Condition Monitoring System for Railway Structures in Hammersmith

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ABSTRACT

In this paper, we describe a large scale wireless sensor network (WSN) system installed at Hammersmith Station in the London Underground for monitoring the deterioration due to age of structures. We also describe analysis results of the network topology and the packet loss rate of sensing data using data from the WSN. In this analysis, we examine the train operation affects on the network topology and the deployment environment affect on the packet loss rate. Finally, we explain the backend application system that allows sensing data collected in the WSN to be accessed via the Internet.

1. Introduction

The maintenance of railway structures has historically depended on periodic inspections. However, inspections are normally conducted every several months or years. Therefore, it is difficult to detect defects in a structure immediately after they form. Detecting any symptom of deterioration due to age in structures is difficult since data volume from periodic inspection is often not large enough to accurately assess the structure. Recently condition monitoring of structures in real-time by wireless sensor network (WSN) has attracted attention as a possible way to address these issues [1, 2].

For maintaining railway structures, it is preferable to combine periodic inspection and a WSN condition monitoring system. This makes the periodic inspection of structures effective as the degree of importance of each monitoring target can be evaluated based on the detailed WSN data. If early detection becomes possible, the repairs can be simple and low-cost. In the following paper, we describe a WSN installed at Hammersmith Station in the London Underground for the condition monitoring of structures and the data analysis results of the network topology and the packet loss rate. We also describe the backend application system that allows sensing data to be accessed via the Internet.

2. WSN systems at Hammersmith Station in the London Underground

This paper describes a large-scale WSN monitoring system installed at Hammersmith station in London Underground in 2009. The WSN consists of 42 nodes; 26 inclinometer motes and 10 relay motes on the retaining walls and 6 inclinometer motes on the train platform of Hammersmith station (see Figure 1). A gateway was deployed between inclinometer 10001 and 10101 on the train platform.
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Additional motes were also installed on a road bridge next to Hammersmith station (see Figure 2). Sixty motes were placed on four piers (6 inclinometers, 8 displacement gauges and one relay node for each four piers) to monitor displacements of the bridge bearings, inclination of piers and bending strain. The data from these sensor motes were transmitted to the gateway deployed on the platform in Hammersmith station.

Figure 3 shows the locations of the sensor nodes deployed in the WSN. In Figure 3, the left photo shows the inclinometer deployed under the platform; the centre photo, the inclinometer and the strain gauge deployed on one of the bridge piers; and the right photo, the strain and displacement gauges deployed on the underground part of the pier.
The wireless module for each sensor and relay node is an Iris mote provided by Crossbow Technology Inc. and the networking software that was used to construct the transmission route for the sensing data is XMesh also provided by Crossbow Technology Inc. [3]. As for the components of sensor node, the strain gauge node consists of a LPDT (linear potentiometric displacement transducer) and two environmental sensors to collect relative temperature and humidity data from the inside and the outside of the sensor box. The inclinometer node consists of a MEMS (micro-electro-mechanical systems) inclinometer and two environmental sensors. Figure 4 shows a sensor node deployed at Hammersmith on the bridge piers. The strain gauges and the inclinometer are packed in the one sensor box. Each sensor node transmits sensing data and health packet data to the gateway every 3 minutes and 10 minutes respectively. Here, information about the quality and communication environment of data is contained in the health packet data.

Figure. 4 Composition of the sensor node deployed at Hammersmith

3. Network Configurations

In this section we describe the network topology obtained by using data from the deployed WSN. The network topology strongly depends on the installation environment. Therefore a train passing might affect the network topology because the WSN in Hammersmith station is deployed along an active railroad line. We divide the time for investigation into two parts in order to consider the effect of trains passing. One is the time from 1 AM to 5 AM (engineering hours) during which the effect of trains passing seems to be small as there are few, if any, trains that pass during this time, and the other is the time from 7 AM to 9 AM (traffic hours) during which the effect of trains passing seems to be large. Then we compare these topologies for each time period. Figure 5 shows network topologies for the engineering hours and the traffic hours. The gateway is shown by the red node. From Figure 5, it can be found out that the change in network topologies for the nodes located on the bridge piers is small, but there are some differences in the network topologies during engineering hours versus traffic hours in the vicinity of the gateway. That is, the network topology during engineering hours has more long distance transmission paths exceeding several dozen meters than the one during traffic hours. Currently, trains passing is considered to be the cause of these differences and trains passing with high frequency might prevent some long distance transmission paths.
The network topology affects many factors in a WSN, e.g. total energy consumption in the network, network lifetime (the period during which all nodes in the WSN are working without depletion of their batteries) and the robustness of the network against node failure. Therefore, it is now very important to design an efficient network topology by evaluating and reviewing the network topologies shown in Figure 5 using several indices.

4. Packet Loss Rate Analyses

In this section the analysis results using packet loss rate are discussed. The packet loss rate also strongly depends on the installation environment in a similar manner to the network topology. Then, we divided the investigation time period into the engineering hours and the traffic hours, in order to examine the effect of trains passing and compared the packet loss rates during each time period. As a result of this comparison, it has been shown that the difference in packet loss rate between each time period is small and accordingly that the effect of trains passing on packet loss rate is small. Next, we investigated the packet loss rate for several nodes deployed at different locations, in order to examine the change in packet loss rate with respect to different node deployments. Firstly, nodes 2110 2210 were considered. These nodes are deployed on the same bridge pier and are thought to be positioned in relatively similar locations. Figure 6 shows the packet transmission ratio with time for nodes 2110 and 2210. The data shows that the ratio varies with the height of mote even on the same pier.
This difference is considered to be caused by the fact that node 2110 is deployed 1 meter higher than node 2210, and is deployed closer to the top of the pier than node 2210.

On the whole, the success packet loss rate goes from 80% to 90% and relatively good communication is created in the WSN. However, there are some nodes for which the success packet loss rate is extremely low (left in Figure 7) or for which the packet loss rate varies widely (right in Figure 7). The quality of wireless communication in particular areas often decreases dramatically due to destructive radio interference (commonly called fading). The nodes showing low success packet loss rate in Figure 7 are thought to be deployed in an area of fading. Hereafter, we need to improve the data quality for these nodes with low success packet loss rate by considering the deployment of a relay node or increasing the transmission power level.

![Figure 7 Packet Transmission Ratio](image)

**Figure 7** Packet Transmission Ratio (The y-axis shows success packet transmit rate)

5. **Backend Application**

The WSN data is transmitted to a server at the University of Cambridge. A web-based graphical user interface has been developed as shown in Figure 8. This system can alert users to defects defined by threshold values for each sensing data type by E-mail (see Figure 8).

![Figure 8 Screen of the configuration for the abnormal state notification](image)

**Figure 8** Screen of the configuration for the abnormal state notification

Therefore, maintenance workers only need to input the data type for condition monitoring and its threshold value on this system in advance and then they will receive notification from the system by E-mail when the system detects an abnormal state. This allows us to confirm an abnormal condition...
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promptly and to repair it quickly. Accordingly, the risk of leaving structures in an abnormal state for a long time as well as the cost for maintenance is reduced. Moreover, we can easily check the network topology via a display function based on Google maps and Google Earth. This system can also display time series data for each sensing data type, which can allow deterioration due to age and the potential abnormal states to be detected easily.

6. Conclusions

In this paper, we introduced a structural health monitoring system for railway structures installed at Hammersmith in London, UK. It is expected that structural health monitoring systems utilizing WSNs will be installed in more and more structures later on and more technical research will be required. Condition monitoring systems utilizing WSNs are already installed in the London Underground (Jubilee Line), Prague Metro and Barcelona Metro (Sagrada Familia Station) as well as Hammersmith station. The system installed on the Jubilee Line of the London has given good results in terms of detecting early stage risk in a railway tunnel [5, 6]. In the future, we would like to develop technology such as device miniaturization and low energy consumption in anticipation of their actual application to WSN systems.

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References


