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DEVELOPMENT OF A LOW-COST TRAIN PATROL SUPPORT METHOD FOR RAILWAY TRACK MAINTENANCE USING A SMARTPHONE

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Abstract

Japan is home to over 200 railway companies of various sizes. Small-scale regional railway companies, in particular, are grappling with challenging business conditions due to a declining birthrate, an aging population, and the recent coronavirus pandemic. Despite these challenges, it is imperative for these companies to conduct thorough inspections and maintenance of railway facilities and rolling stock to ensure the safety and stability of train operations. In this study, we developed a train patrol support application software that aligns with the requirements outlined in the "Maintenance Standard for Railway Structures (Track Part)" in Japan. This application software is designed to facilitate a practical approach to train patrol support using smartphones, offering a cost-effective track condition management solution suitable for small regional railway companies. We conducted experimental measurements on the commercial lines of several railway companies using the developed application software and analyzed the utility of the obtained measurement data, including acceleration data and forward-view video data, from different angles of dip. Our findings suggest that acceleration data could be instrumental in managing train vibrations by offsetting the impact of the smartphone's angle of dip. Similarly, forward-view video data could be crucial for inspecting the condition of the railway line and its immediate surroundings, with the effectiveness of the data varying according to the angle of dip at which the smartphone is positioned. By integrating this method into regular train patrols, we propose that it could enable track inspections to be conducted remotely from an office, thereby assisting in the maintenance and management efforts of regional railway companies.

Keywords: smartphone, train patrol, track condition monitoring, train vibration, forward-view video

1 Introduction

Japan is home to over 200 railway operators that vary significantly in size and span the entire country. In recent years, these operators have been confronted with the challenges posed by a declining birthrate and an aging population, further exacerbated by the global COVID-19 pandemic. Urban railway operators, located in areas with high population densities, typically enjoy a more stable business environment. Some of these operators are adopting new technologies, such as high-frequency track condition monitoring systems installed on commercial trains [1]. Conversely, local railway operators, which serve less populated areas, face a more challenging business landscape. In Fiscal Year 2022, approximately 90% of the 95 companies classified as local railway operators reported a current account deficit.

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Furthermore, many of these operators manage lines that were established before the 1940s, leading to aging infrastructure, including tunnels and bridges. Despite these adversities, it is crucial for all operators to conduct thorough inspections and maintenance of their infrastructure and vehicles to ensure the safe and consistent operation of trains.
In light of these challenges, this study investigates the potential of smartphones as a cost-effective method for managing track conditions, accessible to local railway operators. A train patrol support application software leveraging smartphone technology was developed, and its efficacy was evaluated through field tests on the commercial lines of local operators. The study specifically focused on the utility of data collected by the application software, such as acceleration and forward-view video, from various analytical perspectives.

2 Overview of train patrol and train vibration inspection

Figure 1 shows the track maintenance process in Japan, as detailed in the "Maintenance Standards for Railway Structures (Track Part)" established by the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), distinguishes clearly between track patrol and inspection [2]. These standards are intended to serve as supplementary guidelines to the "Technical Regulatory Standards on Japanese Railways (Ministerial Ordinance)" [3]. As shown in this figure, there is a clear distinction between track patrol and track inspection.

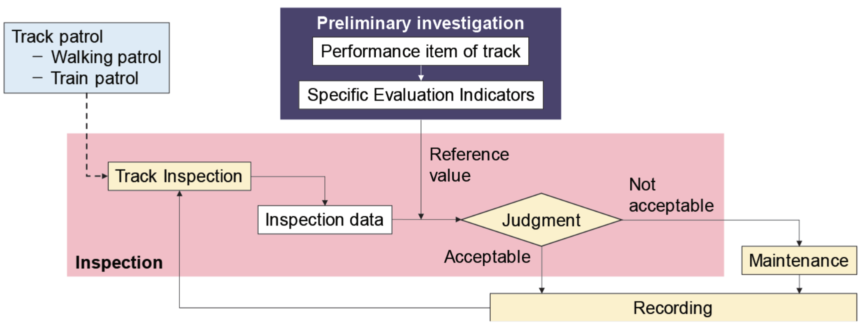

Figure 1 Track maintenance process in Japan

Track patrols are regularly conducted to assess the general condition of the tracks, and there are two types: "walking patrol" by foot or "train patrol" by railway vehicle, such as trains or maintenance vehicles. Walking patrols provide a comprehensive review of the track and its surroundings on visually check by railway staff, focusing on maintenance and material conditions. Train patrols provide a review of relationship between vehicle behavior and track conditions on physically and visually check by railway staff, primarily monitoring for abnormal vibrations, noises, and operational disturbances.
There are two types of track inspections carried out on a regular basis: "track condition inspection" and "track component inspection." Track condition inspection is mainly aimed at ensuring track performance through assessments of track geometry and train vibrations. Although train vibration inspections are not mandatory, likely due to the high cost of vibration measuring devices at the time the Maintenance Standards were established (circa 2007), they are considered vital for assessing running safety through the analysis of dynamic vehicle behavior, especially on local railways with suboptimal track conditions. Track component inspection is aimed at ensuring that various track components meet the performance requirements.

3 Train patrol using a smartphone

3.1 Outline of developed train patrol support app

Figure 2 presents the measurement screen of the train patrol support application software we developed. The application software is designed for smartphones running Apple iOS (e.g., iPhone), leveraging the ubiquity and affordability of these devices to achieve a cost-effective solution. The interface of the measurement screen is intuitively designed to ensure ease of use. Railway staff are required to carry a smartphone equipped with this application software on board the train to initiate and conclude measurements during patrols.

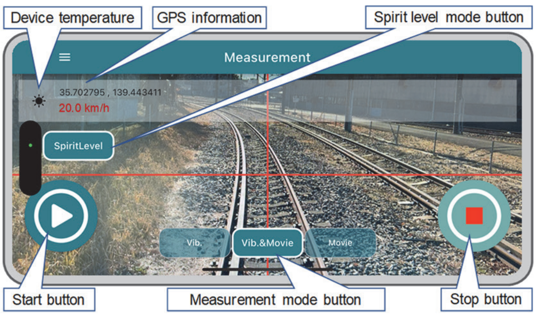

Figure 2 Measurement screen of developed train patrol support application software

Table 1 details the primary measurement functionalities of the application software. It is capable of determining the train's speed and its geographical coordinates using the smartphone's built-in GPS receiver. Moreover, the application software utilizes the device's motion sensors to measure acceleration and angular velocity across three axes and employs the rear camera and microphone to capture video and audio, respectively. Users can select from three measurement modes—"Vibration," "Vibration & Video," and "Video"—depending on their specific needs. The application software supports video with sound recording at a maximum quality of 60 frames per second (fps) and 4K resolution.

Table 1 Major measurement items of train patrol support application software

Sensor	Measurement item	Measurement mode			Sampling & file format
		Vib.	Vib. & Movie	Movie	
GPS Receiver	Travel speed	✓	✓	✓	1 Hz
	Latitude and longitude	✓	✓	✓	Text file
Motion sensors	3-axis acceleration	✓	✓		100 Hz
	3-axis angular velocity	✓	✓		Text file
Rear camera & microphone	Video with sound		✓	✓	10/20/30/60 fps, VGA/HD/ Full HD/4K, Mp4 file

The adoption of this application software is anticipated to digitalize the traditional visual inspections conducted during train patrols by utilizing video recordings. This allows for a detailed review of specific sections of interest at a later time.

The physical sensations of train vibrations, previously assessed subjectively by the railway staff, will be quantitatively measured using the application software's acceleration data. This advancement not only facilitates the numerical management of train vibrations but also potentially enables the integration of this data into formal train vibration inspections.

3.2 Installation method on railway vehicle

Typically, vibration measurement devices are mounted directly above the bogie within the railway vehicle to capture train vibrations accurately. However, this placement often results in poor GPS signal reception. By positioning the measurement device, in this case, a smartphone, at the front of the train, not only is GPS reception significantly improved, but it also facilitates the capture of forward-view video footage. It is important to note, though that installing the device at the front can lead to higher acceleration readings due to the vehicle's pitching motion and other factors [4]. The angle at which the smartphone is installed, particularly when capturing forward-view video, greatly influences the coverage area of the track in the footage.

3.3 Methods of processing measurement data

The data collected by the developed application software is saved in a standardized file format (refer to Table 1), allowing for processing with various software tools. The typical process for data handling is as follows: In Windows OS environments, the collected data is transferred to a PC using Apple's iTunes media player. Alternatively, if a Wi-Fi connection is available, the data can be uploaded directly from the application software to a dedicated server. The data is then segregated for individual processing, including acceleration, angular velocity, GPS information, and video with sound.
For processing acceleration, angular velocity, and GPS data, LABOCS [5], a track maintenance management database system developed by the Railway Technical Research Institute and widely adopted by Japanese railway operators, is utilized. LABOCS excels in signal processing related to railway tracks, capable of performing operations such as filtering, conversion from time axis to distance axis, and assignment of kilometrage. Specifically, acceleration data is transformed from time-axis waveforms to distance-axis waveforms using train speed, following the necessary filtering to evaluate train vibration. Additionally, this data can be used to generate subtitles that display kilometrage, train speed, and acceleration values on the forward-view video. Moreover, a bird's-eye view image can be created by applying a projective transformation to the forward-view image extracted from the video [6]. Due to space constraints, further details on the data processing methodologies are not provided here.

4 Example of test implementation to railway commercial line

4.1 Example of smartphone installation

Figure 3 illustrates a setup where smartphones were mounted inside a commercial train for testing. For this study, as shown in Figure 2, two smartphones (iPhone 14 Pro) were mounted at the same time for comparison. The trial was conducted on an electrified, single-track section in a rural area of Japan. Smartphone A was affixed directly to the inner surface of the windscreen using double-sided tape, while Smartphone B was mounted using a commercially available suction cup fixture. In this setup, Smartphone A was positioned at a 0° angle of dip, and Smartphone B at a 28° angle. The "Spirit level" feature of the application software was utilized to measure and record the orientation of the smartphones.

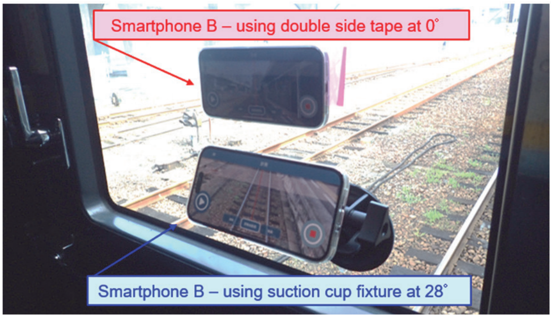

Figure 3 Example of Smartphone Installation on Commercial Trains

4.2 Example of the use of acceleration in train vibration management

Figure 4 presents a waveform of train vibration measured under the conditions depicted in Figure 3. The train vibrations, represented by the processed accelerations, were filtered through a band-pass filter with a range of 0.5–8 Hz. The waveforms from the two smartphones, despite their differing angles of dip, were largely identical.

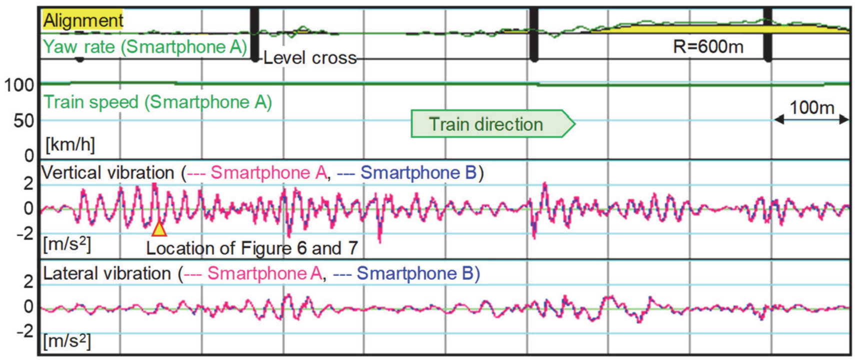

Figure 4 Example waveform of train vibration

Figure 5 displays the power spectral density (PSD) of train vibrations for a segment that includes the area shown in Figure 4. The average train speed for the analyzed segment was about 95 km/h. The frequency response showed no notable difference in both vertical and lateral vibrations. The PSDs for lateral vibrations matched closely, indicating that the mounting method did not affect the measurements. However, the vertical vibrations measured by Smartphone B were slightly lower, suggesting an impact from the angle of dip. It was determined that this effect could be mitigated by vectorially combining the accelerations measured along the X and Z axes of the smartphone.

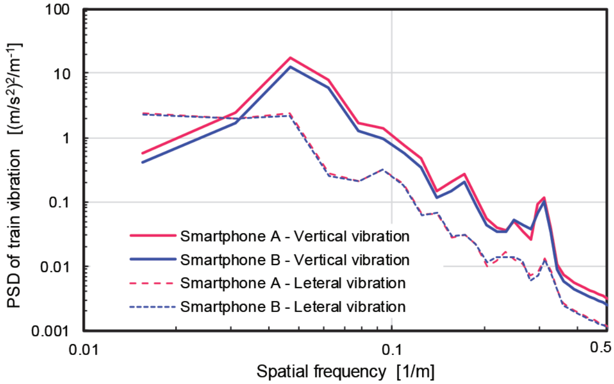

Figure 5 Example PSD of train vibrations

4.3 Example of use of forward-video for checking track condition

Figure 6 illustrates the example of to a forward-view video image with subtitles, which has been cropped for clarity. By employing the kilometrage assignment technology provided by LABOCS, it is feasible to overlay kilometrage data on the forward-view video with a precision of a few meters. The figure includes images from the location indicated by Δ in Figure 4, where mud pumping was observed in the track bed. Forward-view videos annotated with kilometrage are particularly useful for evaluating track conditions in areas with significant train vibrations, facilitating desk-based track patrols. The field of view in the forward-view video is significantly influenced by the angle of dip of the smartphone. A smaller angle allows for a broader view of the track, including overhead lines, while a larger angle provides a closer look at the immediate track surroundings.

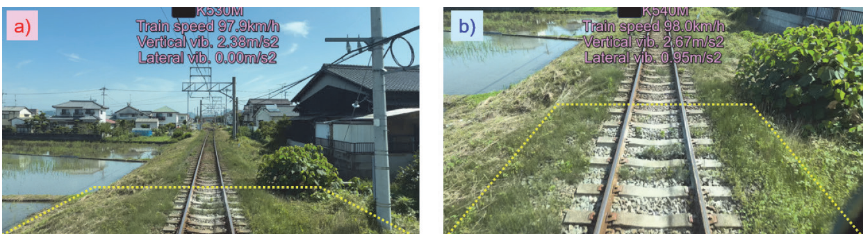

Figure 6 Example of forward-view video image: a) angle of dip 0°; b) angle of dip 28°

Figure 7 presents a bird's-eye view of the forward-view video images from Figure 6, obtained through projective transformation. The bird's-eye view from Smartphone A encompasses a relatively small area around the track, whereas the view from Smartphone B covers a wider area. Consequently, the angle of dip for the smartphone installation should be selected based on the specific area or feature under examination. These bird's-eye view images offer a detailed perspective of track conditions, surpassing the forward-view video, and are thus valuable for in-depth inspections at points of interest during desk-based track evaluations.

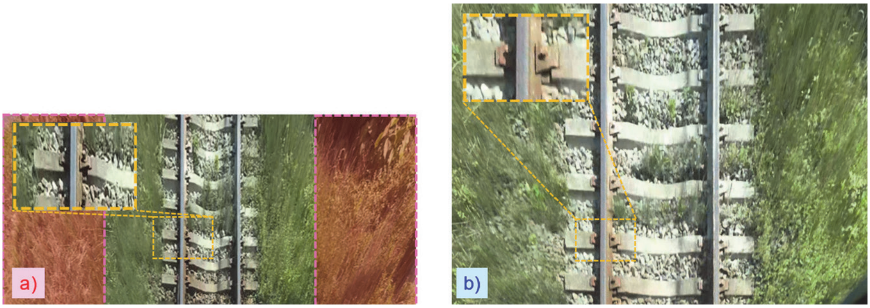

Figure 7 Example of a bird's-eye view image of forward-view image with projective transformation: a) angle of dip 0°; b) angle of dip 28°

5 Conclusion

This study explored a smartphone-based train patrol support method as an economical solution for monitoring track conditions. A dedicated application software was developed, and field tests were conducted on the commercial lines of a local railway operator, yielding the following findings:

- The application software leverages the smartphone's integrated sensors to measure train speed, geographical coordinates, acceleration, and angular velocity across three axes, as well as to record high-definition 4K/60 fps video with sound.
- A method was devised for accurately assigning kilometrage to both acceleration data and forward-view videos, facilitating efficient desk-based track patrols. It was demonstrated that acceleration data could be adjusted for the angle of dip, enhancing train vibration management. Furthermore, by manipulating the angle of dip, forward-view videos can capture a desired field of view, and the addition of subtitles enables comprehensive track inspections from a desktop environment.

Future endeavors will focus on developing a cloud system for processing and analyzing data collected through the application software, aiming to advance low-cost digital transformation initiatives within the railway sector utilizing smartphone technology.

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