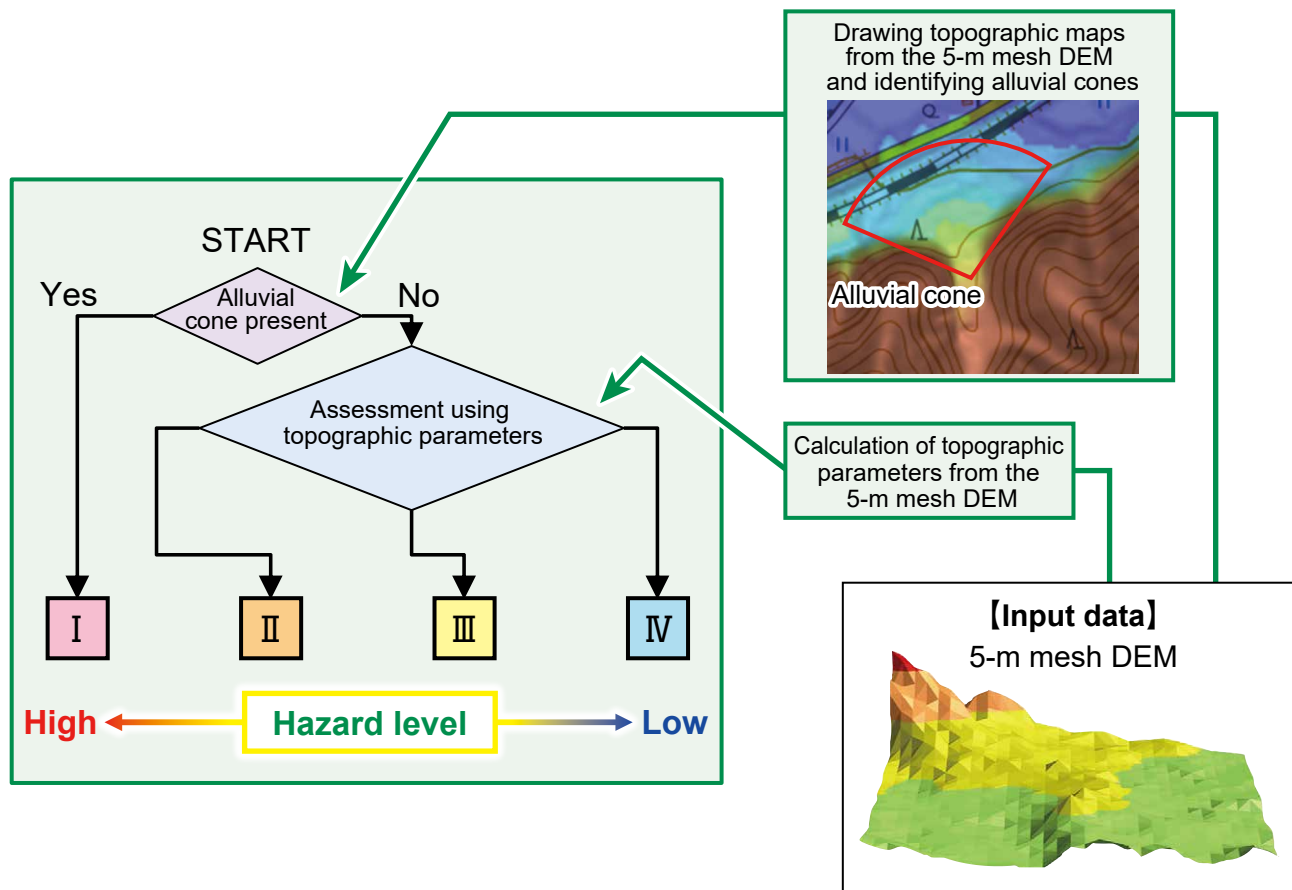
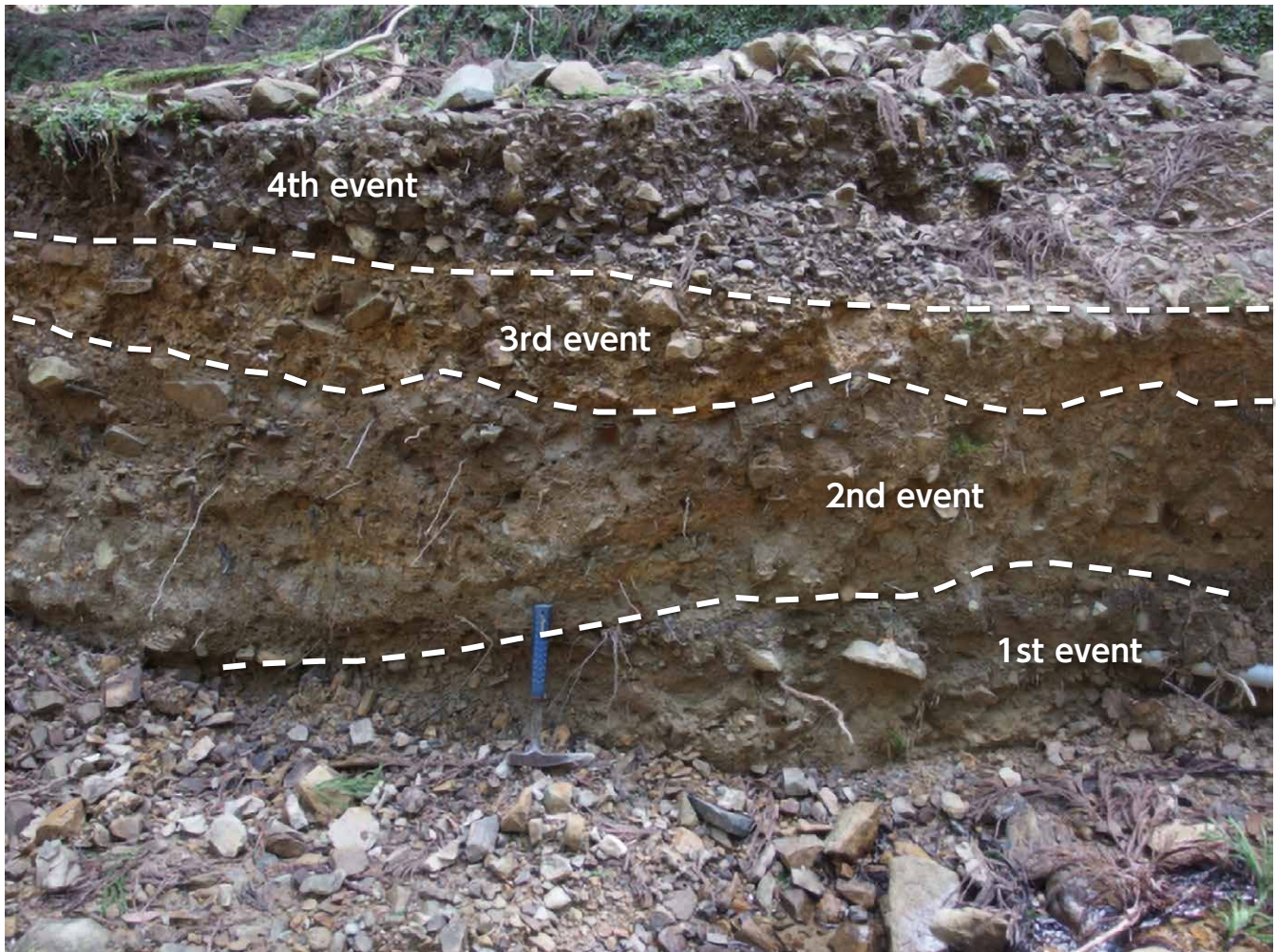


Figure 3 Method for hazard level assessment

When no alluvial cone is identified, the hazard level is further classified into three categories using indices representing landform characteristics calculated from the DEM

(hereinafter referred to as "topographic parameters"). These topographic parameters include various indicators such as those related to slope gradient and valley density.

After examining the relationship between these topographic parameters and past debris-flow events, those showing strong correlations are selected for hazard level



The numbers indicate the order of debris-flow events inferred from the condition of the deposits.

Figure 4 Cross-section of deposits at a stream outlet

assessment.

A key feature of this assessment method is that the identification of an alluvial cone—evidence of past debris flows—results in a high hazard level classification. This reflects the tendency of debris flows to recur in the same mountain stream. Cross-sections of deposits at stream outlets (*Figure 4*) reveal evidence of multiple debris-flow events.

As described above, the hazard level is assessed in four categories using only the 5-m mesh DEM.

Impact level assessment: degree of impact on railway tracks in the event of debris flow

The impact level assessment (*Figure 5*) evaluates the degree of impact on railway tracks in the event of a debris flow based on the estimated volume of sediment generated during the debris-flow event and the estimated volume that would be retained within the stream channel before reaching the track.

To estimate the volume of sediment generated during debris-flow events,

topographic parameters calculated from the 5-m mesh DEM are also utilized. Topographic parameters that are correlated with sediment discharge volumes from past debris-flow events are selected, and these parameters are then used to estimate the generated sediment volume.

Part of the generated sediment is deposited on gently sloping areas within the stream channel, and the remaining sediment may reach the railway track. Therefore, the volume of sediment retained within the stream channel before reaching the railway

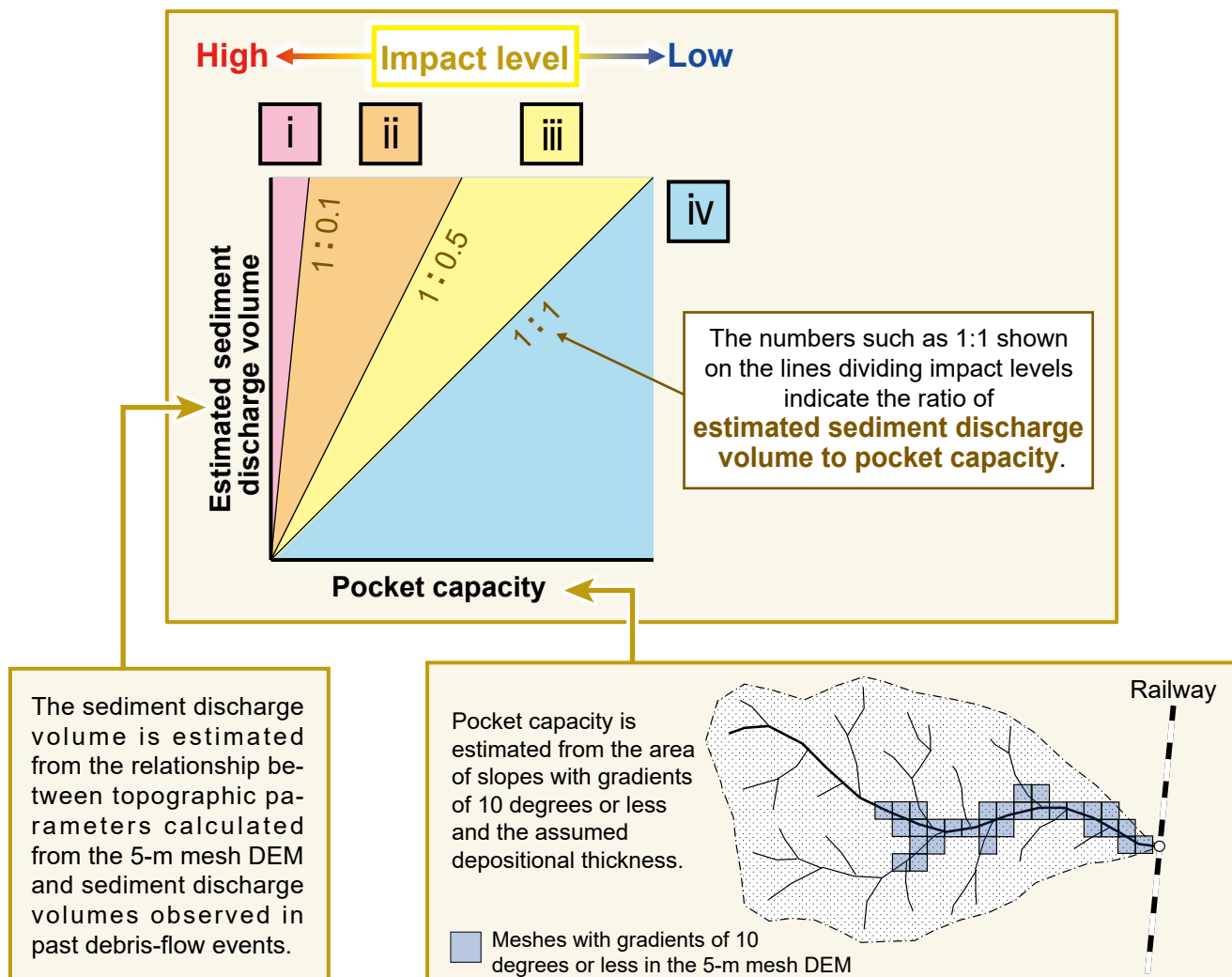


Figure 5 Method for impact level assessment

track (hereinafter referred to as "pocket capacity") is estimated from the area of slopes with gradients of 10 degrees or less and an assumed depositional thickness. The area of slopes with gradients of 10 degrees or less can be calculated from the DEM, and the assumed depositional thickness is set at 0.1 m based on field survey results.

Using the estimated volume of generated sediment and the pocket capacity obtained as described above, the impact level is assessed in four categories, with a higher impact level assigned when the estimated

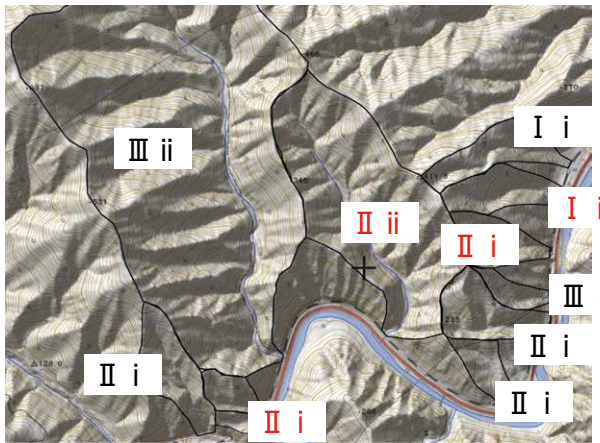
sediment volume exceeds the pocket capacity by a greater amount.

Extraction of debris-flow-prone mountain streams

Figure 6 shows the results obtained by combining the hazard level of mountain streams with the impact level for railway tracks in the event of a debris flow. For each mountain stream, the hazard level is classified from I to IV and the impact level from i to iv, with their combinations shown in Figure 6. Among these, the results shown

in red represent mountain streams where debris flows have actually occurred.

Table 1 shows the results obtained by applying this analysis to an entire railway section and summarizing the resulting hit rates. Here, the hit rate is defined as the percentage of mountain streams where debris flows have actually occurred. The results indicate that actual debris-flow-events fall within the range of hazard levels I–II and impact levels i–iii, indicating that this method can effectively identify debris-flow-prone mountain streams.



Red text : Mountain streams where debris flows have occurred

Black text : Mountain streams where debris flows have not occurred

Figure 6 Example application of the method for extracting debris-flow-prone mountain streams

Table 1 Verification example of the method for extracting debris-flow-prone mountain streams

Hit rate		Hazard level			
		I	II	III	IV
Impact level	i	25%	43%	0%	0%
	ii	50%	60%	0%	0%
	iii	50%	100%	0%	0%
	iv	0%	0%	0%	0%

*Hit rate = number of mountain streams with debris-flow events / number of mountain streams in each category

Conclusions

This report presented a method for extracting debris-flow-prone mountain streams by utilizing high-resolution DEM data published by GSI. Since fiscal year 2023, the publication of 1-m mesh DEM data has also been in progress. In anticipation of these government data development plans, RTRI will explore potential applications of the new data in railway fields such as hazard prevention, enabling their effective use as soon as they become available to further enhance the safety and reliability of railway systems.

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*1 Interrogator Unit (IU)

The DAS observation device; a transceiver for optical signals. Connected to one end of an optical fiber cable, it emits light pulses into the optical fiber cable and receives the backscattered light reflected within the optical fiber cable, from which strain is calculated.

*2 STA/LTA

The STA/LTA (short-term average/long-term average) method detects the onset of wave-forms characterized by abrupt amplitude changes—such as P-wave arrivals—by computing the ratio of the average amplitude within a short-term window to that within a long-term window. In the present study, the amplitude ratio was computed using a short-term window of 0.5 s and a long-term window of 10 s.

*3 hypomh

A method for determining hypocenter location by maximum likelihood estimation using P-wave arrival times obtained at multiple observation points. Maximum likelihood estimation is an approach in which the model parameters (here, the hypocenter) are estimated so as to maximize the probability (likelihood) of obtaining the observed data.

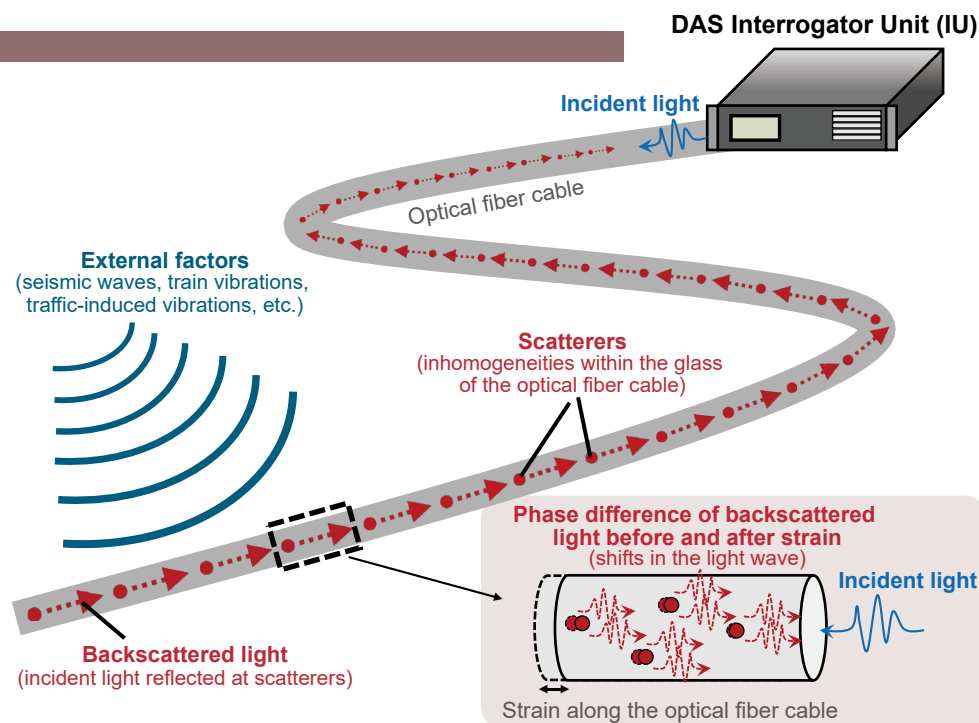


Figure 1 Conceptual diagram of the DAS measurement principle

Construction of a Railway Seismic Observation Network Utilizing Optical Fiber Sensing Technology: Distributed Acoustic Sensing (DAS)

Introduction

In recent years, the application of Distributed Acoustic Sensing (DAS)—a technology that uses optical fiber cables as sensors rather than solely as data communication media—has advanced rapidly. This technology analyzes changes in the optical phase (i.e., shifts in the light wave)

of backscattered light generated at inhomogeneities (scatterers) within the glass of the optical fiber in response to incident light pulses emitted by an interrogator unit (IU^{*1}) connected to one end of a single-core fiber, thereby enabling real-time, high-density measurement of strain along the optical fiber at intervals of a few meters (Figure 1)¹⁾²⁾.

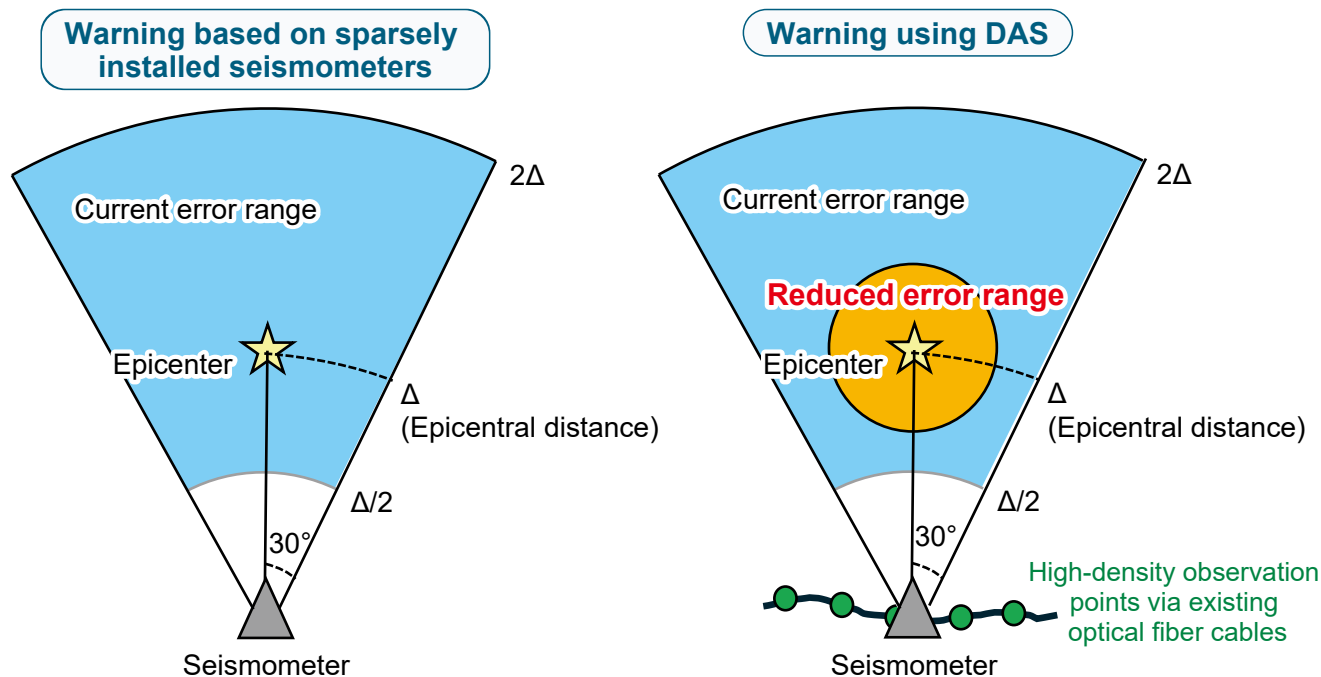


Figure 2 Comparison of error ranges in earthquake early warning between the conventional method (seismometers) and DAS

Optical fiber cables for telecommunications are commonly installed along railway lines, and by connecting an IU to such a single-core fiber, DAS-based measurements can be conducted along the railway line. Moreover, DAS-based seismic observation has been extensively tested at numerous sites on land and on the seafloor, demonstrating that a wide variety of seismic waveforms, including those from local earthquakes and teleseismic events can be recorded using optical fiber cables^{3/4)}.

The current algorithm for seismic parameter estimation used in earthquake early warning (EEW) for Shinkansen lines estimates parameters such as epicentral distance ($C-\Delta$ method) and epicentral azimuth (principal component analysis) from single-station data. While this approach enables warnings to be issued more rapidly than methods based on multi-station data (with a minimum lead time of 1 s), the

estimated epicentral distances are subject to uncertainties up to a factor of 2, and the estimated epicentral azimuth to uncertainties of $\pm 30^\circ$ (Figure 2). In contrast, because DAS can acquire data at intervals of a few meters, it is possible to detect seismic waves at multiple points almost simultaneously (e.g., within 0.5 s), thereby enabling the application of high-precision hypocenter determination methods that utilize data from multiple observation points (Figure 2). In addition, post-earthquake operations—such as train withdrawal and the delineation of areas requiring inspection—currently rely on representative indices of seismic intensity (e.g., acceleration) recorded by sparsely distributed seismometers at intervals of approximately 10–40 km along the railway line. High-density acquisition of such indices through DAS is thus expected to enable more precise delineation of inspection zones and optimization of related

operations (Figure 3). Furthermore, the use of DAS has the potential to facilitate more rapid and rational post-earthquake inspection activities and decisions to resume train operation. An additional major advantage is that a high-density seismic disaster prevention system along railway lines can be constructed at reduced cost by leveraging existing telecommunication optical fiber cables. Against this background, this article presents the results of seismic observations conducted by connecting DAS interrogator units to existing optical fiber cables installed along railway lines.

DAS-based seismic observation along the Kyushu Shinkansen line

DAS-based seismic observations were conducted twice over approximately one-month periods each, utilizing existing telecommunication optical fiber cables

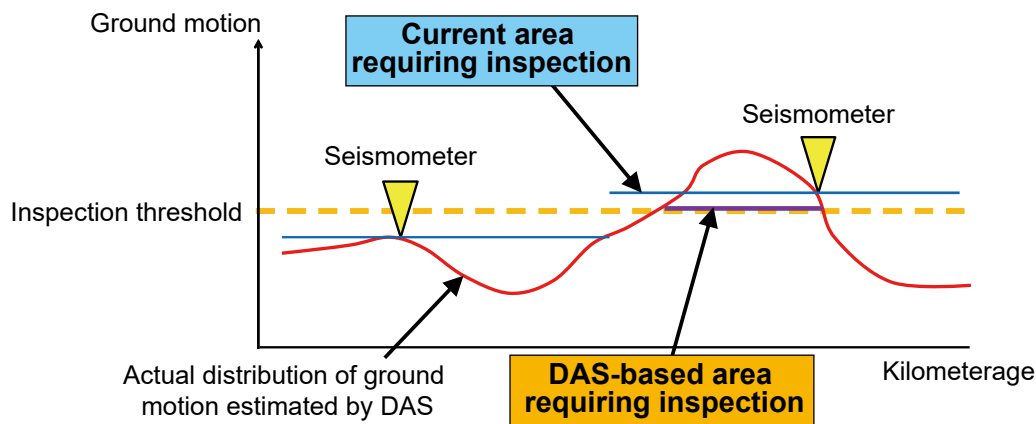


Figure 3 Optimization of areas requiring inspection based on DAS-derived spatial distributions of ground motion along the railway line

Table 1 DAS observation parameters

	FY2022	FY2023
Observation distance	Approx. 75 km	Approx. 100 km
Observation period	Early January–Early February	Early February–Early March
Observation section	Shin-Yatsushiro–Shin-Omuta stations	Shin-Yatsushiro–Kurume stations
Sampling rate	500 Hz	1,000 Hz
Gauge length	10 m	5 m
Spatial sampling interval	5 m	5 m
Total number of channels (observation points)	15,082 channels	20,762 channels

installed along the Kyushu Shinkansen line⁵⁾. The observation parameters are summarized in *Table 1*. Here, gauge length refers to the length of the optical fiber segment over which strain is calculated; for example, a gauge length of 10 m means that the elongation and contraction of the cable over a 10 m section can be measured. The spatial sampling interval was set to 5 m. The observation sections were approximately 75 km and 100 km long, corresponding to 15,082 and 20,762 channels (observation points), respectively. The observation sections encompass a variety of railway structures, including rigid-frame viaducts (Rahmen viaducts), bridges, tun-

nels, and embankments. In general, the optical fiber cables are routed inside cable ducts installed beside the tracks on these structures. Within tunnels, however, the cables are fixed to the tunnel walls at regular intervals and suspended from the walls.

Seismic and train vibration waveforms recorded by DAS

During the observation period, numerous waveforms were recorded, including seismic waveforms associated with earthquakes occurring in and around the observation area, and train vibrations from Shinkansen trains in service. Representative

examples of DAS-recorded strain rate data are shown below:

- Seismic waveform of an earthquake (Mj 3.3) that occurred in Kumamoto Prefecture on January 19, 2022 (*Figure 4a*)
- Non-seismic waveforms including train vibrations and tunnel compression waves (*Figure 4b*)

During the observation period, numerous earthquakes occurred in Kumamoto Prefecture and the surrounding subduction zone. *Figure 4a* shows the DAS strain-rate waveforms recorded for a Mj 3.3 earthquake that occurred within a few

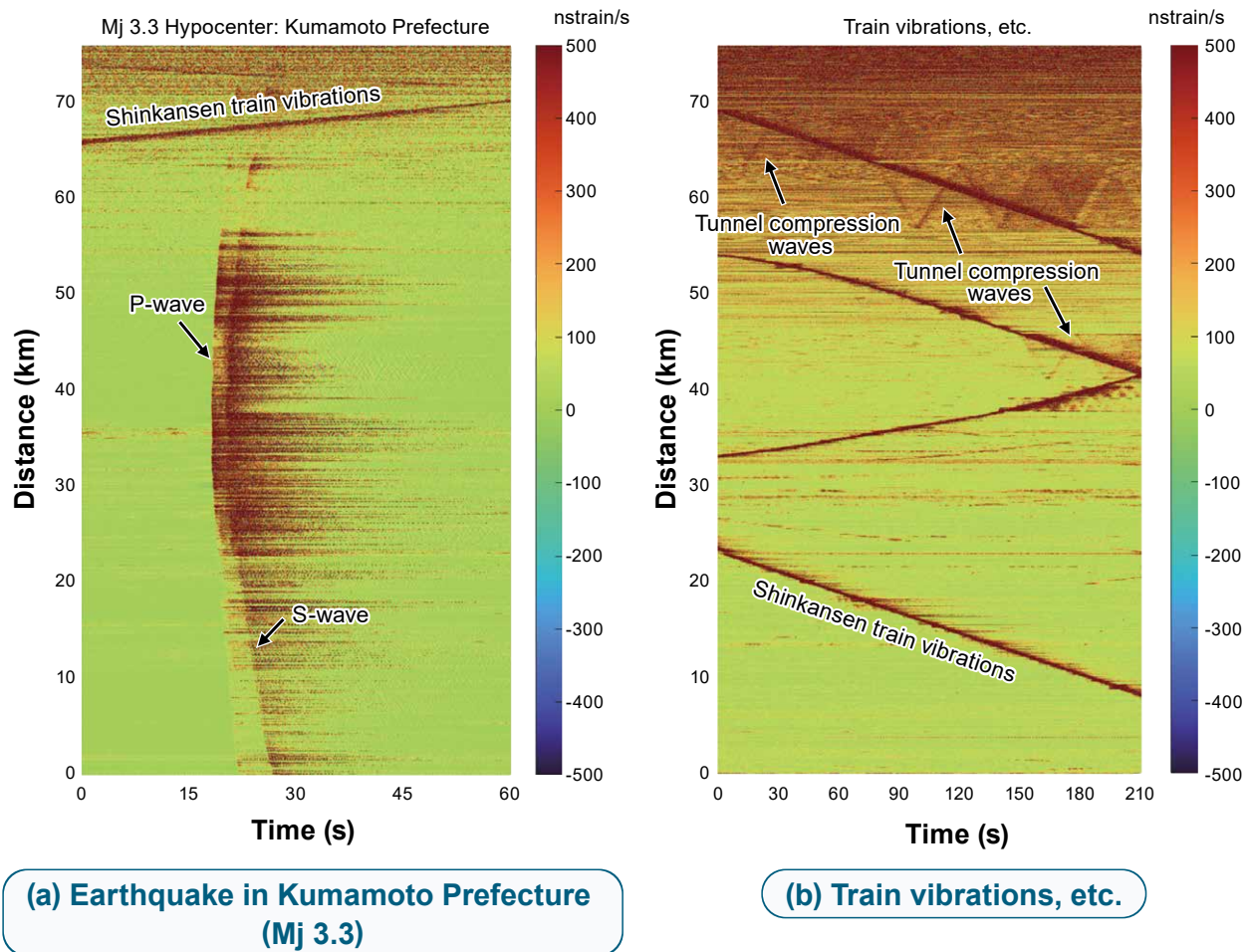


Figure 4 Various strain rate waveforms recorded by DAS

tens of kilometers of the railway line. Data from each channel were bandpass filtered between 1 and 10 Hz, with color intensity representing strain rate amplitude. Clear P-wave and S-wave arrivals are identifiable in most channels. However, at approximately 55-64 km and 66-70 km along the line, waveform amplitudes appear relatively small. This is attributed to reduced coupling between the optical fiber cable and the surrounding ground in tunnel sections, where the cable is partially suspended from the tunnel walls, resulting in lowering sensitivity to ground motion. At the section

closest to the hypocenter (approximately 35 km along the line), the maximum strain rate was recorded, and the propagation of seismic waves in both directions away from that point is clearly visible.

In addition to seismic waveforms, passages of several hundred Shinkansen trains were also recorded during the observation period. *Figure 4b* shows the strain rate waveforms acquired by DAS after bandpass filtering between 10 and 40 Hz. Vibrations associated with downbound train passages are identifiable at approximately 8-23 km, 42-54 km, and 55-69 km, while those from

upbound trains are visible at approximately 33-41 km. In certain tunnel sections (particularly 42-47 km and 58-63 km), tunnel compression waves generated as trains enter and exit the tunnels are observed; these reflect air pressure waves propagating within the tunnel interior. These results demonstrate that DAS can simultaneously acquire not only the spatial distribution of seismic ground motion along the railway line, but also a diverse range of signals including train vibrations, train positions, and tunnel compression waves.

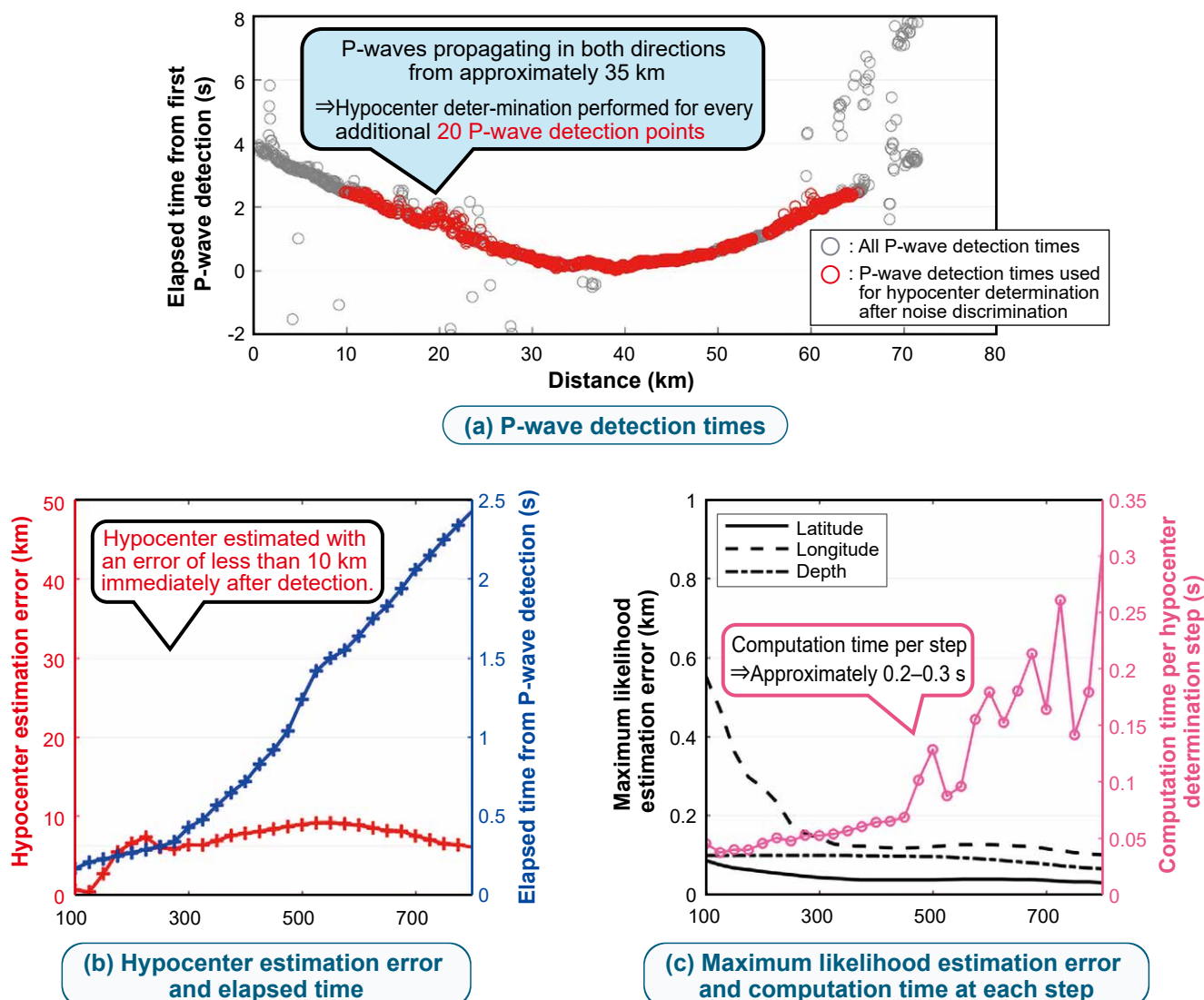


Figure 5 Results of applying the immediate hypocenter determination method using DAS

Development of immediate hypocenter determination method using DAS

Using DAS seismic observation data acquired via existing optical fiber cables, a method was developed to rapidly estimate the hypocenter by integrating information from multiple observation points following seismic wave detection⁶⁾. The processing workflow is outlined as follows:

- (a) The $\text{STA/LTA}^{*2,7)}$ is computed continuously at 10-channel intervals.
- (b) When the cumulative number of channels in which P-waves have been detected by the STA/LTA method reaches 100, the initial hypocenter determination is performed using $\text{hypomh}^{*3,8)}$.
- (c) The hypocenter location obtained in step (b) is saved as the initial estimate.

- (d) Each time the number of P-wave detection channels increases by an additional 20, the hypocenter is re-estimated using hypomh .
- (e) Steps (c) through (d) are repeated sequentially until the total number of P-wave detection channels reaches 800.

Applying this method to the Mj 3.3 earthquake in Kumamoto Prefecture (Figure 4a), clear P-wave detections were obtained at

multiple observation points (*Figure 5a*). Even when only P-wave arrival times obtained within approximately 1 s of the first P-wave detection were used, the hypocenter was estimated with an error of approximately 5 km (*Figure 5b*). Although the estimation error slightly increased thereafter, the hypocenter was again determined to within approximately 5 km accuracy approximately 2.5 s after the initial detection. As the number of P-wave detection points increases, the computational load also grows; however, the computation time at each step was generally less than 0.3 s, confirming that real-time processing is fully feasible (*Figure 5c*). The temporary increase in hypocenter estimation error (observed at approximately 500 P-wave detection points) is attributed to the predominantly north-south orientation of the optical fiber, which renders east-west positional determination unstable. The developed method

demonstrates that, compared with conventional single-station hypocenter estimation methods (C- Δ method and principal component analysis), it achieves far superior hypocenter determination accuracy while maintaining equivalent immediacy. In addition, it was confirmed that earthquake magnitude can be estimated with an error of approximately ± 0.5 units within 1-2 s after P-wave detection, thus demonstrating the applicability of this method to earthquake early warning systems.

Conclusion and future perspectives

Seismic observations were conducted using existing telecommunication optical fiber cables installed along the Kyushu Shinkansen line, with the aim of applying DAS technology to the railway sector. By leveraging the high temporal and spatial resolution of real-time DAS observation, it

is possible to enhance the accuracy and immediacy of earthquake early warning and to obtain instantaneous spatial distributions of ground motion along the railway line immediately following an earthquake. This is expected to support the efficient delineation of areas requiring inspection and to provide information assisting train operation control decisions (e.g., train withdrawal), thereby further improving the seismic disaster prevention capability of railways. Moreover, DAS is considered applicable not only to earthquake ground motion but also to the detection of other disaster-related phenomena such as sediment inflow, rockfalls, avalanches, and fallen trees. Future development of a comprehensive multi-hazard monitoring system capable of simultaneously detecting and assessing these phenomena is therefore anticipated.

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Automatic Evaluation of Track Component Conditions Using Image Processing and AI



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* DataDepot Memory of DataDepot system

The DataDepot system consists of DataDepot Memory (wayside transponder), which is fixed to track components such as sleepers and stores position information (kilometerage) required for maintenance and management, and an on-board transponder mounted under the floor of a vehicle. On track geometry cars and similar vehicles, the on board transponder detects when it passes DataDepot Memory while the train is running, and the position information thus obtained is used to correct the kilometerage of the measurement data.

Introduction

Maintenance and management tasks in railway operations, such as inspection of track components and updating of track component inspection ledgers, are generally carried out on site by track maintenance engineers through visual inspection. However, in view of the shrinking population and rapidly declining birthrate and aging of society, it is becoming increasingly difficult to secure track maintenance engineers and pass on inspection skills; therefore there is a strong need to improve work efficiency and reduce manpower requirements. Against this background, RTRI has been developing a wooden sleeper deterioration evaluation system that uses commercially available video cameras mounted at the front of trains to capture forward-view images, transforms these images by image processing into images that appear as if they were taken from directly above the track (hereinafter referred to as "overhead images"), and then automatically detects wooden sleepers and determines their deterioration levels by applying deep learning.

The overhead images generated by this system can also be used to check the condition of components other than wooden sleepers. Therefore, in order to obtain an integrated understanding of the condition of track components and to update the inspection ledgers used in the field more

efficiently, functions have been developed that use deep learning to automatically identify not only wooden sleepers but also other types of sleepers and rail fastening systems. In addition, another function has been developed to detect DataDepot Memory of DataDepot system* installed on the track and correct kilometerage errors in the same way as track geometry cars. Kilometerage is defined as the cumulative distance measured along the railway track from a designated origin point. At present, RTRI is developing a track component condition evaluation system in which these functions are implemented.

Outline of the track component condition evaluation system

Figure 1 shows an outline of the track-component condition evaluation system. To enable low cost and simple image acquisition, the system uses commercially available video cameras with 4K or higher resolution (or a handheld information terminal such as a smartphone) and suction cup mounting fixtures to record the track ahead from inside the cab through the front window. As shown in *Figure 2*, the acquired forward-view image is then transformed into an overhead image by applying a projective transformation, an image-processing technique that transforms a trapezoidal two-dimensional image into a rectangular

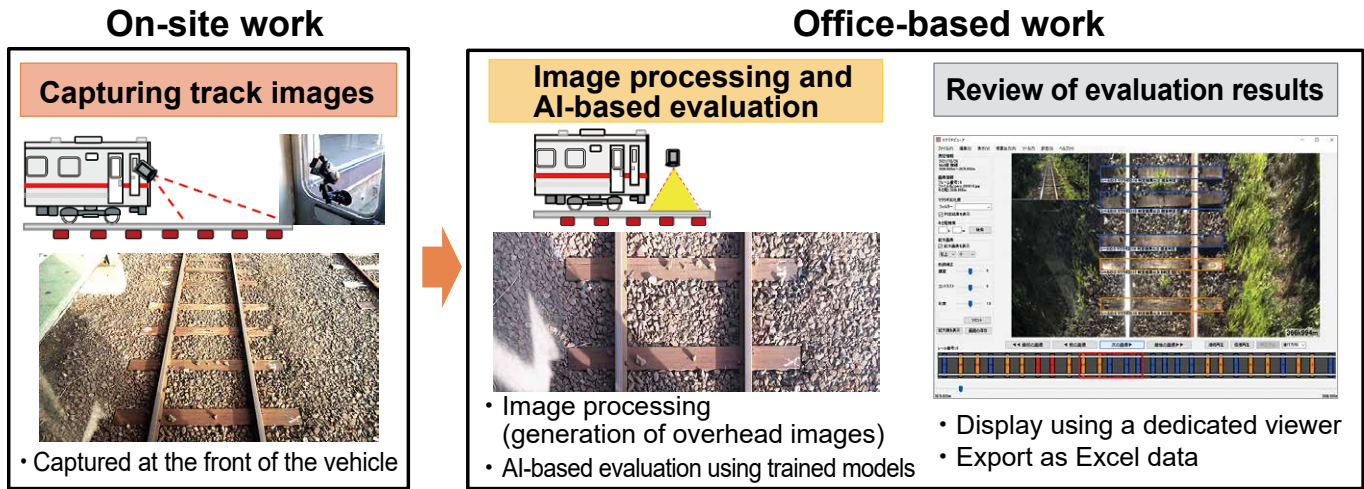


Figure 1 Outline of the track component condition evaluation system

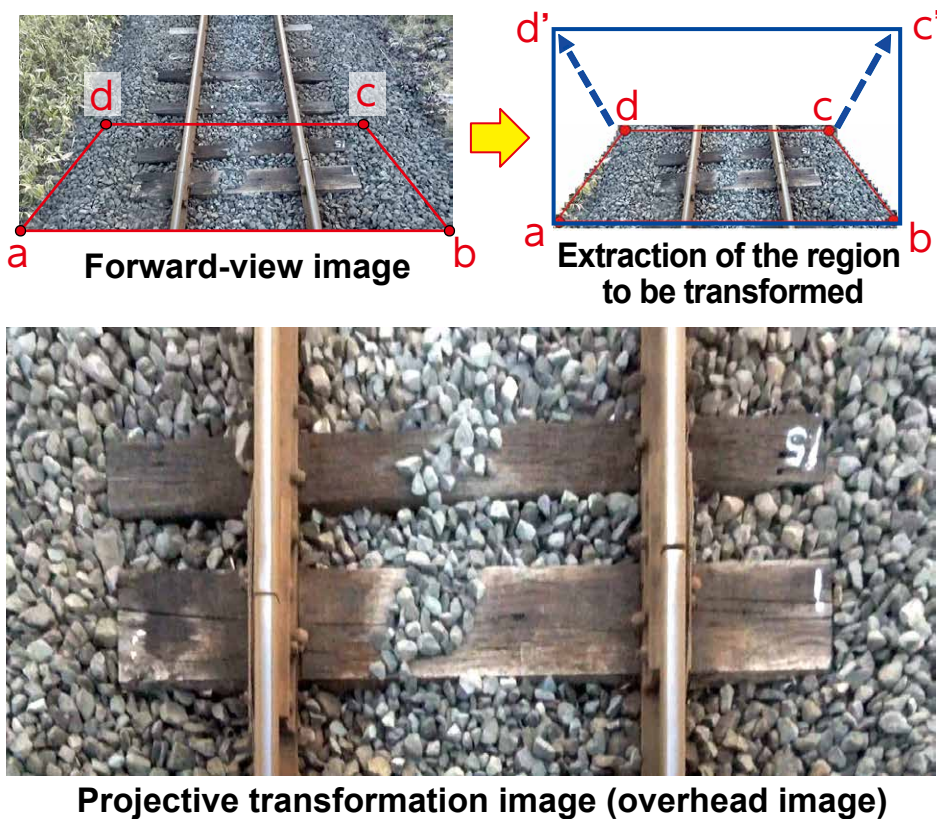


image. In a forward-view image, objects become narrower from the bottom to the top of the image and appear trapezoidal, so, in the projective transformation, the four coordinates of the required trapezoidal region (abcd) are first determined, after which the four coordinates of a rectangular region (abc'd') matching the actual aspect ratio of the sleepers are calculated, thereby generating an overhead image. In this transformation process, the transformation targets sleepers in the nearer part of the image, where the resolution is higher, and the aspect ratio is adjusted to match the real geometry, so that an image closely representing the actual laying condition in the field is obtained. As a result, track maintenance engineers can check the condition of track components from a viewpoint similar to that used in ordinary inspection work and, because the shapes of track components are made uniform regardless of their positions in the image, it becomes easier to develop deep learning models than when using forward-view images directly.

In this system, deep learning is applied to the overhead images to implement the following three functions:

- (1) a function for detecting wooden sleepers and determining their deterioration levels,

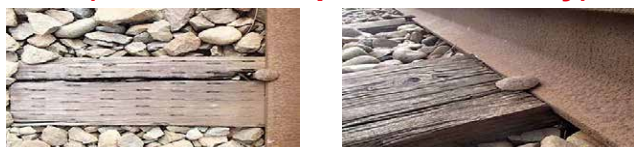
A1 (Risk of contact with rolling stock)



A2 (Reduced gauge-retention capability)



B (Reduced sleeper functionality)



C (Minor damage)



D (Good condition)



Undetermined



Figure 3 Standard for evaluating deterioration levels of wooden sleepers

- (2) a function for automatically identifying not only wooden sleepers but also other types of sleepers and types of rail fastening systems (hereinafter referred to as the “track component type identification function”), and
- (3) a function for detecting DataDepot Memory and correcting the kilometrage in the same way as track geometry cars (hereinafter referred to as the “kilometrage correction function using DataDepot Syetem”).

Functions of the track component condition evaluation system

Wooden sleeper deterioration evaluation function

To evaluate deterioration levels of wooden sleepers, RTRI has developed a deterioration evaluation model based on the evaluation standard shown in *Figure 3* (deterioration levels A1 to D and “undetermined”) using deep learning and applied this model to overhead images to detect wooden sleepers and determine their deterioration levels. Because defective sleepers in the field (categories A2 and B) are relatively rare, color-tone processing

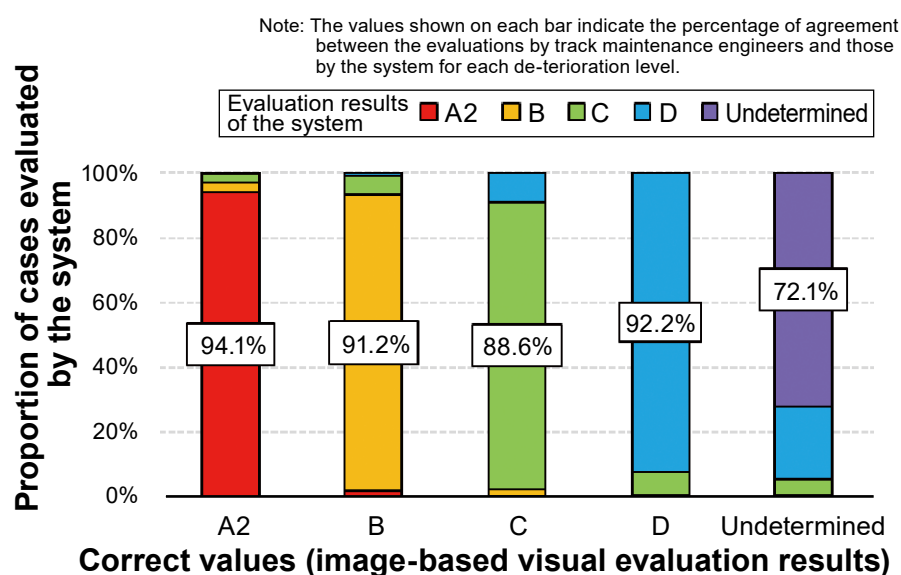


Figure 4 Accuracy of wooden sleeper deterioration evaluation (comparison with levels de-termined by track maintenance engineers using overhead images)

applied during development of the deterioration evaluation model to vary the brightness and contrast of the captured images, thereby generating four images with different color tones. Defective sleepers categorized as A1, which pose a risk

of infringing the structure gauge, are also rarely present in the field and are therefore excluded from automatic evaluation. The wooden sleeper deterioration evaluation model was trained using about 180,000 images corresponding to approximately

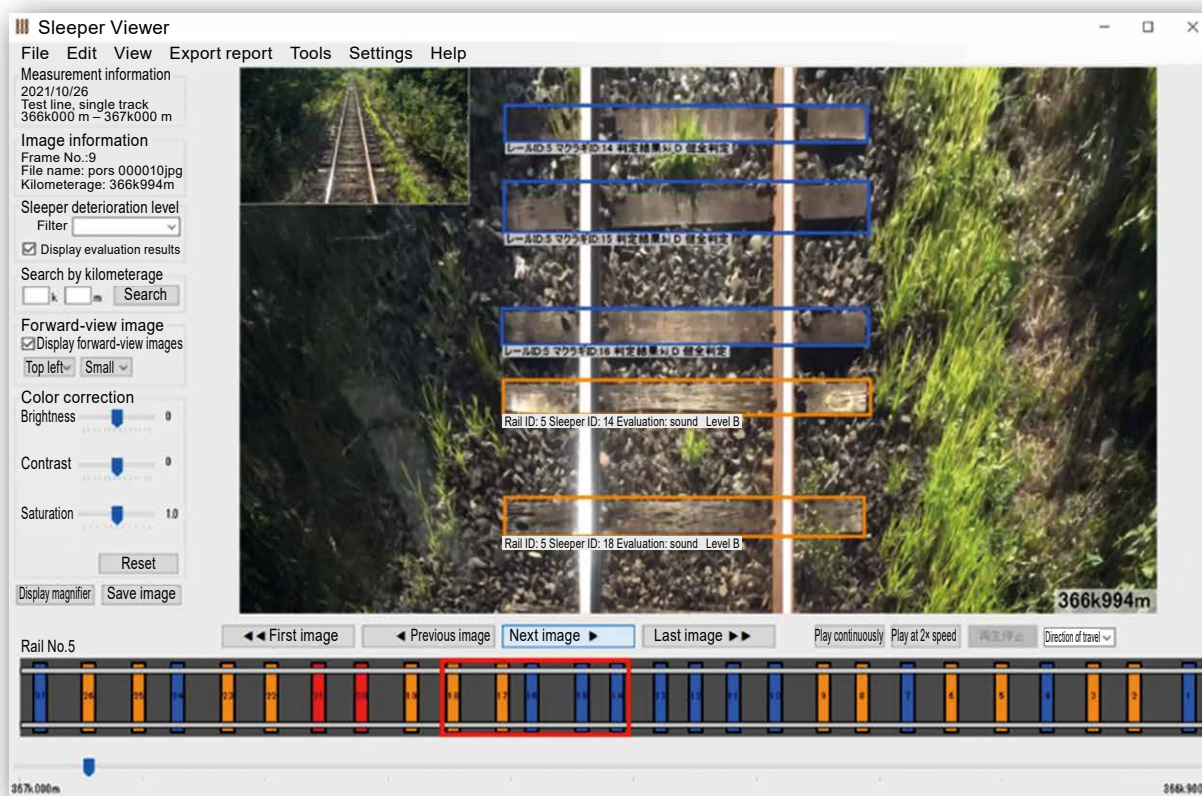


Figure 5 Example screen showing wooden sleeper deterioration evaluation results

350,000 sleepers, with deterioration levels distributed as follows: 61 sleepers at level A1, 21,329 at A2, 68,520 at B, 78,779 at C, 164,036 at D, and 12,812 undetermined.

We verified the accuracy of the wooden sleeper deterioration evaluation model using 16,111 wooden sleepers photographed on a commercial line different from the section used for developing the model. The sleeper detection accuracy was 99.5% (100% when sleepers whose surfaces were heavily covered by a significant amount of ballast or other materials were excluded). In addition, when the deterioration levels determined by track maintenance engineers from the overhead images were taken as the correct values (image-based visual evaluation results), we confirmed, as shown in *Figure 4*, that the system can automatically determine the deterioration levels of wooden sleepers with an accuracy of at least 90%.

Figure 5 shows an example of how the deterioration evaluation results for wooden sleepers are displayed by a dedicated viewer. In this viewer, each sleeper is shown in a color-coded format according to its deterioration level, so that railway operators can visually and easily identify locations where defective wooden sleepers occur consecutively, which can be a factor in derailments due to gauge widening.

Track component type identification function

To classify track component types, RTRI has developed classification models for the track components shown in *Figure 6*, namely two types of rail fastening systems and three types of sleepers. Among the many types of rail fastening systems, we have broadly classified them into two categories whose shapes can be relatively easily distinguished in overhead images,

namely rail fastening system using bar clip spring and leaf spring clip, and have constructed models based on this classification. For turnout sleepers, models have been developed according to the type and designated number of the turnout. The numbers of labeled samples (training data) for each track component are 40,537 for rail fastening systems using bar clip spring, 21,733 for rail fastening systems using leaf spring clip, 252 for prestressed concrete (PC) sleepers for cable protection, 6,551 for track panel concrete (TPC) sleepers, and 1,839 for turnout sleepers.

To evaluate the accuracy of the track component type identification model, we carried out verification on a 2.4 km stretch of line different from the section used for developing the model. As shown in *Table 1*, we confirmed that all track component types can be detected and identified with a high accuracy of at least 95%.

Kilometerage correction function using DataDepot system

Because railway facilities are maintained and managed on the basis of the kilometerage of their installation locations, when using this system for inspection, it is necessary to assign kilometerage to each frame of the overhead images. In this system, the running distance is accumulated on the basis of image displacement between frames, and DataDepot Memory of DataDepot system (Figure 7), which are used by track geometry cars that measure track condition such as track irregularities for kilometerage correction, are detected from the overhead images. The kilometerage of the images is then corrected to the pre-registered installation kilometerage of the DataDepot Memory stored in the database.

Figure 8 illustrates the concept of kilometerage correction using DataDepot system. Taking into account the actual installation intervals, the detection zone for DataDepot Memory is set as ± 200 m around the kilometerage registered in the database. For example, if a DataDepot Memory installed at an actual kilometerage of 15k000 m is detected at an image based kilometerage of 15k030 m, the corresponding image falls within the detection zone from 14k830 m to 15k230 m, so the kilometerage associated with the detected DataDepot Memory

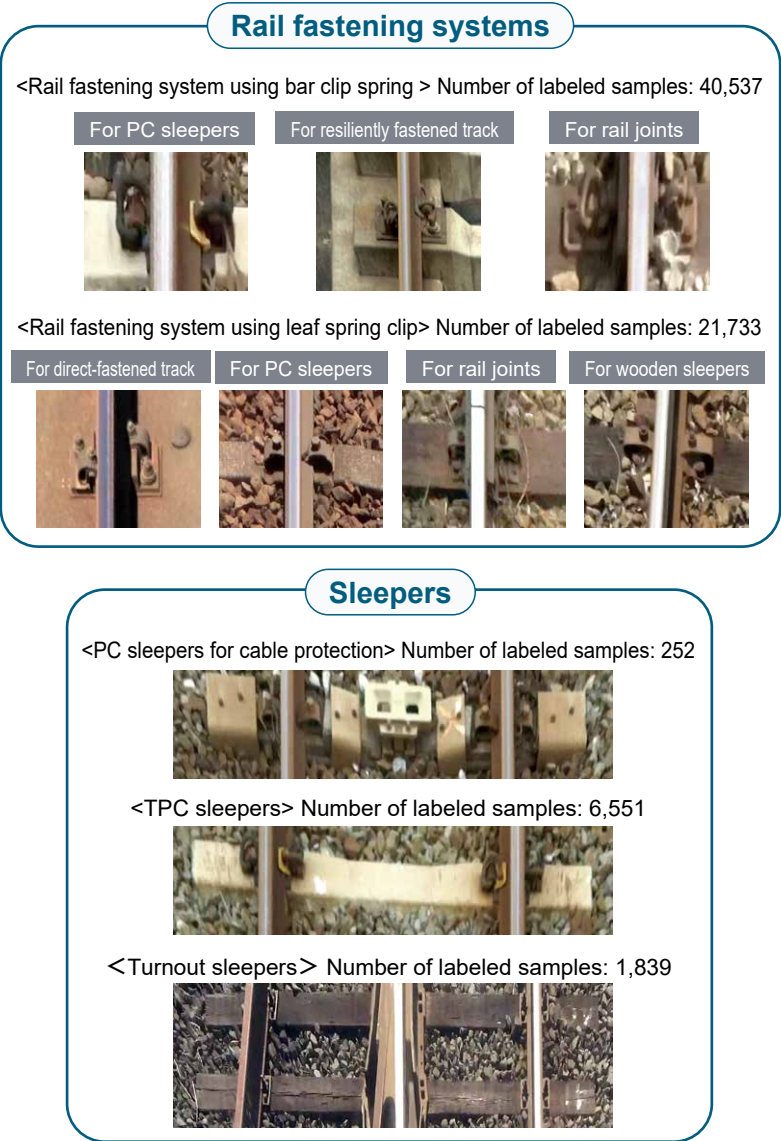


Figure 6 Track component types classified by the model

Table 1 Accuracy of the track component type classification model

	Rail fastening system using bar clip spring	Rail fastening system using leaf spring clip	PC sleepers for cable protection	TPC sleepers	Turnouts
Number installed [units]	3,168	6,909	53	760	79
Number of missed detections [units]	19	5	0	0	1
Number of false detections [units]	93	11	0	2	0
Detection rate [%]	99.4	99.9	100.0	100.0	98.7
Correct classification rate [%]	97.0	99.8	100.0	99.7	98.7
Missed detection rate [%]	0.6	0.1	0.0	0.0	1.3
False detection rate [%]	2.9	0.2	0.0	0.3	0.0

is corrected from 15k030 m to 15k000 m. By combining this function with the track component type identification function, the system is expected to contribute to more efficient updating of ledgers for sleepers and rail fastening systems.

Conclusions

We have presented a system that automatically detects track components and evaluates their condition by applying image processing and deep learning to forward-view images captured by commercially available video cameras. The system enables inspections to be conducted without requiring track maintenance engineers to visit the site, which is expected to increase inspection speed and frequency while reducing inspection workload and costs.

In the future, we plan to further study the application of this system to other track components while continuing to consider the needs of railway operators.



Figure 7 Example installation of a DataDepot Memory of DataDepot system

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- 2) Tsubokawa, Y., Takahara, Y., Nagamine, N., Goda, W., “Development of Track Components Condition Evaluation Method Using Forward View Image from Train Cab,” Journal of the Reliability Engineering Association of Japan, Vol. 47, Issue No. 3, 2025 (in Japanese).

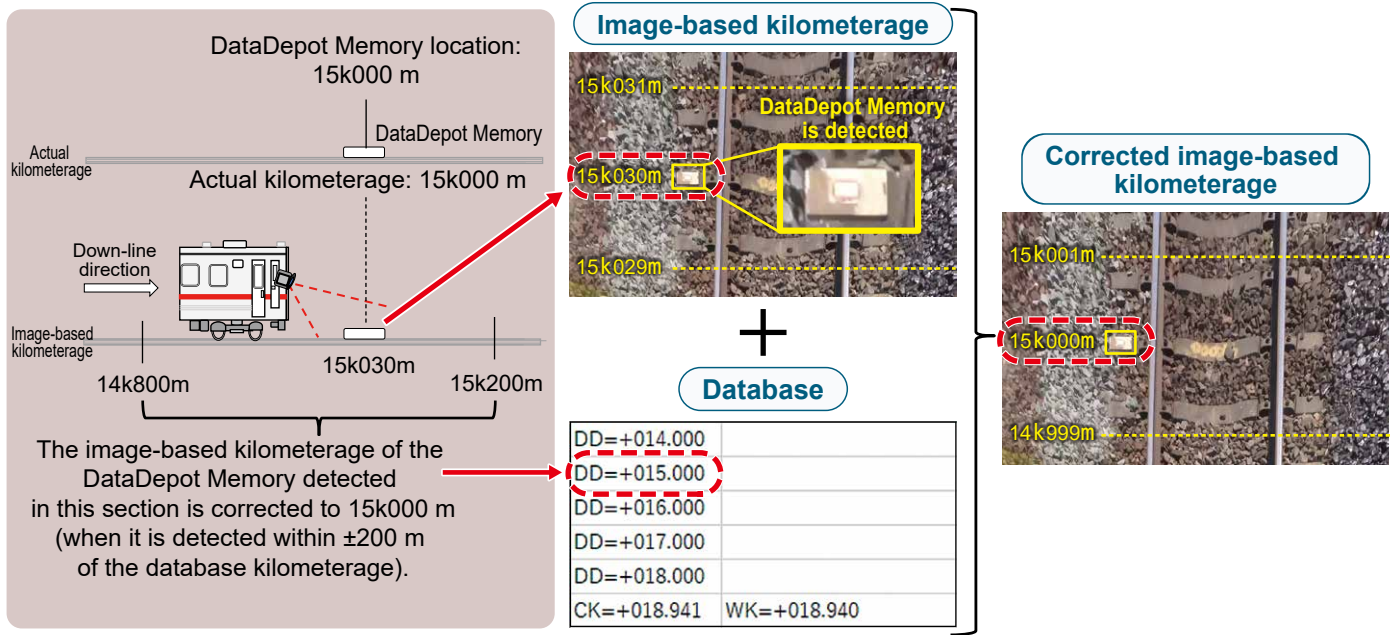


Figure 8 Conceptual diagram of kilometerage correction using a DataDepot system



Ms. Riho MAEDA

Researcher, Image Analysis and AI Laboratory,
Information and Communication
Technology Division

*1 How does AI evaluate deterioration?

In our system, we use an image classification AI model trained on a large number of images to identify visual features, such as the presence or absence of rust and surface damage. Based on these features, the model evaluates the condition of equipment from images in a manner similar to human visual inspection.

*2 What is the image segmentation AI "SAM"?

To extract only the pole region from an image, this method uses a technique called SAM (Segment Anything Model). SAM is an AI model that finds and segments required objects from within an image and is characterized by its ability to handle a wide variety of image types. Since it can be used without pre-training on a large number of images of specific equipment, it is particularly useful when dealing with categories as diverse as those found in railway equipment.

Estimating Deterioration of Wayside Equipment Using AI

Introduction

Wayside equipment, such as signals and equipment boxes, is installed at various intervals along railway lines, requiring maintenance engineers to walk along the tracks to identify each piece of equipment and inspect its installation condition and visual deterioration level. With Japan's working-age population continuing to decline due to demographic changes, reducing the workload associated with maintenance management has become increasingly important.

To address this challenge, RTRI has developed a management support system that uses rapidly advancing AI technology to analyze images captured by cameras mounted on running trains, determine the kilometerage and types of wayside equipment, and output their visual deterioration levels and inclination angles¹⁾. By using this system, it is expected that part of the maintenance management work of wayside equipment conventionally carried out on foot can be replaced by camera-based inspection from onboard the train.

Management support system for wayside equipment

System overview

A schematic diagram of the proposed management support system for wayside equipment is shown in *Figure 1*. In this system, cameras are installed in the driver's cabs of commercial trains and other rolling stock to record forward-facing images of railway lines, and the captured data are analyzed using image processing and AI so that the condition of wayside equipment can be understood on a PC. For this purpose, the processing unit performs the following four steps on captured video images, such as the example shown in *Figure 2*: (1) estimating the kilometerage of each video frame, (2) recognizing wayside equipment in the images, (3) evaluating the visual deterioration level of the identified equipment, and (4) estimating the inclination angles of poles. As a result, the system can display both the kilometerage and thumbnail images of each piece of equipment captured in the video, thereby enabling users to diagnose the condition of

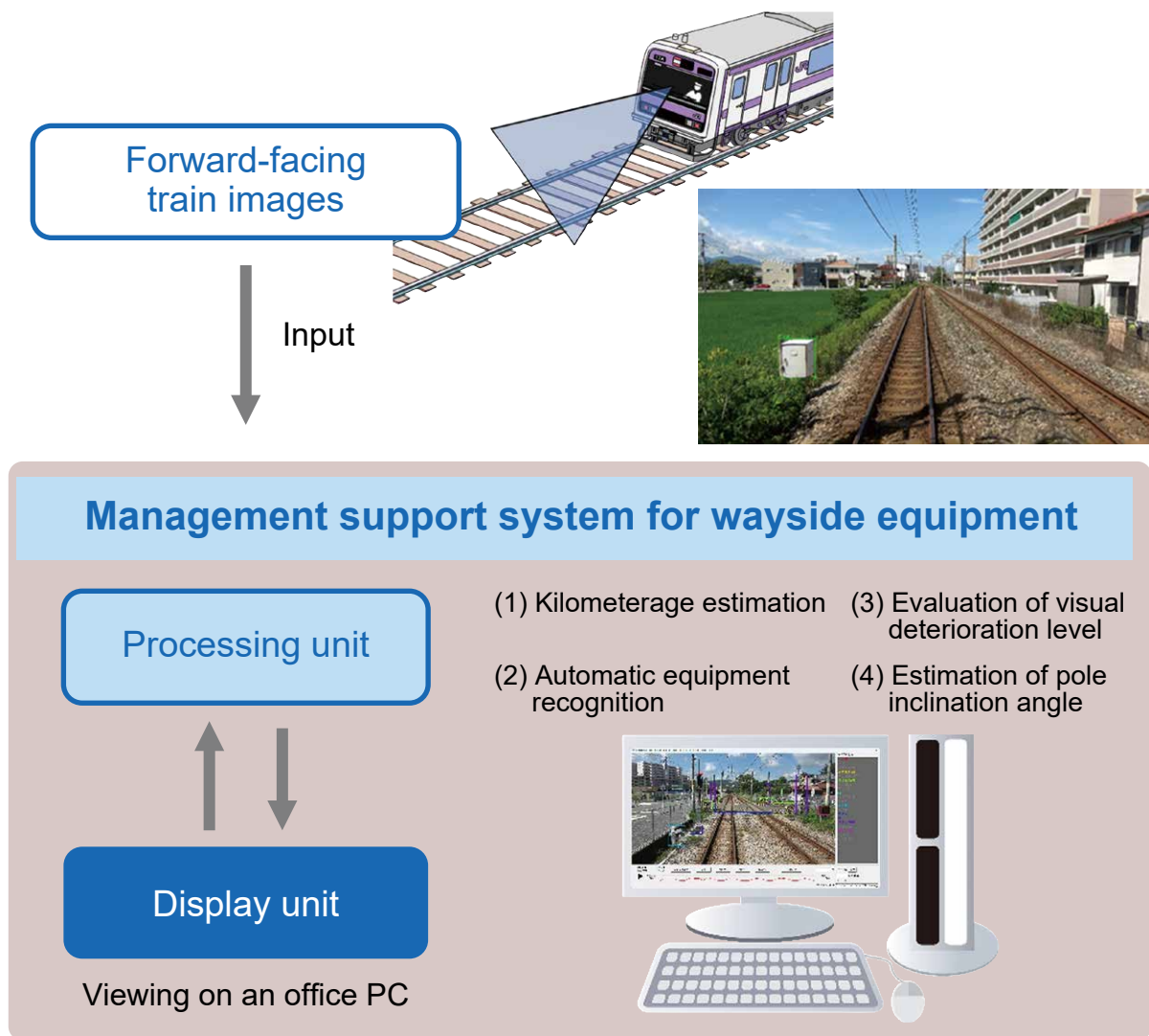


Figure 1 Overall schematic of the management support system for wayside equipment

equipment from the images. The details of these four processing steps are described below.

Kilometerage estimation

To make effective use of captured video images for maintenance management work, it is necessary to understand the kilo-

meterage at which the locations and pieces of equipment appearing in the images are situated. Therefore, we use image processing to calculate the travel distance from the video and assign kilometerage information to each video frame. This approach enables all processing to be performed using images alone, without requiring external inputs

such as those from GPS receivers or speed sensors, thereby simplifying the system configuration.

For kilometerage estimation from video images, we use a technique called optical flow, which calculates the motion of objects or feature points between consecutive images or frames. By applying optical flow



Figure 2 Example of forward-facing images captured from a train

to forward-facing images captured from a moving train, the travel distance and speed of the train can be obtained. To convert the calculated distance into kilometerage, two reference points with known kilometerage values, such as stations or wayside equipment visible in the video, are used, and kilometerage is then assigned to all frames.

Recognition of wayside equipment

Recognition of wayside equipment from video is performed using an object detection AI model. This AI program reads im-

ages or videos, recognizes objects, and displays their positions as rectangles called bounding boxes. In this study, we constructed an AI model trained on 18,000 forward-facing train images to recognize 22 categories of equipment. When the trained AI is applied to actual images, rectangles are drawn at the equipment positions, with different colors used for each equipment type, as shown in *Figure 3*.

Because kilometerage is assigned to each video frame in the preceding step, the proposed system can associate each detected

piece of wayside equipment with its kilometerage, enabling efficient assessment of its condition.

Evaluation of visual deterioration level

Because wayside equipment is used outdoors for long periods of time, it inevitably deteriorates due to factors such as rain, snow, and ultraviolet radiation, which cause rust and peeling of paint. Therefore, periodic monitoring of equipment appearance and deterioration is important for



Figure 3 Example of AI-based recognition results for wayside equipment

maintenance management.

Currently, however, visual inspections are mainly conducted by maintenance engineers visiting sites and visually inspecting the actual equipment. This method relies heavily on human experience, resulting in variations in judgment among inspectors and requiring substantial time because maintenance engineers must travel to the site.

To address these issues, we have developed a method that automatically evaluates the degree of deterioration using

images and AI^{*1}. In the proposed method, the AI analyzes the surface condition of the equipment based on captured images and evaluates the deterioration level on a numerical scale from 0 to 10, where 0 indicates a sound condition and 10 indicates that replacement is required. By quantifying deterioration numerically, inspection results can be compared using a common standard regardless of who performs the inspection.

When the proposed AI-based deterioration evaluation was applied to images

of signal equipment boxes, as shown in Figure 4, images with low numerical deterioration scores were found to be in good condition, whereas images with higher scores exhibited more advanced rust and corrosion. This confirms that representing deterioration levels numerically is effective for evaluating the condition of equipment.

Incorporating this automatic visual deterioration evaluation function into the system enables evaluation of the equipment condition in the office while reviewing a large number of equipment images, sig-

Figure 4 Results of deterioration-level evaluation for images of signal equipment boxes



nificantly reducing on-site inspection. Furthermore, automating the evaluation process can reduce variability among inspectors, leading to more reliable and efficient equipment management.

Pole inclination angle estimation

Estimation of pole inclination angle is a technique for determining whether equipment installed along railway lines—for example, traction poles that support overhead lines and signal masts—is upright or leaning. Conventionally, the inclination angle has been measured manually using measuring instruments; however, this approach requires considerable time and effort when a large number of poles must be inspected.

In this study, we employ a method that uses AI to automatically calculate the inclination angle of equipment from images alone. This method uses images captured from vehicles running along the track and calculates the angle by means of AI and image processing. Because no additional measuring equipment is required, the method can reduce on-site work, which is a major advantage. *Figure 5* illustrates this process using a traction pole as an example.

To estimate the angle, it is first necessary to extract only the equipment region, such as a traction pole, from the equipment images recognized in the previous step. Equipment images usually contain background elements such as sky, vegetation, and buildings, which are unnecessary for angle calculation, therefore, accurately segmenting only the equipment is important. For this segmentation process, we use an image region extraction method based on an AI model called SAM, Segment Anything Model^{*2, 2)}.

After extracting the equipment region, the inclination angle is calculated by analyzing its orientation in the image using image moments. By calculating the image moments, the direction in which the object extends within the image can be determined, and thus the angle relative to the horizontal can be obtained. This calculated value serves as the estimated inclination angle.

Through this series of processing steps, the inclination angle of equipment can be efficiently estimated using only image data. Incorporating this technique can reduce on-site measurements while still confirming the soundness of equipment, thereby contributing to labor-saving in maintenance management and improved safety.

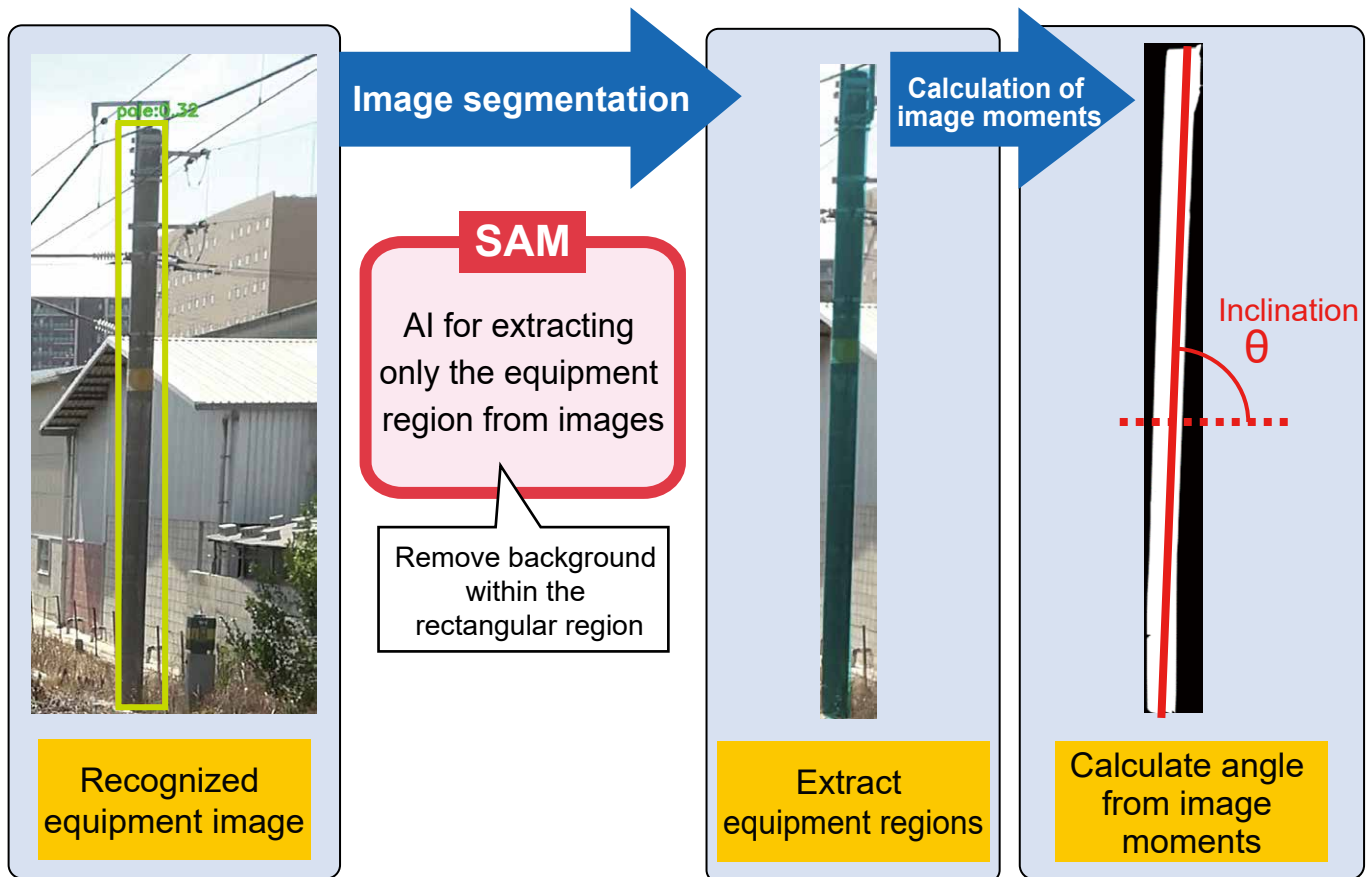


Figure 5 Flow of inclination angle estimation for traction poles

Conclusion

This study presented a management support system that utilizes forward-facing train images to reduce the workload associated with maintenance management work for railway wayside equipment. By applying AI to image processing, the system digitalizes part of the work that has previously relied on on-site visual inspections and thus enables more efficient equipment management.

In particular, we introduced a mechanism for evaluating the condition of equipment from images, enabling condition diagnosis

such as estimation of visual deterioration levels and pole inclination angles. This demonstrates that equipment soundness can be assessed without on-site visits and the resulting information can support inspection and maintenance planning.

Going forward, we plan to continue improving the system in line with the needs of field users and to further contribute to enhancing the safety and efficiency of maintenance management work for railway equipment.

References

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- 2) Kirillov, A., Mintun, E., Ravi, N., Mao, H., Rolland, C., Gustafson, L., Xiao, T., Whitehead, S., Berg, A. C., Lo, W. Y., Dollár, P., Girshick, R., "Segment Anything," *arXiv preprint arXiv:2304.02643*, 2023.

RTRI Researchers Receive ISO Excellence Award

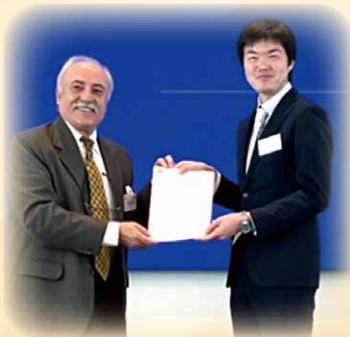
The Railway Technical Research Institute (RTRI) is pleased to announce that its researchers have received the ISO Excellence Award from ISO (the International Organization for Standardization) in recognition of their contributions to the development of international standards in the field of railway track engineering. The award ceremony was held on Thursday, June 11, in Berlin, in conjunction with the plenary meeting of ISO/TC 269/SC 1.

ISO Excellence Award

The ISO Excellence Award is presented to technical experts who have made outstanding contributions to the international standards published by ISO.

Summary of major contributions (as released by ISO):

They were recognized for demonstrating outstanding organizational management and consensus-building skills, as well as for making technical contributions to the development of ISO/TS 18973:2025, Railway infrastructure—Rail fastening systems—Two directional test method for resistance to repeated loading.*



Dr. Mitsuru HOSODA,

Former Senior Researcher, Rail Maintenance and Welding Laboratory, Track Technology Division (currently seconded to the International Union of Railways (UIC))

- Dr. Tadashi DESHIMARU is an international expert of ISO/TC 269/SC 1/WG 7, "Rail fastening systems," and served as project leader for ISO/TS 18973:2025.
- Dr. Mitsuru HOSODA is an international expert of ISO/TC 269/SC 1/WG 7, "Rail fastening systems," and served as secretary for ISO/TS 18973:2025.

* ISO/TS 18973 is a technical specification that presents a standard procedure for evaluating and verifying the fatigue resistance of rail fastening systems by repeatedly applying loads from two directions to the rail head.



Dr. Tadashi DESHIMARU,

Head of Rail Maintenance and Welding Laboratory, Track Technology Division

RTRI Researchers Receive ISO Excellence Award

Summary of major contributions (as released by ISO):

He was recognized for demonstrating outstanding organizational management and consensus-building skills, as well as for making technical contributions to the development of ISO/TR 8955:2025, Railway infrastructure—Track quality evaluation—Chord-based methods.*

- Dr. Hirofumi TANAKA is an international expert of ISO/TC 269/SC 1/WG 2, "Track quality evaluation," and served as project leader for ISO/TR 8955:2025.

* ISO/TR 8955 is a technical specification that explains chord-based methods widely used in Japan to evaluate railway track irregularities (distortion from the designed track geometry).

Dr. Hirofumi TANAKA,
Head of Track Geometry and Maintenance Laboratory, Track Technology Division



International Standard on Distance-Speed Diagrams and Speed Curves, Proposed and Led by Japan, Now Issued

—International standardization of technologies that support highly punctual railway operation—

The Railway Technical Research Institute (RTRI) established the Railway International Standards Center (RISC) and, together with RISC member organizations, has been promoting activities related to international standards, including the international standardization of railway technologies.

The International Organization for Standardization (ISO) issued ISO 24675 2:2026 “Railway applications—Running time calculation for timetabling—Part 2: Distance-speed diagrams and speed curves,” an international standard proposed and led by Japan, on April 15, 2026.

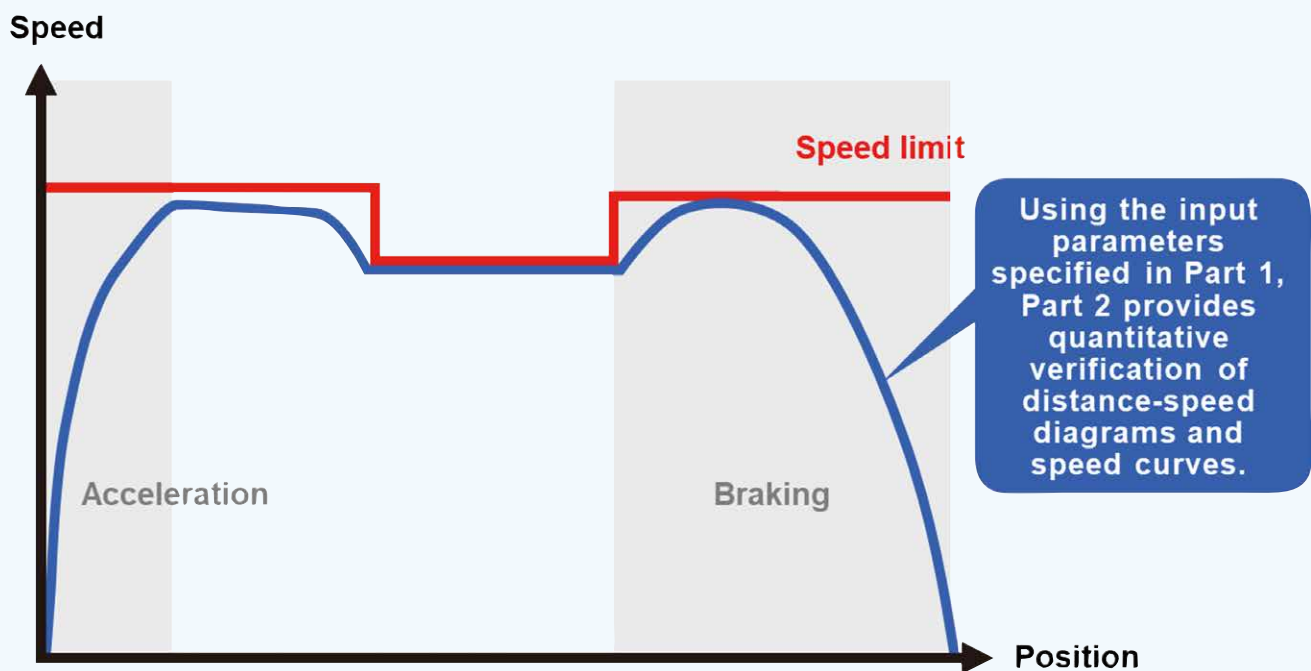


Figure 1 Example of a distance-speed diagram and speed curve representing the train running condition

1. Background to the international standardization of running time calculations

- To operate trains safely and on time, it is essential to calculate the running time between stations accurately and to develop feasible timetables based on such accurate calculations.
- Running time calculation is a sophisticated technique that takes into account many factors, including infrastructure conditions, rolling stock performance, and operational conditions, and Japanese railways possess particularly high technological capabilities in this field.
- To make Japan's strength in running time calculation an international benchmark, Japan proposed and led the development of ISO 24675 1:2022 "Railway applications—Running time calculation for timetabling—Part 1: Requirements."
- Part 1 specifies 12 input parameters required for running time calculations and sets out methods for qualitative verification of the validity of such calculations. Furthermore, Japan proposed Part 2 to achieve more quantitative verification of the validity of running time calculations, specifying a practical method through examination of calculation results as well as distance speed diagrams and speed curves.

2. Outline of international standard ISO 24675 2:2026 "Railway applications—Running time calculation for timetabling—Part 2: Distance-speed diagrams and speed curves"

- ISO 24675 2:2026 specifies a method for quantitatively verifying the validity of both the shape of speed curves, which shows the position and speed of a train (*Figure 1*), and the values obtained from running time calculations. Thus, it defines a method for confirming the validity of running time calculations with higher precision than Part 1.
- As requirements for verification of running time calculations, ISO 24675-2:2026 specifies the use of the 12 input parameters set out in Part 1 and requires that calculations reflect speed limits, infrastructure conditions, rolling stock performance, and operational conditions between stations.
- For verification of the validity of running time calculations, ISO 24675-2:2026 stipulates that calculations performed using the 12 input parameters set out in Part 1 must result in running times that fall within specified ranges, and that, in the result-

ing distance speed diagrams and speed curves, position, speed, and time must lie within prescribed ranges.

The issuance of this international standard will provide Japan with greater competitiveness in exporting systems for timetable planning and related applications and will enable Japanese railway operators to procure such systems more efficiently under the WTO Agreement on Government Procurement.

3. Progress towards international standardization

- | | |
|-----------------------|--|
| (1) June 2022 | Japan submitted a proposal for international standardization to Subcommittee SC 3 (Operations and services) of ISO/TC269 (Railway applications). |
| (2) January 2023 | The participating countries agreed to proceed with international standardization, and Japan then led the deliberations over a period of approximately three years (<i>Figure 2</i>). |
| (3) February 27, 2026 | ISO/TC 269/SC 3 approved international standardization. |
| (4) April 15, 2026 | ISO issued ISO 24675 2:2026 "Railway applications—Running time calculation for timetabling—Part 2: Distance speed diagrams and speed curves." |



Figure 2 Deliberations at an international meeting



Railway Technical Research Institute