Routing Algorithm Based on the Transmission History for Monitoring Railway Vehicles

Nagateru Iwasawa, Satoko Ryuo, Tomoki Kawamura and Nariya Iwaki
Signalling and Transport Information Technology Division
Railway Technical Research Institute
Tokyo, Japan
e-mail: iwasawa.nagateru.81@rtri.or.jp

***Abstract*— Efforts have been made to utilize the Wireless Sensor Network (WSN) to monitor the state of railway facilities, such as structures, tracks, vehicles, etc. In monitoring the condition of railway cars, items such as the brakes, the train speed, the truck vibration, etc. are subjected to monitoring. We are developing a system under which the crew can monitor the condition of the train's vehicle in real time. In cases where data are transmitted when the train is running, it is assumed that the communication distance between the wireless terminals changes according to changes in the radio wave propagation environment. Therefore, in this paper, we propose a transmission method when the train is driving, and also conduct a functional verification test by an actual machine.**

Keywords-routing algorithm; railway vehicle; monitoring; radio wave environment.

I. Introduction

Recently, with the development of information and communication technology, studies on the monitoring of the condition of the railway facilities by using the WSN have been in progress [1][2]. They cover diverse fields, such as the structures, the tracks, the overhead contact lines and the vehicles. Furthermore, the purpose of the monitoring is extensive. Two examples are the detection of abnormal values due to sudden condition changes, such as the landslide and derailment, and understanding, via long-term monitoring, of the tendency to deterioration of the facilities. In the railway vehicle condition monitoring, data such as the control information of brakes and air conditioning, train speed, train positions, temperature and vibration of the bogie are collected. In this paper, our purpose of the railway vehicle monitoring is that the crew of the train confirms the control information of the brake in a minute.

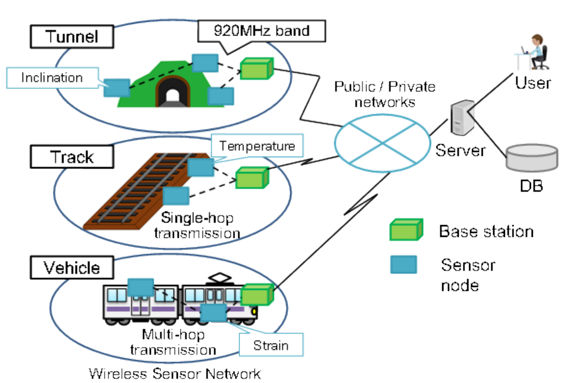

Figure 1. Example of WSN for railway condition monitoring

Figure 1 shows a typical WSN setup for railway condition monitoring [2]. The WSN consists of sensor nodes that measure the physical quantity and wirelessly transmit it as sensor data and a base station that collects data. Furthermore, the base station transmits the data to the server via a network like the mobile telephone network as necessary. Also, the server accumulates the data in the Data Base (DB). The users can access the data in the DB via the public or the private network. In the train consisting of multiple vehicles, if the vehicles condition is monitored, the sensor nodes of the WSN are installed linearly. The ways of the transmission the sensor data from these sensors to the base station are single-hop and multi-hop. Besides, in areas where fixed power sources, such as a bogie cannot be supplied, the sensor nodes are driven by the batteries, so efficient power consumption is required. When the distance between the lead vehicle and the last vehicle is several hundred meters, in order to make a single-hop network, it is necessary to increase the transmission power. Of course, there is a possibility that direct communication between the lead vehicle's node and the last vehicle's node cannot be performed with the prescribed transmission power. So, it is important that the WSN of the train need efficient multi-hop routing. For example, some sensor nodes are grouped, and one sensor node in each group aggregates the sensor data, and the base station collects data via the aggregated sensor nodes [3][4][5]. In addition, a method of constructing a Wireless Personal Area Network (WPAN) using ZigBee for communication within a group and configuring a Wireless Local Network (WLAN) using Wi-Fi for communication between groups and base stations has been proposed [6]. However, the sensor nodes included in each group are fixed, so it is not taken into consideration that the coupling given thought that the coupling and the decoupling train vehicles causes groups and the base station to change. And the wireless communication technology for WSN called Low Power Wide Area (LPWA), such as LoRaWAN and SIGFOX can be construct a fixed wide network. So, it is applicable as long as the train set does not change.

On the other hand, in the ad hoc network, it is possible to construct a network with a base station and the sensor nodes among neighbor vehicles and collect data. So, it is suitable for a system under which all the sensor data of the trains in the area are accumulated in the DB and the users can browse the data in it. But in such a system, overhead occurs when the train crew browse the data in the DB due to data transmission from the base station to the DB and the access to the data by the train crew. Therefore, it is necessary to construct a network among the base station and the sensor nodes of one train set so as to reduce the length of time until the crew checks the data. For example, it is possible to construct an ad hoc network between the base station and the sensor nodes by manually setting the same network IDentification (ID) on base station and sensor nodes. But considering the time required for setting the network ID and the possibility of misconfiguration, it is desirable to automatically construct the network in the train set. In ad hoc network research, a method of estimating the location of a sensor node based on the Received Signal Strength Indicator (RSSI), the Time Of Arrival (TOA) and the Time Difference Of Arrival (TDOA) has been proposed [7]. However, it is not realistic because it may result in errors with a probability of 50% or more. Also, instead of the Global Positioning System (GPS) with high power consumption, a method capable of discriminating between vehicles of the same train and different train based on the correlation between the data for several seconds obtained from the acceleration sensor has been proposed [8]. However, there are problems in that it is necessary to scale down in order to implement it on the Central Processing Unit (CPU) of the sensor node, etc., because MATrix LABoratory (MatLab) [9] analyzes data offline.

Therefore, we have proposed a system configuration and a method of automatically constructing a closed network within a train set at the time of the train is stopping at a station, taking into consideration the coupling and decoupling [10]. In this paper, we propose a method of efficiently collecting data in the network of the system mentioned above at the time the train is running.

The rest of the present paper is organized as follows: Section II presents our proposed system for the railway vehicle monitoring. In Section III, we propose the routing algorithm for the monitoring system at the time the train is running. In Section IV, we implement the proposed algorithm in a prototype, and we indicate the result of the function verification test with it in Section V. Finally, Section VI concludes the present paper.

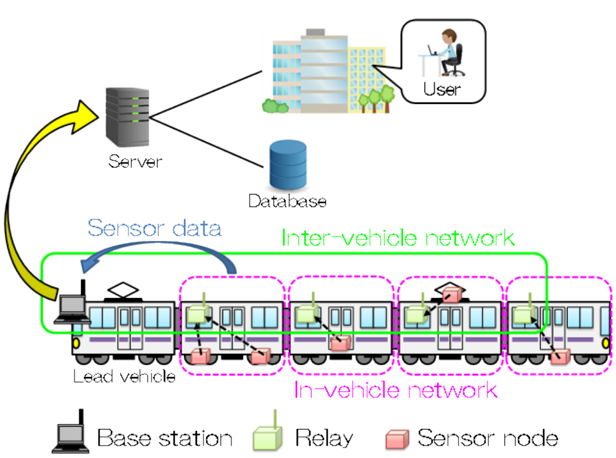

Figure 2. Proposed system configuration for monitoring vehicles

II. SYSTEM PROPOSED

A. System Configuration [10]

Figure 2 shows the system configuration we have proposed regarding the construction of a network for each train set for collecting data. First, the in-vehicle network consists of a relay and sensor nodes in one vehicle. The relay relays the sensor data from the sensor nodes. The networking components of this network are not variable even if the train set changes according to the coupling and decoupling, so it may be a fixed network. Therefore, the communication between the relay and the sensor node in this network is possible using a wired as well as a wireless network.

Next, the inter-vehicle network consists of a base station and relays in one train set. The base station collects the sensor data from the relays. The base station comprehends the vehicles and the relays of its own train and constructs a network based on the organization information in the operation plan of the vehicles. By selecting a frequency band different from that of the in-vehicle network, it is possible to communicate using the in-vehicle network independently from the communication which is being made simultaneously using the in-vehicle network, suppressing the interference in the own system.

B. Problem of Communication at the Time the Train is Runnning

There is concern that the communication quality at the time the train is running fluctuates under the fading and the influence of change in radio environment. Figure 3 shows the measurement results of the radio environment of a band of 920MHz, which is the Industrial, Scientific and Medical (ISM) band of Japan at two stations in the suburban and urban areas. Figure 4 shows a scene of the measurement. It indicates that the frequency used differs according to the location. Therefore, when using a specific frequency, it is assumed that the communication quality fluctuates as the location changes. In particular, it is thought that the influence on long-range inter-vehicle communication is greater than the in-vehicle communication. In this paper, we propose a routing algorithm in the inter-vehicle network considering change in communication environment.

III. PROPOSAL OF NEW ROUTING ALGORITHM

A. Transmission Matrix[10]

In the inter-vehicle network of the system proposed, a transmission matrix as show in the Table I is created at the time of network configuration and it is memorized in the base station. Since the transmission matrix is created based on the train sets information and communication confirmation, the physical distance and the communication environment at the time of network configuration are taken into consideration. The relay number represents a vehicle number, for example, relay 1 means a relay of the first vehicle. The vehicle number is a unique number of a vehicle,

 ISBN: 978-1-61208-669-9

and the same number does not exist elsewhere. And 1 in the Table I indicates a communication candidate link, 0 indicates that it is not a communication candidate link. For example, between the base station and relay 1, 2, 3 there are communication candidate links. It means that the communication candidates of the base station are relay 1, 2 and 3. In addition, we assume symmetric communication quality, the communication candidate of relay 1, 2 and 3 is the base station. Also, if the communication toward the base station is designated as the communication in the uplink direction and the communication toward the relay as the communication in the downlink direction, the base station and the relays hold uplink direction and downlink direction communication candidates in the routing table respectively. For example, relay 2 holds {Base station, Relay 1} as the uplink communication candidate, {Relay 3, Relay 4} as the downlink communication candidate in the routing table. In the data collection immediately after the network configuration in stopped train, based on this routing table, the routing is performed with the number of hops as a metric in [10]. When changes in the communication environment are not considered, it is desirable to transfer data to the relay close to the destination node and reduce the total number of hops, thereby reducing the total power consumption in the

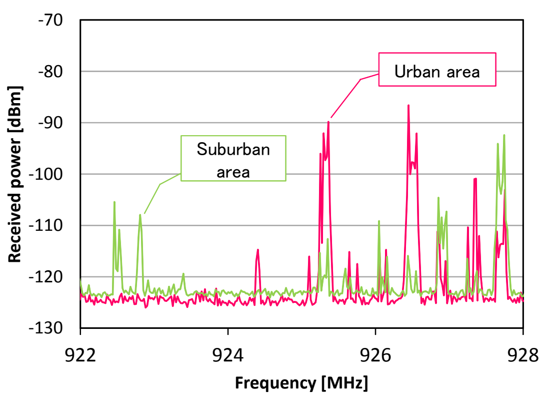

Figure 3. Measurement results of radio environment

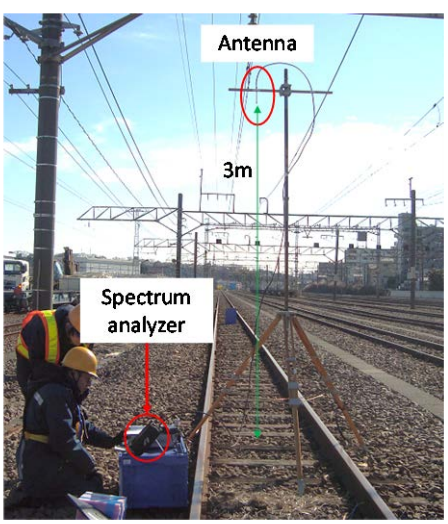

Figure 4. Scenery of measuring radio environment

network. However, if the communication quality deteriorates and data cannot be transferred from the relay 3 to the base station, the relay 3 tries to transfer them to the relay 1. Changing the transfer destination causes an increase in the power consumption due to retrial and in the latency due to timeout.

B. Routing Algorithm Considering Environmental Change

As a method of grasping changes in the communication environment, there is a method of periodically sending the hello packets between nodes as communication candidates and monitoring the RSSI [6]. However, periodic packet transmission increases the traffic of the entire network, and the power consumption of the entire network also increases. Therefore, we examined a method of dynamically determining a transfer destination from communication candidates based on the result of past data communication. Regardless of the frequency of hello packets, it does not need the power to transmit them. The base station and the relays hold a table of an arbitrary length α + 1 called a transmission history table; one for the uplink direction (called forward history table) and the other for the downlink direction (called backward history table). Figure 5 shows an example of the transmission history table of relay2 in Table I. They hold the result of, in order of lateness, the most recent to the αth transmissions which were made in the uplink direction and those in the downlink direction and the downlink direction and update them in the First In First Out (FIFO) format. Character 1 in the transmission history table indicates successful data transmission and character 0 in it indicates data transmission failure. The data transmission failure or success is judged by the presence of the ACKnowledgement (ACK) from the destination node to the source node. The first column always holds 1. If it does not hold 1, there is a

TABLE I. EXAMPLE OF TRANSMISSION MATRIX

	Relay 1	Relay 2	Relay 3	Relay 4	Relay 5
Base station	1	1	1	0	0
Relay 1	—	1	1	0	0
Relay 2	—	—	1	1	0
Relay 3	—	—	—	1	1
Relay 4	—	—	—	—	1

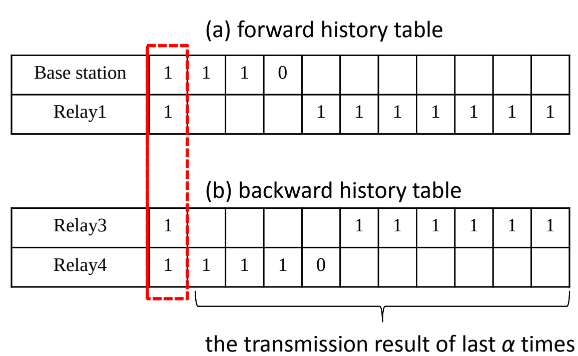

Figure 5. Example of a transmission history table

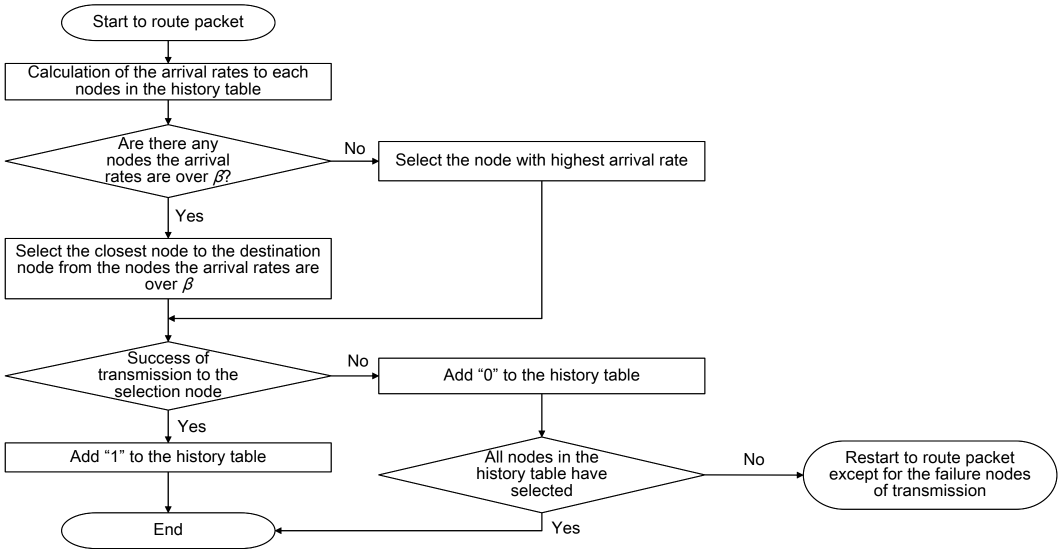

Figure 6. Basic procedure for determining the transfer destination relay

Base station	1	1	1	0								75%
Relay1	1				1	1	1	1	1	1	1	100%

Base station	1	1	0									67%
Relay1	1			1	1	1	1	1	1	1	1	100%

Base station	1	0										50%
Relay1	1		1	1	1	1	1	1	1	1	1	100%

Base station	1											100%
Relay1	1	1	1	1	1	1	1	1	1	1	1	100%

Figure 7. Example of the operation of the transmission procedure

possibility that the node whose priority has dropped due to deterioration of the radio wave environment may not be selected again. This leads to the increase in the number of hops. Therefore, holding 1 in this column, it is possible to raise the priority again for the node whose priority has dropped.

Figure 6 shows the basic procedure for determining the transfer destination relay based on the transmission history table. The arrival rate is the probability that a transmission from a node to the other node in a specific period $\alpha + 1$ has succeeded. This algorithm preferentially selects the furthest node among the nodes whose arrival rate is higher than the threshold value β set. In the forward history table of relay 2 in fig. 5 (a), we will assume β, which is the threshold of arrival rate, to be 0.9. Figure 7 shows an example of the operation of the transmission procedure. First, in fig. 5 (a), since the rate of arrival at the base station is 0.75 and the rate of arrival at relay 1 is 1.0, transmission from relay 2 to relay 1 the arrival rate of which is greater than β in the uplink direction is selected. After that, the forward history table in cases where it was transferred to relay 1 successfully is shown in fig. 7. Next, the table is updated with the passage of time, and the arrival rate from relay 2 to the base station decreases. Last, since the rate of arrival from relay 2 at the base station and that at relay 1 are both 1, base station is selected in the next transmission. In this way, by always holding 1 in the first column, the relay which failed in transmission is also selected again. Therefore, when the communication environment is improved, it can be expected to reduce the number of hops. It is assumed that the communication distance between nodes changes according to changes in the radio wave propagation environment. However, even if this algorithm is used in the environment where the communication distance does not change, the performance equivalent to the hop metric algorithm.

TABLE II. SPECIFICATIONS OF THE WIRELESS MODULE

Standards-compliant	ARIB STD-T108 (Japan), IEEE 802.15.4g/e
Frequency	922.3 ~ 928.1 MHz
Band width	200 kHz, 400 kHz
Modulation method	2GFSK
Baud rate	50 kbps, 100 kbps
Transmission power	1 mW, 10 mW, 20 mW

IV. IMPLEMENTATION

We implemented the proposed method described in Section III(B) in a prototype. Figure 8 shows the prototype. The base station consists of a wireless module and a laptop that controls it. And the relay consists of a wireless module, a CPU board that controls it, and a battery. Table II shows the specifications of the wireless module [11]. Then, Figure 9 shows the frame format in the inter-vehicle network. In this

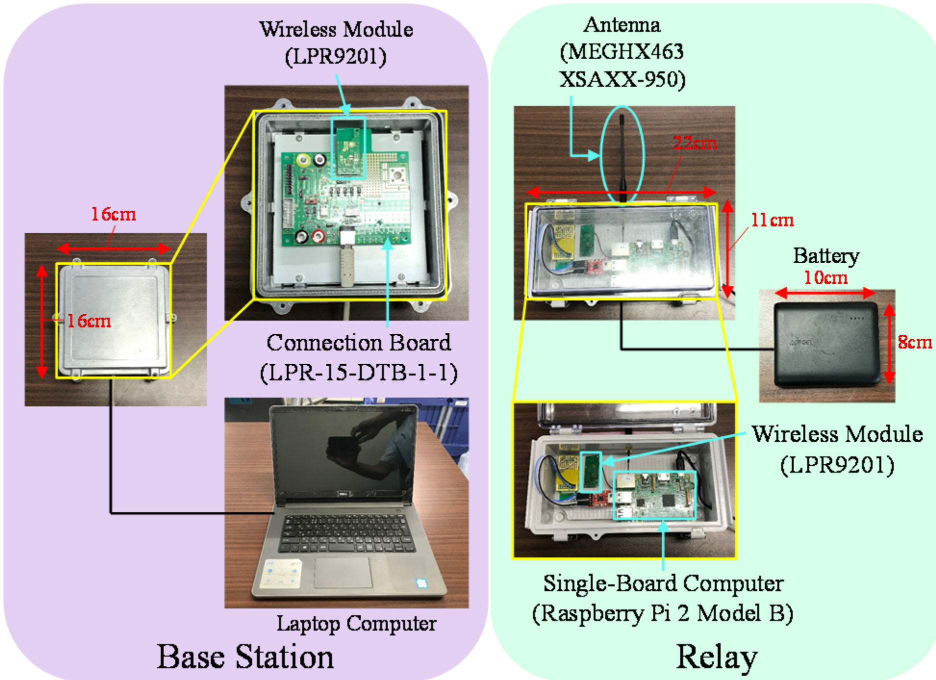

Figure 8. Prototype of the base station and the relay

Max 500 bytes							
Sequence frame number [4 bytes]	Frame control [1 byte]	Reserved [2 bytes]	Retry number [1 byte]	Source node ID [5 bytes]	Destination node ID [5 bytes]	Payload [variable]	Frame check sequence [2 bytes]

Figure 9. Frame format of the prototype in the inter-vehicle network

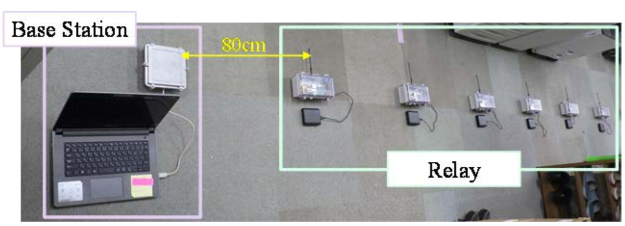

Figure 10. Scenery of the experiment

paper, we set 8 bytes of dummy data for the payload assuming 1 byte of data length, 4 bytes of dates and time, and 3 bytes of sensor data.

The data collection sequence of this prototype is that the base station sequentially performs data request and data reception for each relay. Therefore, by reconsidering the data collection sequence, the processing time can be expected to reduce.

V. EXPERIMENT

We conducted an experiment to confirm the function of data transmission taking account of the changes in the radio wave environment using the prototype introduced in Section IV. Figure 10 shows the scenery of the experiment. Inside the room, one base station and ten relays were linearly arranged at 80-cm intervals. Also, the transmission power was 1 mW. For this experiment, the sensor data are collected from all relays once. After collecting data 5 times, the antennas were removed and data were collected again 5 times. After that, the antennas were attached and data were collected 5 times. We simulated the radio environmental change by detaching and attaching the antennas. These operations were carried out by the method which was applied with the number of hops as a metric, and they were repeated by the method proposed, and then evaluation was made based on the length of time required for data collection. In the proposed method, we assumed that the length of the table $\alpha = 3$ and the threshold of the arrival rate $\beta = 0.9$. Since this is a function verification test, α was set to be small and β was set to a large value in order to frequently change the node selection. Table III shows the experimental results. The values in Table III represent the average time. The average length of time required for data collection of the first five and the last five operations conducted with the antennas attached is about 36 seconds. On the other hand, that of the intermediate five operations conducted with the antennas detached is 103.7 seconds, almost 3 times as long as 36 seconds, when the former method is applied, and 48.9 seconds, 1.4 times as long as 36 seconds, when the latter method (the method proposed) is applied. In this

 ISBN: 978-1-61208-669-9

TABLE III. RESULT OF THE EXPERIMENT (AVERAGE TIME)

	First 5 times (antenna attached) [s]	Next 5 times (antenna detached) [s]	Last 5 times (antenna attached) [s]
Hop number metric	36.1	103.7	37.6
Proposed method	35.8	48.9	36.1

environmental condition change, the difference in length of time required for data collection between the two methods becomes about two times. If we apply the method proposed, the communication distance is actually shortened, and we confirmed that in the static environment, under the method proposed the node which sends data is capable of switching the forwarding destination to the node closer to it, and that the method proposed is effective when change in radio wave propagation environment occurs.

VI. CONCLUSION AND FUTURE WORK

We are developing a monitoring system aimed at confirming control information, such as brakes in real time in crew members. We have been transmitting hop count metrics for stoppage until now. In this paper, we propose a data transmission method considering radio wave environment change during driving. We implemented the proposed method in prototype and carried out function verification test. We simulated the deterioration of the radio wave environment and the time required for data collection became less than half, so we confirmed that it is effective when the radio wave environment deteriorates. In addition, it was confirmed that even when the environment improved, it returned to the state before deterioration. In the future we will study the following.

• How to set the appropriate length and threshold of the transmission history table

If the length of the transmission history table α is short and the threshold value β is high, steep change can be made, the length of that α is long and it can deal with gentle fluctuation if the threshold value β is low. It is necessary to appropriately set them according to the allowable delay of data and the acquisition interval.

• Method of leveling power consumption

In the proposed method, since the communication time becomes shorter, it can be expected that the electric load of the whole network is reduced. However, even if a specific relay is loaded, it will not be avoided. Considering battery replacement, it is also important that no load is placed on a specific relay.

• Demonstration experiment of running condition

Since the experiment in this paper was carried out in a stationary state, it is important to demonstrate even in the running state.

REFERENCES

[1] G. M. Shafiullah, A. Gyasi-Agyei, and P. Wolfs, "Survey of Wireless Communications Applications in the Railway Industry," The 2nd international conference on Wireless Broadband and Ultra Wideband Communications (AusWireless 2007), Aug. 2007, pp.65-70, doi: 10.1109/AUSWIRELESS.2007.74.

[2] V. J. Hodge, S. O'Keefe, M. Weeks, and A. Moulds, "Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey," IEEE Transactions on Intelligent Transportation Systems, Nov. 2014, pp. 1088-1106, doi: 10.1109/TITS.2014.2366512.

[3] H. Scholten, R. Westenberg, and M. Schoemaker, "Trainspotting, a WSN-based train integrity system," Proceedings of ICN 2009, March 2009, Gosier, France, pp. 226-231, IEEE Computer Society Presse, DOI: 10.1109/ICN.2009.59.

[4] N. Wang, Y. Liang, and L. Wang, "On-line Monitoring Method of Bearing in Rotating Machinery Based on Wireless Sensor Networks," The 3rd international forum on energy, environment science and materials (IFEESM 2017), Jan. 2017, pp. 564-571, doi: 10.2991/ifeesm-17.2018.107.

[5] W. Nan, M. Qingfeng, Z. Bin, L. Tong, and M. Qinghai, "Research on Linear Wireless Sensor Networks Used for Online Monitoring of Rolling Bearing in Freight Train," Journal of Physics: Conference Series, vol.305, no. 1, July 2011, pp. 1-10 doi: 10.1088/1742-6596/305/1/012024.

[6] P. Mahasukhon, et al., "A study on energy efficient multi-tier multi-hop wireless sensor networks for freight-train monitoring," The 7th international wireless communications and mobile computing conference (IWCMC), Aug. 2011, pp. 297-301, doi: 10.1109/IWCMC.2011.5982549.

[7] A. Savvides, C. Han, and M. B. Strivastava, "Dynamic Fine-Grained Localization in Ad-Hoc Networks of Sensors," The 7th annual international conference on Mobile computing and networiking (Mobicom '01), 2001, pp. 166-179, doi: 10.1145/381677.381693.

[8] H. Scholten, R. Westenberg and M. Schoemaker, "Sensing Train Integrity," the IEEE International Conference on Sensors, Oct. 2009, pp. 669-674, doi: 10.1109/ICSENS.2009.5398340.

[9] MathWorks, https://mathworks.com/ [retrieved: August 2018]

[10] S. Ryuo, N. Iwasawa, T. Kawamura, A. Hada, and K. Kawasaki, "Method for Creating Networks between Vehicles to Monitor Vehicle Condition," Quarterly Report of RTRI, vol. 58, no. 4, pp. 285-291, Nov. 2017, doi: https://doi.org/10.2219/rtriqr.58.4_285.

[11] SATORI ELECTRIC CO., LTD., http://www.satori.co.jp/english/ [retrieved: August 2018]

 ISBN: 978-1-61208-669-9