Automatic Evaluation of Track Component Conditions Using Image Processing and AI



Mr. Yosuke TSUBOKAWA
Former Head of Track Geometry and Maintenance Laboratory,
Track Technology Division
(Currently, General Manager, Head of JR Affairs, Research and Development Promotion Division)

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

* 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.

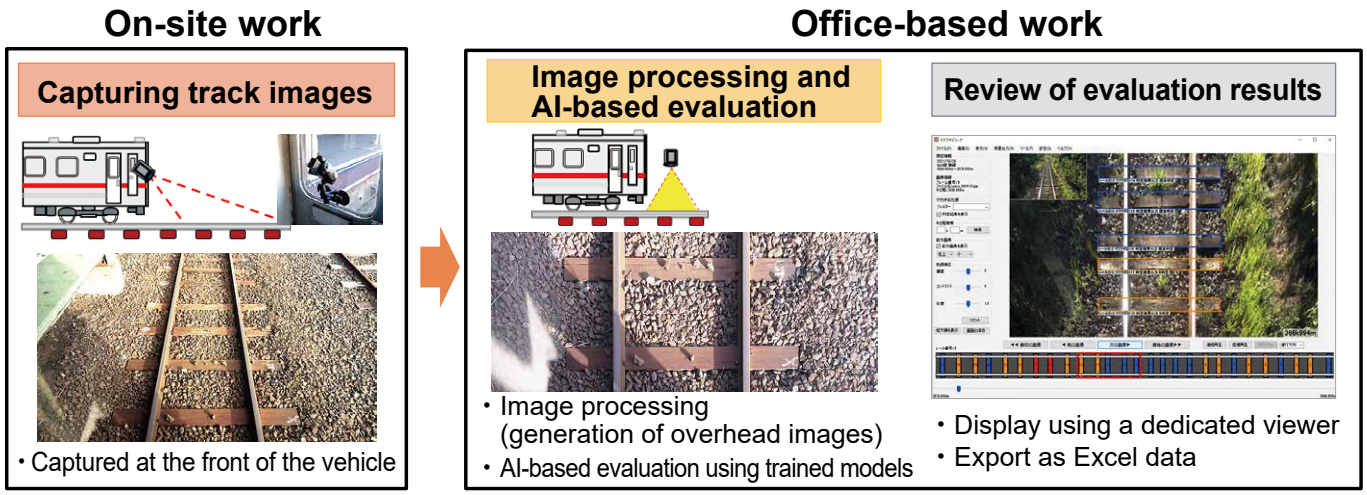


Figure 1 Outline of the track component condition evaluation system

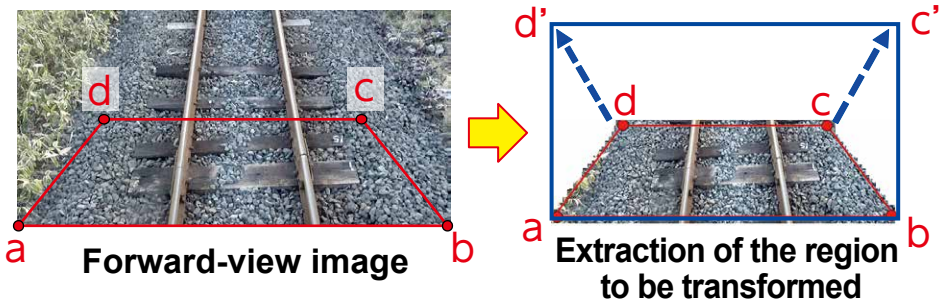




Figure 2 Generation of overhead images using projective transformation

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,

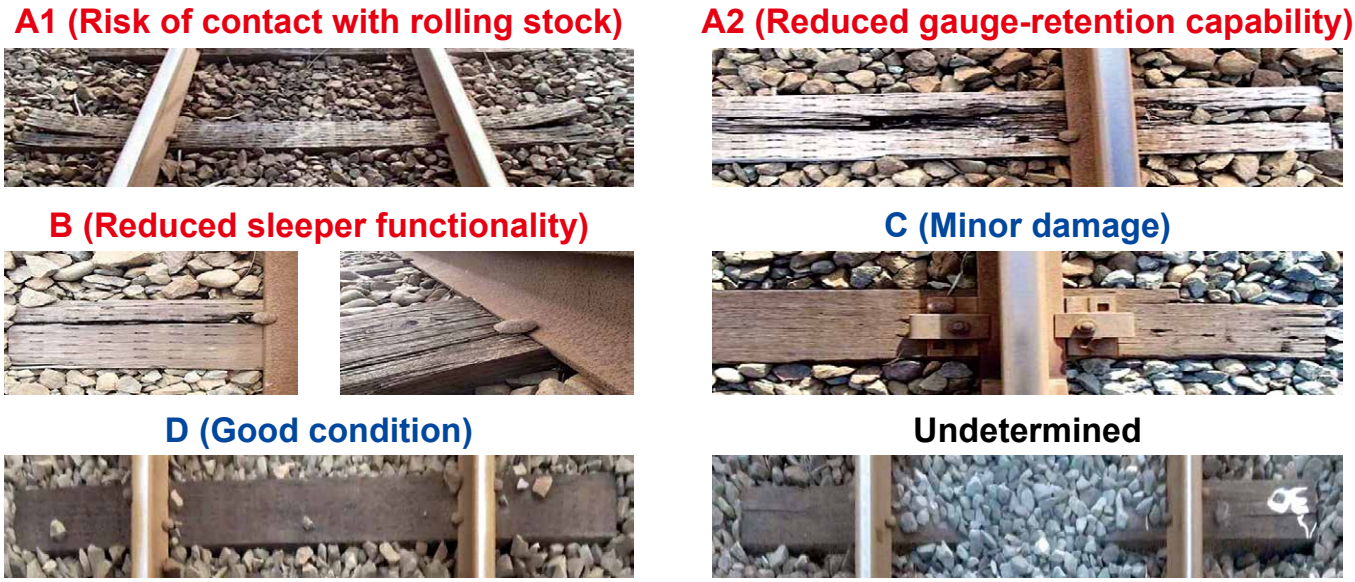


Figure 3 Standard for evaluating deterioration levels of wooden sleepers

(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 kilometerage in the same way as track geometry cars (hereinafter referred to as the "kilometerage 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 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 corre-sponding to approximately

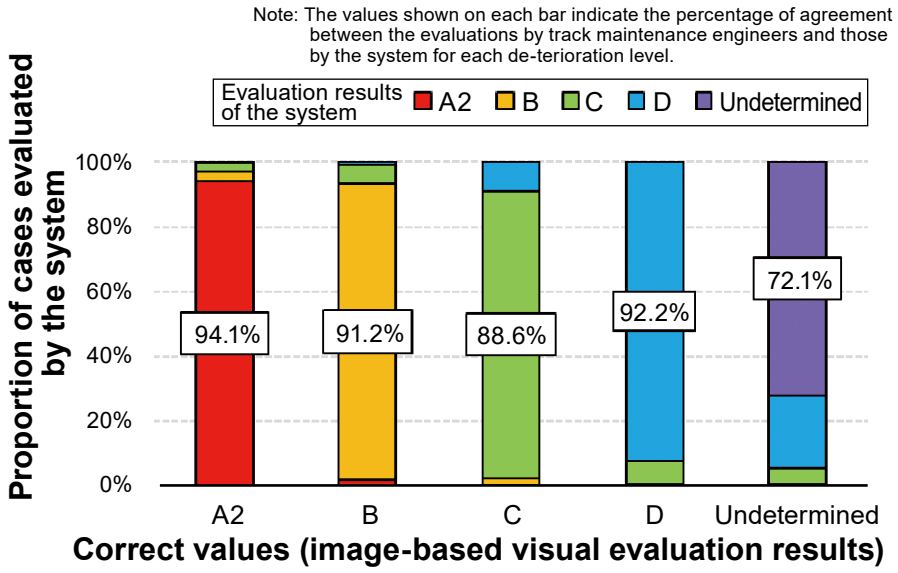


Figure 4 Accuracy of wooden sleeper deterioration evaluation (comparison with levels de-termined by track maintenance engineers using overhead images)

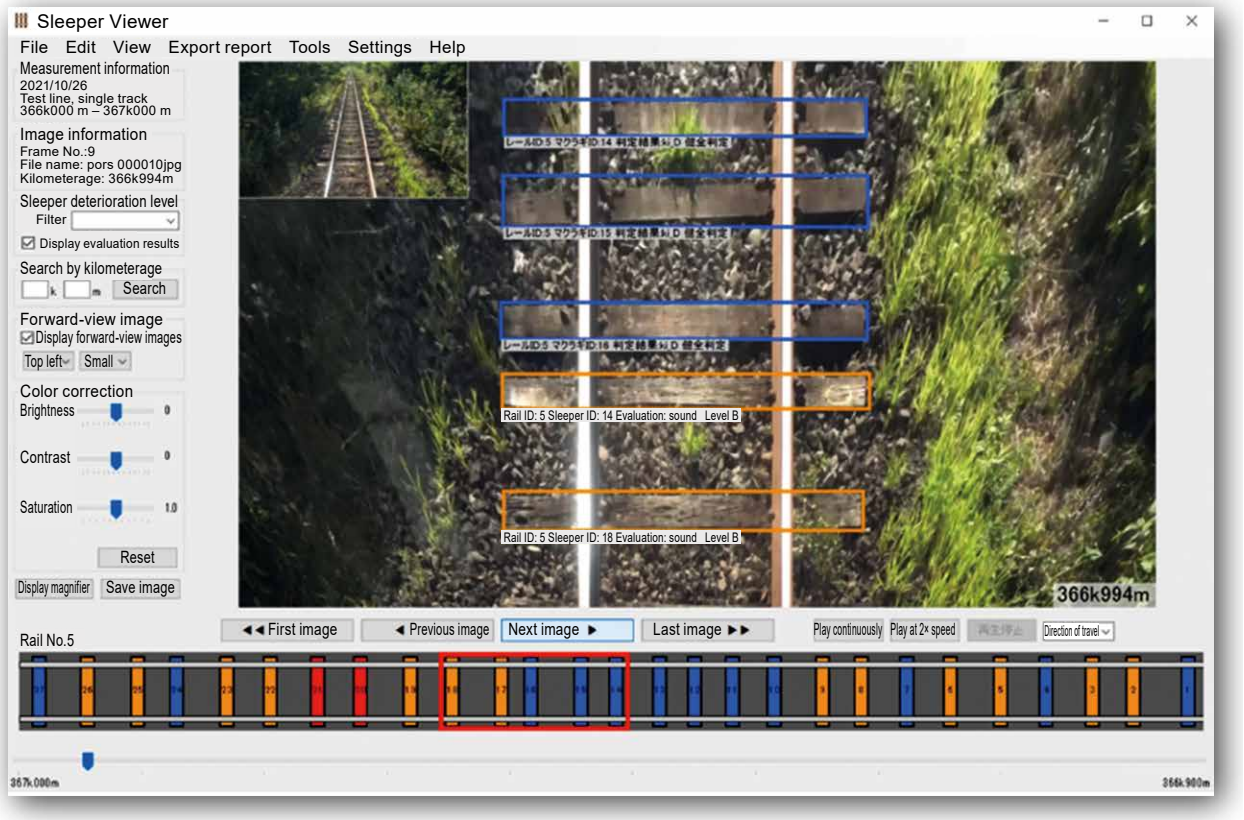


Figure 5 Example screen showing wooden sleeper deterioration evaluation results

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 Memorys 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 DetaDepot Memorys 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

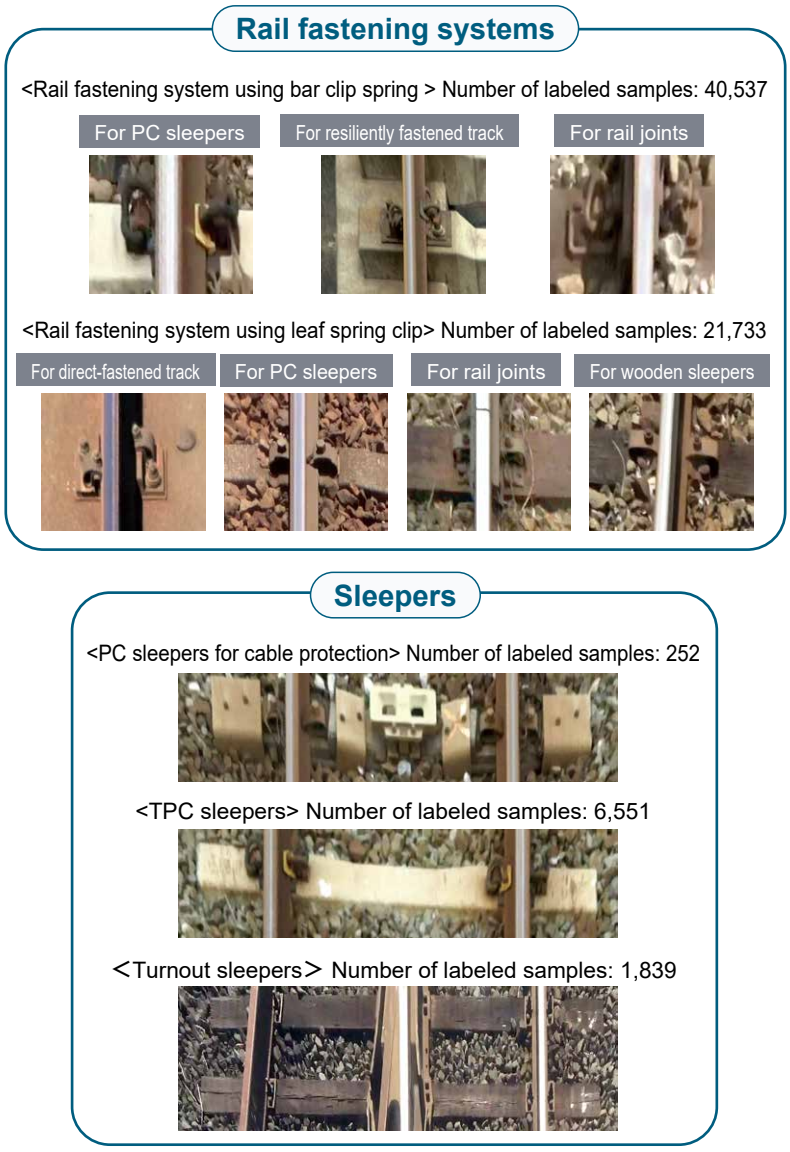


Figure 6 Track component types classified by the model

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

References

1) Railway Technical Research Institute, "Maintenance Standards for Railway Structures and Commentary (Track Structures)," Railway Technical Research Institute, 2007.
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).

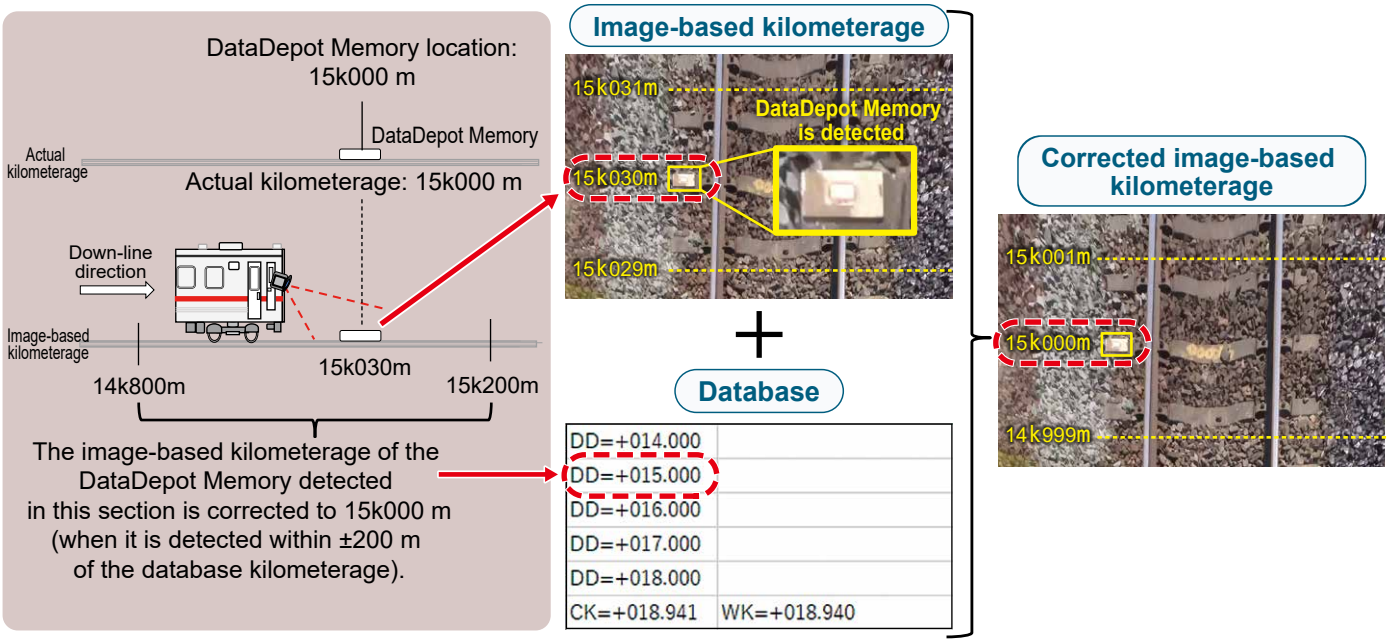


Figure 8 Conceptual diagram of kilometerage correction using a DataDepot system