Paper:

Condition Monitoring of Yangon Circular Railway and Yangon–Mandalay Railway Based on Car-Body Acceleration Response Using a Portable Device

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The population of Yangon has increased more than two times in the last 40 years and will reach 9.5 million by 2035. Owing to changes in car import policies, the number of cars in Yangon has increased from 3.6 million to 6.3 million in 5 years. This causes severe traffic congestion, resulting in social, economic, and environmental impacts. Rail transportation is one solution to this problem, but regular maintenance of railway tracks is necessary. In this study, onboard sensor measurement and satellite image analysis are used to monitor rail track conditions for the early detection of damage. The accelerometer in a smartphone is placed against the car body to measure the vertical and lateral acceleration. The smartphone vibrates as the cabin vibrates when the train passes irregular rail track sections. Phased-array-type L-band synthetic aperture radar images are analyzed using the interferometric technique to detect rail track irregularities. Thus, the rail track conditions can be estimated effectively.

Keywords: railway track, onboard sensor measurement, cabin vibration, smart phone

1. Introduction

Yangon, the former capital of Myanmar, is the largest city in the country. Its current population is 7.4 million as of the census data obtained in 2014 by the Department of Population, Ministry of Immigration and Population [1]. This population increased from 2.5 million in 1983, i.e., the population of Yangon increased 2.5 times in 30 years. Mandalay is the second largest city in the country and the focal point of the economy and social welfare in upper Myanmar. Modes of transportation in Yangon City mainly comprise private cars, taxis, buses, circular railways, and water ferries. Modes of transportation in the cities of Yangon and Mandalay mainly comprise high buses, trains, and air flights.

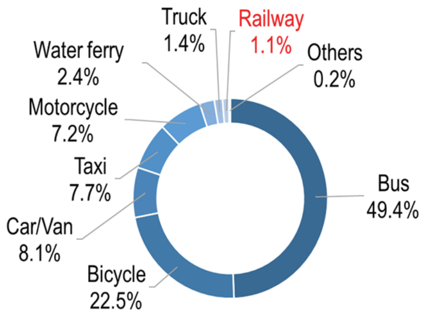


Fig. 1. Modal split of transportation excluding walk trips in Yangon City.

With the changes in car import policies made by the new government in 2010, the number of vehicles in Yangon City has tripled and become 6.3 million from 2010 to 2017 [2]. With the increased number of vehicles and lack of systematic extension of roads and streets, heavy traffic congestion is now having a significant impact on social welfare, economy, air pollution, and environment. **Fig. 1** shows the modal split of transportation in Yangon City excluding walk trips [3]. As shown in the figure, the modal split of railway transportation is approximately 1%, and the number of passengers using railway for intercity transportation is decreasing [4]. The reason for this could be that the railways in Yangon City have noticeable deterioration in facilities, equipment, and customer services. Myanmar Railways manages and operates all the railway lines in Myanmar, and they are now collaborating with the expert team of the Japan International Cooperation Agency to upgrade the railway tracks and services [5].

Synthetic aperture radar (SAR) satellites transmit microwave signals that can penetrate clouds. They are weather independent and can obtain images at all times of the day. The phased-array-type L-band SAR (PALSAR) onboard the Advanced Land Observation Satellite was an L-band radar used for observing the earth surface and was launched in 2006 [6]. Next, PALSAR-2 was

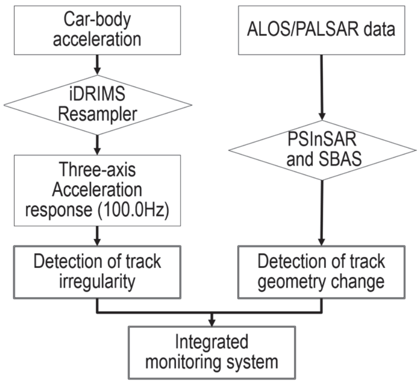


Fig. 2. Flow chart of rail track monitoring system.

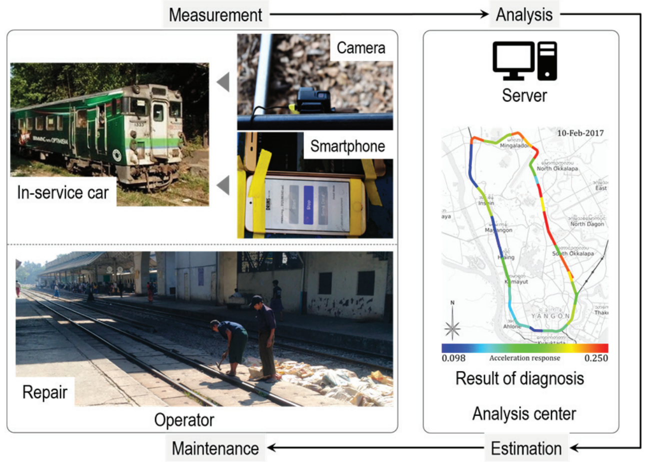


Fig. 3. Overview of portable rail track monitoring system and flow of maintenance.

launched and has been operated since 2014 as a successor model. Arimoto et al. [7] performed a study to measure the land subsidence in Semarang, Indonesia, using a small baseline interferometric SAR time-series analysis with 34 PALSAR images, and their study showed the feasibility of the use of L-band SAR data in monitoring land subsidence over time. Hashimoto [8] analyzed PALSAR images to measure the ground deformation in the Kyoto basin and Osaka plain in Japan using a 2.5D analysis and detected a land subsidence upward of approximately 10 mm/y in the southern area of the Kyoto basin.

Several studies comprising the use of satellite SAR interferometry have been conducted for the detection of surface changes along railway tracks. Chen et al. [9] attempted to observe distinct surface motions along the embankment of the Qinghai–Tibet Railway, which is the longest linear structure through the Tibetan plateau. North et al. [10] studied the use of persistent scatter interferometry for monitoring the response of railways to ground movements across six sites in England.

The objective of this research is to monitor the conditions of railway tracks in early stages of irregularities to improve comfort and speed of railways and to optimize their operation management. The devices used in this research have a low cost, are easy to set up, and are useful for monitoring large railway tracks in this country.

2. Methodology

2.1. Flow Chart and Data

Figure 2 presents a flowchart of the system used in this research. Here, the train car-body acceleration data and PALSAR-2 data are used for detecting rail track irregularities. These measurements were performed twice for the Yangon Circular Railway and Yangon–Mandalay Tracks on February 9–10, 2017, and August 22–23, 2017. Winter season is observed in February with no rain, whereas the rainy season is observed in August. The Yangon–Mandalay track measurement was performed for the train that left for Mandalay.

Table 1. Device used in the measurement and their collected data.

Collected data	Device
Carbody triaxle acceleration response and angular velocities	iPhoneSE (iDRIMS measurement)
GPS log	GPS receiver (IGotU)
Video	Wearable camera (GoPro HERO5)

The SAR images of the Yangon Circular Railway obtained from PALSAR and PALSAR-2 between 2006 and 2010 are used for the detection of the railway subsidence.

2.2. Measurement Method and Device

Figure 3 presents an overview of the portable rail track monitoring system, which comprises a smartphone-based accelerometer, GPS logger, and wearable camera. As shown in the figure, the measurement is carried out by using the dynamic-response intelligent monitoring system (iDRIMS) which is an iPhone-based iOS app that could record triaxle acceleration and angular velocities [11]. After measuring the vibration of the train's car body, data are resampled at exactly 100 Hz by the iDRIMS Resampler. This app was originally developed for road roughness estimation.

GPS track data are used to obtain the position of the train on the track and the time of the measurement, and to identify the position at which irregularities occur. A wearable camera is used to record the track condition, which is also used to compensate the analysis result observed via acceleration response. **Table 1** lists all the devices and their collected data using this rail track monitoring system.

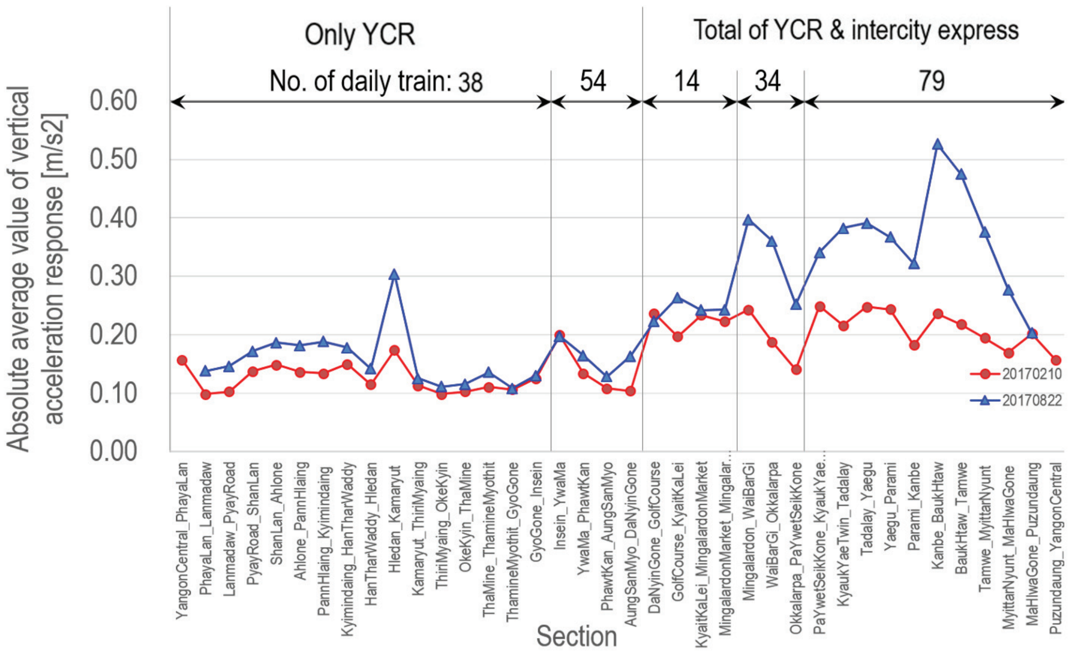


Fig. 4. Absolute average value of car-body vertical acceleration response for each section in Yangon Circular Railway (YCR) separated by stations.

3. Results

The Yangon Circular Railway is double-tracked and comprises 38 stations with a perimeter of 46 km.

The total time for the train to complete one full circle is approximately 200 min. **Fig. 4** presents the absolute average value of the car-body vertical acceleration response as measured on February 20, 2017 (red line) and August 22, 2017 (blue line). The response was calculated between each station while traveling in a clockwise direction. On August 22, 2017, no measurement was obtained between the Yangon Central and Phayalan stations, and Ma Hlwa Gone, and Pazundaung stations. As presented in the graph, there are two sections of the stations, that between Yangon Central and DaNyinGone, and that between DaNyinGone and Pazundaung. The operation frequency of the rail track is higher between Yangon Central station and DaNyinGone station, as both the YCR and intercity trains use this section. As presented in **Fig. 4**, although the operation frequency is high, the vertical acceleration response is lower than that in the other section with a spike between Hledan and Kamayut stations. The acceleration is the highest between the Kanbe and BaukHtaw stations. The acceleration value is lower in February than that in August. **Fig. 5** shows the color mapping of the measurement data presented in **Fig. 4**. A low vertical acceleration value is indicated in green, and a high value is indicated in red. The minimum value is set as 0.098 m/s^2, and the maximum values is set as 0.249 m/s^2.

Figure 6 presents the absolute average value of car-body vertical acceleration response of the railway track between Yangon and Mandalay. The measurement was obtained on August 27, 2017. As shown in **Fig. 6**, the maximum value of the absolute average value of the vertical acceleration response is 0.791 m/s^2, which was observed between Bago and Daiku stations. The values between NyaungLayPin, PeNweKone, and Phyu stations, between Yedashay and Swa stations, and between TutKone and Yamethin stations are also high. The minimum value is 0.311 m/s^2, which is observed between Yangon Central and ToeKyaungKaLay stations. **Fig. 7** shows the color mapping of the measurement data presented in **Fig. 6**.

According to **Figs. 4** and **5**, there are larger vertical acceleration responses in the eastern part of the YCR. This can also be observed in **Figs. 8** and **9**. **Figs. 8(a)** and **(b)** show the gravitational acceleration of the OkeKyin_ThaMine section and KyaukYaeTwin_Tadalay section, respectively. **Fig. 9** shows the location of those sections along the YCR track. As shown in **Fig. 8**, the KyaukYaeTwin_Tadalay section has a higher gravitational acceleration along all three axes: X, Y, and Z. The time stamps in this figure also indicate that this measurement was obtained on the same train that traveled along the right circular route.

4. Discussion

As shown in **Fig. 4**, the blue line is above the red line in the majority of the sections. During the measurement, the same type of devices was installed, but on different train bodies. As a result, the large difference in values between the blue and red lines in some sections could be attributed to different car-body characteristics, such as suspension.

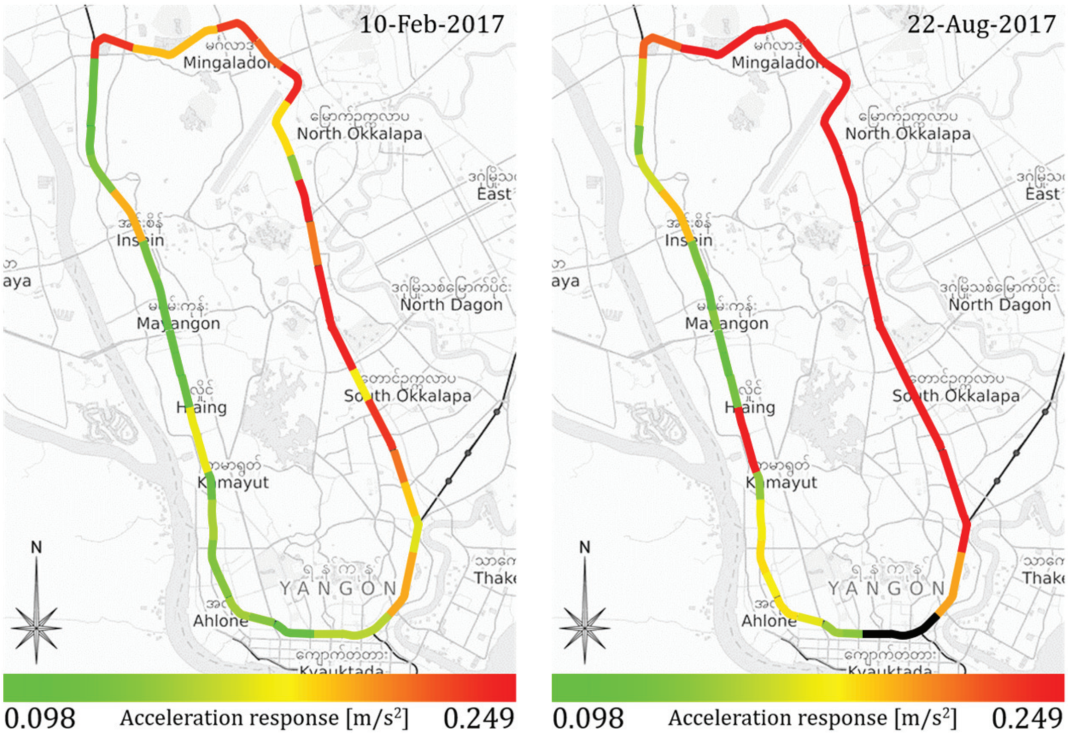


Fig. 5. Car-body vertical acceleration response for each station in YCR.

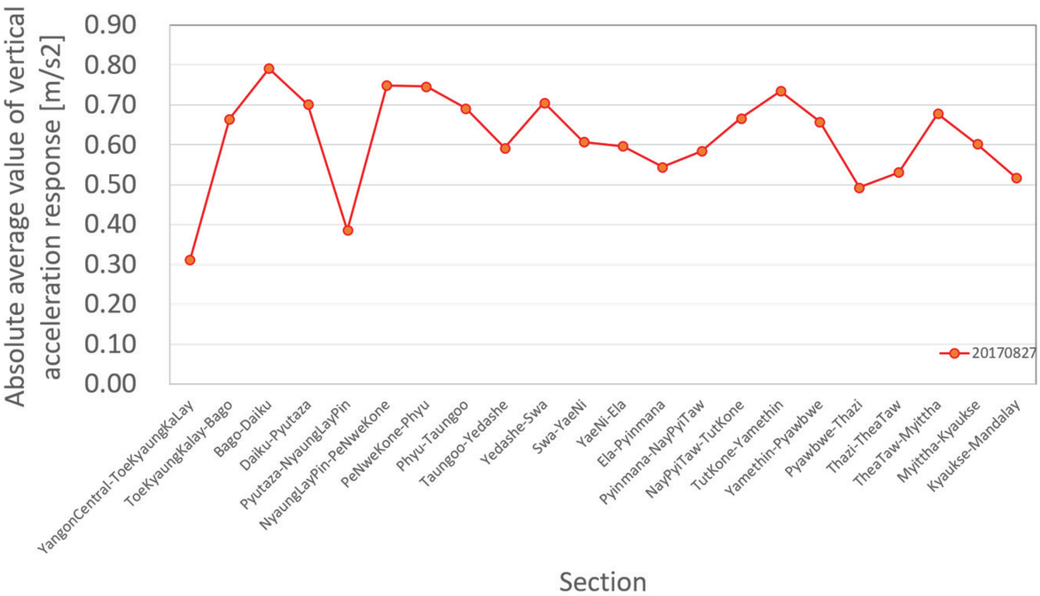


Fig. 6. Absolute average value of car body vertical acceleration response for each station separated by stations in Yangon–Mandalay railway track.

As shown in **Fig. 5**, the lower vertical acceleration values are observed in the western part of the city, that is, between Yangon Central and DaNyinGone stations. However, a higher vertical acceleration was observed in the eastern region between DaNyinGone and Yangon Central stations. Only the YCR lines are operated in the western region, while not only the YCR but also the suburban, local section, and intercity lines are operated in the eastern region.

As presented in **Fig. 4**, the number of daily trains in the eastern part is twice that in the west. This could be one of the reasons why the vertical acceleration is higher in the east. When comparing the two images in **Fig. 5**, a higher vertical acceleration is observed in August, which is the rainy season especially between Hledan and Kamayut stations and near the North Okkalapa region. Heavy rain

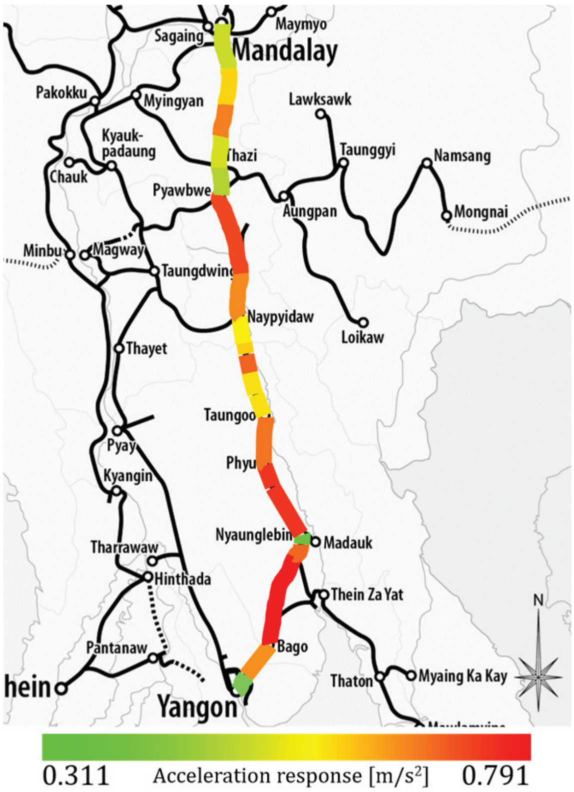
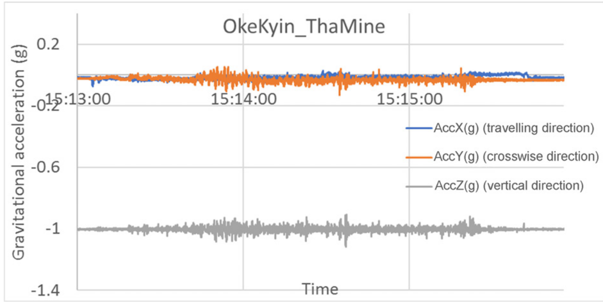
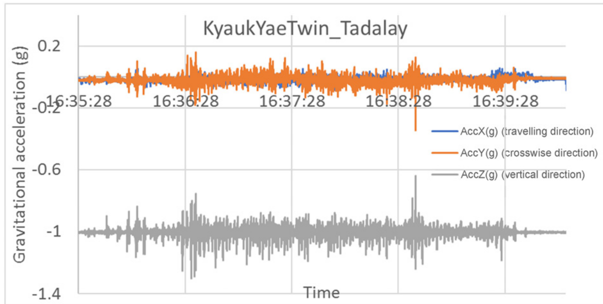


Fig. 7. Car body vertical acceleration response for each station in Yangon–Mandalay railway track separated by stations.



(a)



(b)

Fig. 8. Gravitational acceleration of the section in YCR for (a) OkeKyin_ThaMine section and (b) KyaukYaeTwin_Tadalay section.

could be one of the reasons for the car-body vibrations, and the section between the Hledan and Kamayut stations can be considered as potentially having track damage in the western part.

Moreover, as shown in **Fig. 9**, the OkeKyin_ThaMine section and KyaukYaeTwin_Tadalay section are part of the YCR route in the west and in the east, respectively. In **Figs. 8(a)** and **(b)**, the higher gravitational acceleration values along the X and Y axes in the KyaukYaeTwin_Tadalay section show that the car body shakes to a greater extent in those regions, and this is probably due to the horizontally uneven left and right lines of the railway track in that section. However, bumps in both railway lines could cause higher gravitational acceleration values along the Z axis in the western part of the YCR route.

Figures 10(a), **(b)**, and **(c)** show some bumps and anomalies that exist in the railway lines in the eastern part of the YCR. Some anomalies are found at the joints of two iron rails, as shown in **Fig. 10(a)**; however, some anomalies are randomly found, as shown in **Figs. 10(b)** and **(c)**.

As shown in **Fig. 6**, as compared with **Fig. 4**, the overall values of the car-body vertical acceleration for the Yangon–Mandalay rail track are higher than those of the YCR. The Yangon–Mandalay train is an express train that operates at a faster speed. The large differences between the values in **Figs. 6** and **4** could also be attributed to the different car-body characteristics and speeds of the trains.

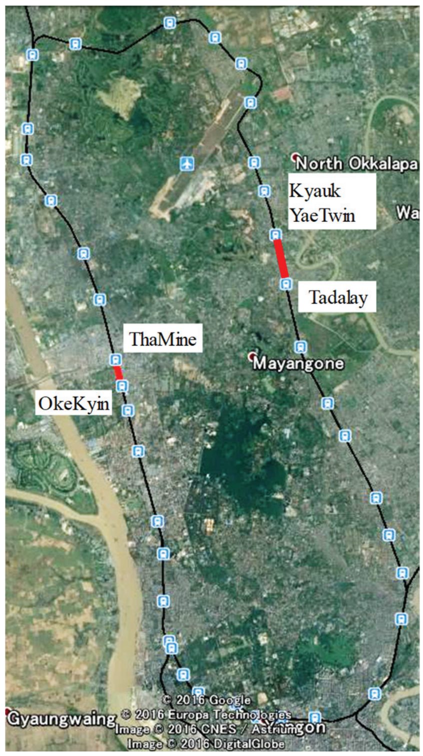
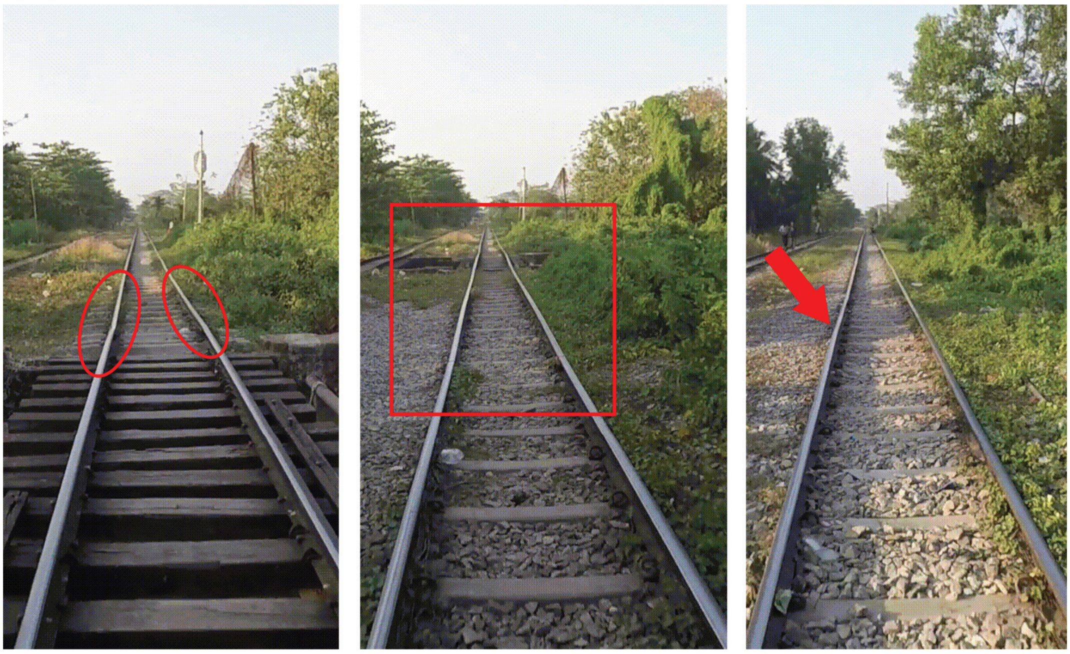


Fig. 9. Locations of OkeKyin_ThaMine section and KyaukYaeTwin_Tadalay section in YCR route.

Moreover, in the Yangon–Mandalay line, after leaving the Yangon urban area, the train passed through the paddy



(a) (b) (c)

Fig. 10. Anomalies in railway lines of YCR in the east part.

fields, wherein the ground condition is significantly different from that in urban areas. Therefore, it can also be assumed that the condition of the ground under the track could also be one of the factors contributing to rail track damage.

5. Conclusions

In this study, vertical car-body acceleration data were used to detect irregularities in the rail tracks of the YCR and Yangon–Mandalay line. In addition to the analysis of the car-body vertical acceleration between each station for YCR, various trends in the track conditions between the western and eastern sections are discussed. These results indicate that the ground conditions under the tracks that are mainly affected by water owing to heavy rains or the existence of paddy fields are one of the important factors resulting in track damage.

Our next step comprises the use of an interferometric SAR analysis of the PALSAR and PALSAR-2 data obtained for these lines and for detecting railway subsidence along the tracks. By analyzing changes in the track chronologically from periodic and instantaneous SAR data, damaged sections of the rail tracks can be inspected at early stages. Moreover, the integration of two monitoring systems, satellite SAR data analysis and onboard portable monitoring system, can improve the outcomes of rail track maintenance and operation works.

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