Basic Concepts of Buried Wireless Sensor under Ballasted Layer

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***Abstract*— The impact of train loading deteriorates ballasted track that has differential settlement of ballasted layer primarily around rail joints. However the formation process of settlement has not yet clarified. With the development of Information and Communication Technology (ICT), the research on applying the remote monitoring system using Wireless Sensor Network (WSN) has become prevalent in railway equipment. This study focuses on the track monitoring, especially ballast condition, and conducted experiments of WSN to apply that monitoring. From a result of the experiments, the large attenuation by ballast was not confirmed, therefore, WSN can be used to monitor the condition of ballast.**

Keywords-railway tracks; ballast; monitoring system; raido wave propagation.

I. Introduction

Ballasted track is a general track structure on railways; it consists of a ballast, such as gravel and crushed stone, sleepers, and rails. Ballast settlement is normally caused by the repeated loading of train traffic and its progression occurs sparsely and locally, which has been a long-standing problem, as a challenge in the track maintenance. It is known that ballast settlement progresses rapidly particularly where impact load occurs, such as rail joint, see Figure 1. Uneven ballast settlement leads to "Hanging Sleeper," which induce sleeper vibration. To provide safety running of trains and comfortable riding, regular track maintenance is required, such as ballast maintenance by ballast tamper, which takes a lot of cost and effort. Therefore, the research of reducing maintenance work has been studied, for example, the method of elastic bottom sleepers to disperse the load transmitted from sleepers to ballast [2] and prevention of ballast settlement to fix the ballast by grout [3]. Also, the vibration acceleration of the ballasted layer is measured by embedding a “ballast sensing stone” with piezoresistive triaxle acceleration sensors in a track ballast [4] to observe the relationship of dynamic response of ballasted layer and ballast settlement. The ballast sensing stone has to be embedded in a track ballast for each measurement, but this will loosen the track.

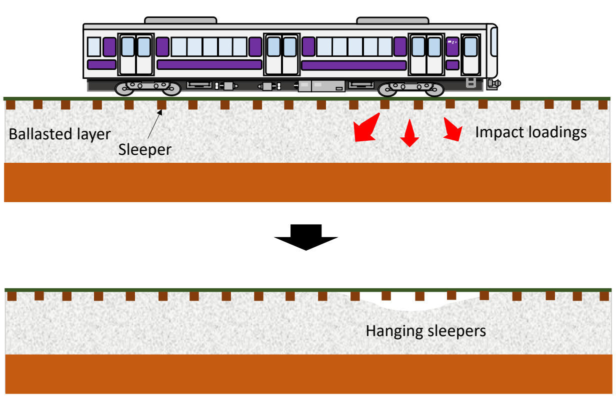

Figure 1. An image of the ballast settlement

With the development of ICT, the research on a condition monitoring system for remotely monitoring the condition of equipment using WSN has proceeded in a railway field. In WSN, the measurement data from sensors can be acquired over a long period of time by the installed wireless sensor node on a monitoring target. Thus, applying WSN can be expected to reduce maintenance and measurement work. By developing a device that integrates vibration acceleration and wireless sensor with respect to the ballast sensing stones installed inside the ballast which mentioned in the above, it is possible to reduce loosening of the track. In this paper, the sensor node, which is buried in the ballast in the long term for condition monitoring and is applied to the wireless sensor network, is examined.

The rest of the present paper is organized as follows: Section II introduces related work about monitoring track. In Section III, we propose the measuring system for the ballast layer. In Section IV, we introduce our verification test for communication between sensor nodes buried under ballasted layer and receiver placed outside of the ballast, and we indicate its result. Finally, Section VI concludes the present paper.

II. Monitoring Track

This section introduces conventional researches and problems for adapting them for monitoring tracks.

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A. Related Work

As the research on the condition monitoring of track, the framework for monitoring tracks, with a network where sensor nodes transmit to base stations via wireless transmission, was proposed [5], see Figure 2. In Figure 2, the data collected by WSN is transmitted to the server via the Internet, and this data is stored in the database at the server and also can be checked on the monitor.

It is required to monitor various points and items for recognizing the condition of tracks in [6], shown in Figure 3. According to [6], it can be seen that the monitoring point exists below the ballasted layer. Correspondingly, track condition monitoring systems have been already proposed with wired or wireless transmission.

As an example of using a wired transmission, a remote monitoring system shown in [7] collects the data under ballast into a laptop pc installed along a track wayside using wired cable called probe and transmits the collected data to a remote place via Internet, shown in Figure 4. As an instance of using wireless transmission, a system for transmitting the sensing data of rail using wireless sensor was proposed in [8]. However, the research on a remote monitoring for points below the ballasted layer using wireless sensor nodes has not been presented. Therefore, it is necessary to verify that the sensor node buried below the ballasted layer can transmit the data to the base station using wireless communication.

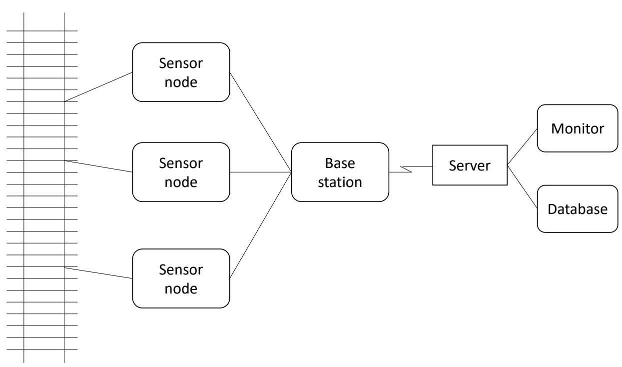

Figure 2. System framework for monitoring tracks [5]

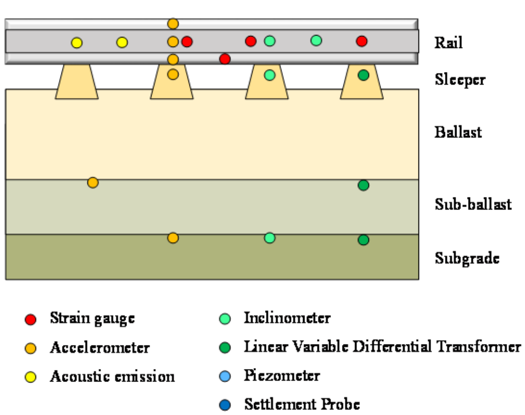

Figure 3. Schematic location of the sensors used for condition monitoring [6]

B. Problems

In the railway system in Japan, the periodic patrol that the maintenance worker carries out inspections by walking on the patrol path provided along tracks is generally conducted. Therefore, in addition to the problems, such as cable break, passages for workers may not be cleared due to the wires for the monitoring system. The wired system can also be expensive to maintain, as they have external damage as described in [6].

When considering a sensor that transmits data by wireless, it is necessary to verify the communication between below ballasted layer and outside ballast. Therefore, this paper proposes the monitoring system collecting data under ballast and its sensor node and discusses the possibility of their application.

III. PROPOSED MEASURING SYSTEM

This section introduces the concept of sensors in ballast layer for monitoring tracks.

A. Overview of the system

The overview of the proposed monitoring system is shown in Figure 5 [9]. As before, we define network from sensor nodes to the base station as WSN.

In the proposed WSN for monitoring under the ballasted layer, sensor nodes installed in the ballast transmit the data to the base station. In cases where a sensor node cannot directly transmit the data to the base station and consume the large power due to frequent communication failure, a relay node is installed in the ballast shoulder, receives the data from the

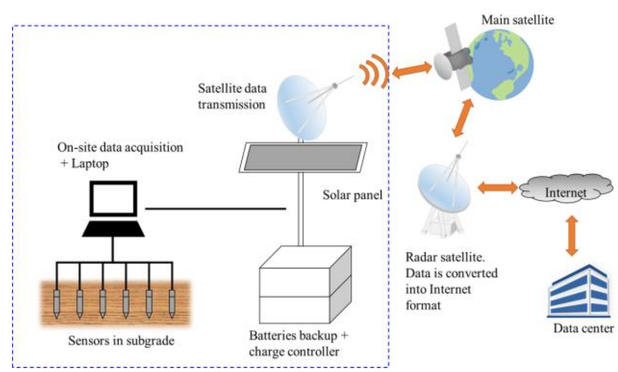

Figure 4. Remote monitoring system package [7]

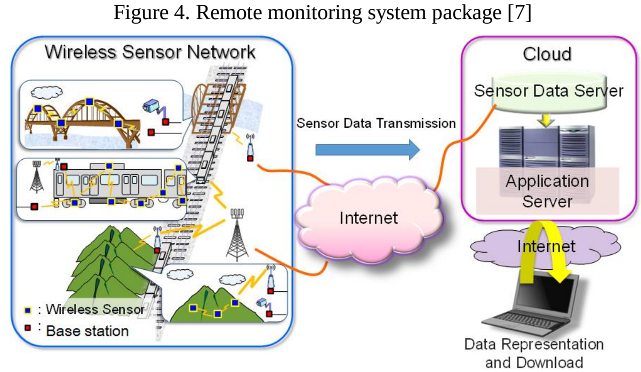

Figure 5. Condition monitoring system for Railway [9]

sensor nodes, and appropriately sends their data to the base station.

B. Buried wireless sensor node under ballasted layer

The following shows the sensor node buried under ballasted layer. Figure 6 shows the position of the sensor under the ballast and its composition. The sensor node consists of a sensor for measurement, memory for temporarily storing sensing data, a wireless module for transmitting sensing data, a CPU for controlling them, and a battery. It has the memory to store the sensing data, so it can transmit when there is no train passing, for example, the time zone of train operation. We suppose that the sensor node is installed under ballasted layer and left to monitor, so its maintenance, such as battery changing is not needed. However, there is some possibility of the sensor node trouble, so it is necessary to consider how to grasp its condition and reliability of sensing data, and so on.

IV. FUNCTIONAL VERIFICATION

429 MHz, 920 MHz, and 2.4 GHz band, which does not need a license, are mainly used for WSN in Japan. We made experiments to verify the reachability of 429 MHz band radio wave and 920 MHz band radio wave from inside of the ballast to outside of the ballast. Both of the frequencies of 429 MHz and 920 MHz band have good diffraction properties, compared with 2.4 GHz band. Although those bandwidths are narrow so those transmission speeds are lower than 2.4 GHz's, those speeds are enough to transmit data several times a day. Moreover, those frequency bands have wireless modules of the radio communication standards classified as Low Power Wide Area (LPWA). We use MU-2-429 (Figure 7 left side) [10] as a 429 MHz band wireless module and BP35A1 (Figure 7 right side) [11] as a 920 MHz band wireless module for the experiment.

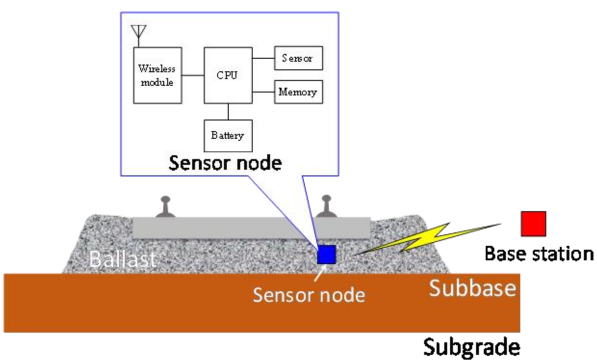

Figure 6. Buried wireless sensor node under ballasted layer

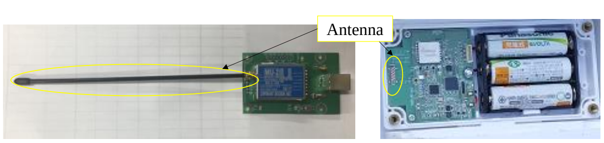

Figure 7. Wireless modules used in the experiment

Figure 8 shows the experimental conditions and Figure 9 shows its scenario. Condition 1 is the state of the transmitters not buried under the ballasted layer, condition 2 is that the ballast is filled by 65mm more than condition 1 and the transmitters are buried under ballasted layer. Then, condition 3 is that the ballast is filled by 60mm more than condition 2 and the transmitters are buried completely under the ballasted layer. We buried wireless modules in a resin-made box under the ballasted layer as transmitters and put wireless modules as receivers at a distance of 5 m from transmitters. We measured the Received Signal Strength Indicator (RSSI) of the receivers.

Figure 10 shows the result of the experiment for using 429 MHz band wireless module, and Figure 11 shows it for using the 920 MHz band wireless module. They show loss of each condition based on the RSSI of the condition 1. Their loss does not exceed 3 dB, so we cannot find an influence of the ballast to propagation characteristics under our experiment's conditions. The possible reason for this is that there were many gaps in the ballasted layer. Then, it is possible to get different results, depending on the positional relation between stones of ballast and antenna. Therefore, the

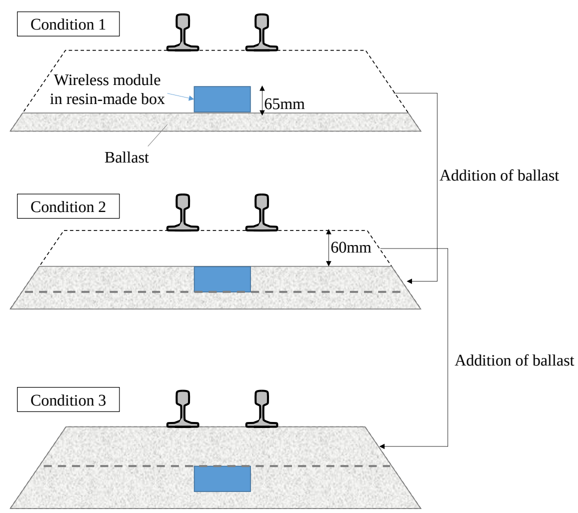

Figure 8. Experiment conditions

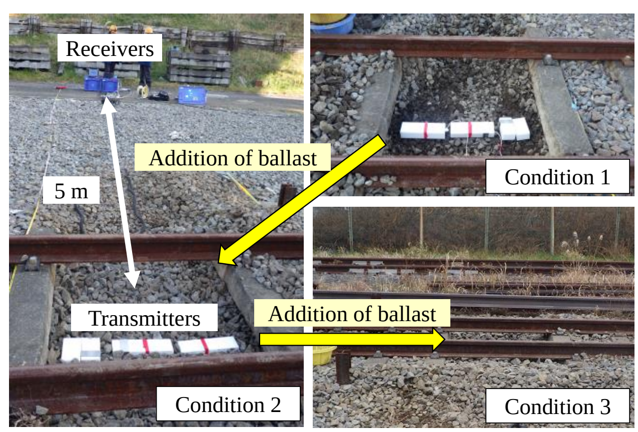

Figure 9. Experiment scenario

loss of RSSI might be affected by ballast fluctuations due to maintenance and train passing, etc.

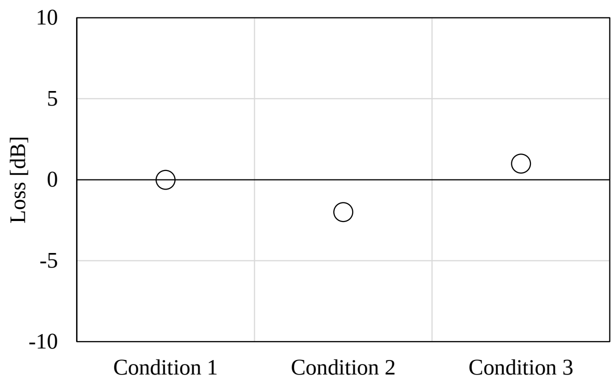

Figure 10. An experiment result for using 429 MHz band wireless module

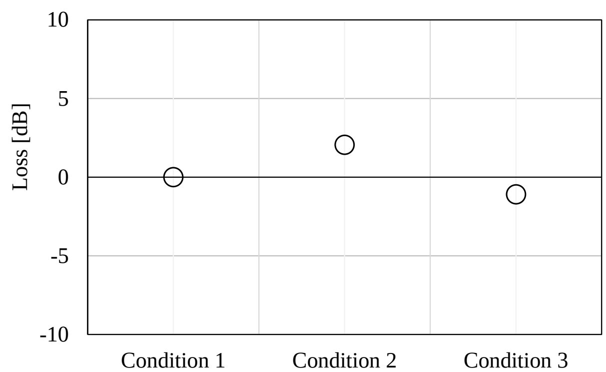

Figure 11. An experiment result for using 920 MHz band wireless module

V. CONCLUSION

This paper proposed the sensor node buried under ballasted layer for the condition monitoring of tracks. To confirm the wireless transmission from the sensor node buried under the ballasted layer, we examined the communication test using wireless devices whose frequency is 429 MHz bandwidth and 920 MHz bandwidth. From the result of the tests, it was confirmed that the amount of attenuation was within 3 dB. Therefore, it can be said that the wireless transmission can be used for communication of the sensor node buried under ballasted layer. However, a dense ballast could cause blockage of the radio propagation path inside that ballast, so further verifications are required under different ballast conditions. We are going to make the prototype and to verify our proposed system at the field considering actual use. In addition, it needs to be examined a method of correcting the acceleration data, because its axis gets shift with long-term use. In practical use, reliability and weatherability of sensors themselves are

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