

WIRELESS SENSOR NETWORK BASED BRIDGE MANAGEMENT SYSTEM FOR INFRASTRUCTURE ASSET MANAGEMENT

Jung-Yeol Kim¹, Myung-Jin Chae², Giu Lee³, Jae-Woo Park⁴, and Moon-Young Cho⁵

¹ Researcher, Korea Institute of Construction Technology, Goyang, Korea

² Senior Researcher(PhD), Korea Institute of Construction Technology, Goyang, Korea

³ Senior Researcher(PhD), Korea Institute of Construction Technology, Goyang, Korea

⁴ Researcher, Korea Institute of Construction Technology, Goyang, Korea

⁵ Research Fellow(PhD), Korea Institute of Construction Technology, Goyang, Korea

Correspond to chae@kict.re.kr

ABSTRACT: Social infrastructure is the basis of public welfare and should be recognized and managed as important assets. Bridge is one of the most important infrastructures to be managed systematically because the impact of the failure is critical. It is essential to monitor the performance of bridges in order to manage them as an asset. But current analytical methods such as predictive modeling and structural analysis are very complicated and difficult to use in practice. To apply these methods, structural and material condition data collection should be performed in each element of bridge. But it is difficult to collect these detailed data in large numbers and various kinds of bridges. Therefore, it is necessary to collect data of major measurement items and predict the life of bridges roughly with advanced information technologies. When certain measurement items reach predefined limits in the monitoring bridges, precise performance measurement will be done by detailed site measurement. This paper describes the selection of major measurement items that can represent the tendency of bridge life and introduces automated bridge data collection test-bed using wireless sensor network technology. The following will be major parts of this paper:

- 1) Examining the features of conventional bridge management system and data collection method
- 2) Mileage concept as a bridge life indicator and measuring method of the indicator
- 3) Test-bed of automated and real-time based bridge life indicator monitoring system using wireless sensor network

Keywords: Asset Management; Sensor; Wireless Sensor Network; Maintenance; Measurement

1. INTRODUCTION

Social infrastructure should be recognized and managed as important assets. Bridge is one of the most important infrastructures to be managed systematically because the impact of its failure is critical. It is essential to monitor the performance of bridges in order to manage them as an asset.

Life of bridge is a function of deterioration of structure, structural characteristics and operational environment. In other words, structures built in different years, at different locations and operated in different conditions are bound to have different service lives respectively. Useful life or residual life is typically estimated by analytical method such as predictive modeling and structural analysis. However, these analytical methods applied to high-value assets can ensure accuracy of useful life estimation, if accurate structural status and performance data are available.

But current analytical performance measurement methods are very complicated and difficult to use in practice. To use these methods, structural and material condition data collection should be performed in each element of bridge. But it is difficult to collect these

detailed data in large numbers and various kinds of bridges. Therefore, simple method that can estimate useful life of bridges is required. To that end, it is necessary to collect data of major measurement items and monitor the performance of bridges roughly with advanced information technologies (IT). When certain indicators reach predefined limits in the monitoring bridges, precise performance measurement will be done by detailed site measurement.

Therefore, it is necessary to develop a practical method for predicting useful life and establishing maintenance strategy based on load history mileage versus structural lifecycle and in consideration of characteristics of wheel load acting on structures such as daily traffic volume or load volume.

This paper describes the selection of major measurement items that can represent the tendency of bridge performance and introduces automated bridge data collection test-bed using wireless sensor network technology:

- 1) Examining the features of conventional bridge management system and data collection method
- 2) Mileage concept as a bridge performance indicator and measuring method of the indicator

3) Test-bed of automated and real-time based bridge performance indicator monitoring system using wireless sensor network

2. Bridge Management System

2.1 Key Features of Bridge Management System

Bridge management systems are implemented in a variety of configurations aligned to the specific needs of different countries respectively, but, in terms of DB administration and bridge management, they have processes shown in Table 1 [1]. To be more specific, current status and maintenance history data are acquired by examiner or measurement instrument and bridge integrity is evaluated by transitional probability and deterioration is predicted in reference to the above data. Notably, aging prediction is essential in enabling preventative maintenance and maximizing cost-effectiveness in a long run. Probabilistic deterioration prediction methods such as Bayesian approach, Binary probit model and Markovian method requires accurate status data of all bridges subject to management and contains complex analytical processes.

However, regardless of accuracy, it is more than obvious that change in bridge status resulting from wheel load of passing traffic impacts bridge deterioration significantly.

Table 1. Bridge Management System

DB Aspect	Management Aspect
History & current maintenance data	Historical data analysis
Data acquisition of bridge conditions	Definition of future bridge conditions
Major physical properties of bridge	Preparing deterioration prediction curve for bridge as a whole or key members
Definitions of maintenance activities	Comparative analysis of alternative maintenance activities
Identification of bridges needing posting	Estimating future management costs
Features of typical damages	Readjusting bridge inspection and measurement frequencies
Characteristics of resources used in maintenance activities	Developing long-term management strategy in consideration of sustainability

In some of the previous studies, cyclic load was used to estimate residual life of reinforced concrete bridge [2].

Therefore, if impact of load acting on bridge is identified and utilized in estimating deterioration, cost-effective maintenance strategy can be developed by simple data acquisition and analysis during bridge lifecycle.

2.2 Data Collection Method of Bridge Management System

One of the most important methods for bridge management system to collect bridge condition data is visual inspection. However, it is such a costly approach that in case of main cable system of Golden Gate Bridge in San Francisco, USA, visual inspection alone costs \$226,900 [3]. Therefore, visual inspection is limited as solution for regular inspection.

In addition, conventional bridge management systems use a variety of sensors to take measurements in an effort to understand bridge status. Notably, long bridges such as Yeongjong Bridge in Korea and Akashi Bridge in China are monitored in real time to capture their behavior. However, as the monitoring systems of those bridges are wire-linked for data communication and powered by power cable, it takes significant amount of costs to install and maintain such systems [4]. Furthermore, even if in-depth data is collected in such a manner, considerable time and efforts are required for data quality evaluation.

To overcome such constraints, monitoring technique based on wireless communication and self-powered module is being studied.

A lot of wireless sensor prototypes such as those developed by Lynch in Stanford University or Mica mote in UC Berkley have been tested in laboratory or site conditions from a variety of perspectives [5]. For example, Kim et. al. conducted a research on bridge monitoring system using Zigbee communication and power battery in UC Berkley [6] and Lynch et. al. evaluated power consumption of wireless sensor embedded with damage detection algorithm and system identification of Alamosa Canyon Bridge in Mexico [7] and Wang et. al. evaluated feasibility of wireless sensor prototype in Viogt Bridge in UCSD campus by modal analysis [8]. In Korea, system identification and modal analysis by real-time monitoring wireless sensor prototype was conducted as well for Geumdang Bridge in Icheon, Gyonggi Province and Yeongjong Grand Bridge [9]. Data comparable to that produced by conventional wired monitoring system was acquired out of such studies in terms of structural health monitoring.

Therefore, even for understanding overall status of various bridges scattered around the country from asset management perspective, monitoring key factors with independent and efficient system based on wireless communication and self-powered module is a viable alternative.

3. Mileage Concept for Bridge Management

From asset management perspective, it is essential to estimate useful life of bridge at least roughly. However, analytical methods available to date are not appropriate, as they cost a lot of time and efforts to collect and analyze data. Therefore, this research proposes a mileage concept for managing bridges as assets. Mileage concept is not intended to estimate useful life by understanding

complete status (performance) of facility with precision measurement. Instead, it is designed to measure representative properties of bridge in a long run to produce high-level but consistent indicators and provide inputs for selection of in-depth examination targets and economic valuation as parts of asset management. Then, various asset management functions such as in-depth inspection and maintenance, development of LOS(Level of Service) indicators and subsequent budget allocation can be fulfilled.

Table 2 indicates steps in applying simple management system using load mileage characteristics.

Table 2. Bridge Management Process Considering Load Mileage Characteristics

Process	Description
1. Build management DB	Maintenance history, useful life, residual life, etc.
2. Condition Data Measurement	Measure wheel load properties (Load, Strain, Acceleration, etc)
3. Analyze bridge status	Number of exceeding yield strain, cumulative load, cumulative threshold-exceeding load
4. Estimate soundness & deterioration	Evaluate residual life by estimating soundness and deterioration in consideration of load impacts and material conditions
5. Development of LCC strategy	Identify long-term R&R option and estimate optimum replacement time

Not only maintenance history, useful life of residual life indicating service availability but also thresholds reflective of change in durability in reference to load action must be included in the bridge management DB to deliver information system necessary for developing long-term maintenance strategy in the future. As the threshold by load action is a function of asset deterioration and life versus physical properties and operating environment in the mileage-based approach proposed herein, official useful life is defined by impact actor considering 7 characteristics such as design standards, construction quality, material quality, operational stresses, maintenance history, asset working environment and external stresses. Useful life is expressed in terms of function of width of concrete crack developed by marginal cyclic load or steel member fatigue characteristics versus traffic volume and load rather than time. For example, useful life of concrete bridge is determined by cyclic load frequency before marginal crack width is reached, which is a simple formula designed to estimate residual life by subtracting cyclic load frequency to date during service life.

In mileage concept, it is assumed that in terms of estimation of integrity and deterioration, overall status transition or service life is directly affected mostly by passing traffic volume and load. Notably, heavy vehicle has approximately 500~1000 times greater impact than

residential vehicle [10]. Therefore, impact by heavy vehicle needs to be singled out as a key management item and deformation characteristics caused by such load needs to be measured. Then, marginal deformation rate that affects bridge life can be analyzed and residual life can be estimated by eliminating life-reducing factors developed during service life. For example, in relation to evaluation of integrity of bending member of concrete bridge, residual life and deterioration can be predicted by classifying fatigue damage by excessive cyclic load into attachment damage, bending damage and compression damage, defining marginal crack width corresponding to each damage criteria and estimating frequency of experiencing marginal deformation rate before reaching damage criteria. As a part of this research, mileage concept is being applied to a testbed built in concrete bridge.

4. Mileage Data Collection Method

To apply mileage concept, it is necessary to keep collecting significant data. Given diverse characteristics of many bridges scattered nationwide, it is not sensible to use conventional wired monitoring system in such case. Simpler, more feasible and independent monitoring system than the conventional one is required.

This research used the wireless data collection method shown in Figure 1.

As wireless communication solution, Zigbee protocol that could support low-power wireless network in local area was used and wireless Internet was used for communication over a distance. Zigbee allows each communication node to have transmission/reception functions and ensure resilience of communication network by supporting ad-hoc, multi-hop communication even when some nodes have failed. Power is sourced independently by solar cell.

The biggest advantage that wireless communication technology can bring to asset management is such that it can automate data collection from bridges scattered extensively over long term. Secondly, not only overall performance of each bridge but also long term bridge status can be understood at network level. Therefore, various asset management functions such as in-depth inspection and maintenance, development of QoS indicators and subsequent budget allocation can be fulfilled.

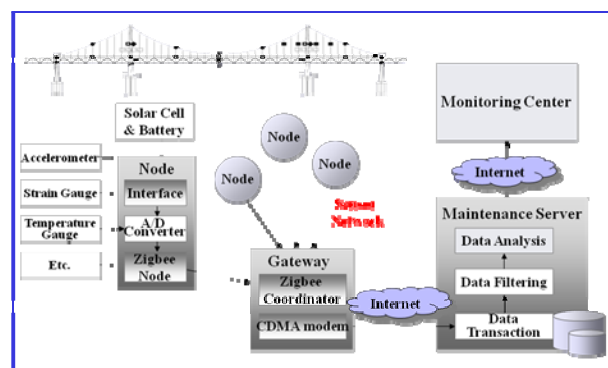


Figure 1. Wireless Mileage Data Collection

5. Test-bed

As a part of this research, prototype system that monitors key factors is now being operated in bridges currently in service to validate wireless bridge mileage data collection system (Figure 2).

Concrete bridge that accounts for more than half of the bridges in Korea is selected and acceleration, strain, temperature and load (Weigh in Motion) are defined as monitoring targets.

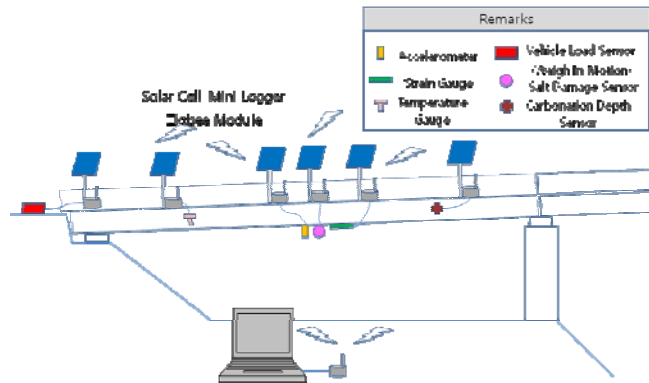


Figure 2. Test Bed Configuration

6. Conclusion

Conventional bridge management system estimates performance and life accurately with analytical method. However, from asset management perspective, it is essential to approximate life of numerous bridges scattered around the country in many different configurations.

This research has introduced mileage concept for bridge management, mileage data collection methodology and testbed in operation from asset management perspective. Mileage concept is built on long-term measurement of representative bridge characteristic to produce approximate and consistent indicator. Such approach enables management of many bridges that are difficult to be managed by conventional analytical methods. In addition, wireless data collection method will enable accumulation of mileage data in a long run to support effective asset management.

ACKNOWLEDGEMENT

This research was performed as a basic project of Korea Institute of Construction Technology (project no. 2009-0013) sponsored by the Ministry of Knowledge Economy.

REFERENCES

[1] K.L. Rens, C.L. Nogueira and D. J. Transue, "Bridge Management and Nondestructive Evaluation", *Journal of Performance of Constructed Facilities*, ASCE, pp.3-16, February 2005.

[2] Kim, Se-Hoon, "Prediction of Crack Width in Reinforced Concrete Bending member under Cyclic Load and Evaluation of Residual Life", 2004 Academic Symposium Paper Collection, Structure Committee, Korean Society of Civil Engineers, pp.129-145.

[3] Los Alamos National Laboratory. 2003. "A Review of Structural Health Monitoring Literature:1996-2001," Los Alamos National Laboratory Report LA-13976-MS. Los Alamos, NM, USA.

[4] Celebi, M. 2002. "Seismic Instrumentation of Buildings (with Emphasis of Federal Buildings)," Report No. 0-7460-68170 United States Geological Survey (USGS), Menlo Park, CA.

[5] Lynch, J. P. and Loh, K. J. (2006) "A Summary Review of Wireless Sensors and Sensor Networks for Structural Health Monitoring" *Shock and Vibration Digest*, Sage Publications 38(2), pp.91-128.

[6] Kim, S. and Culler, D. (2003) 'Structural health monitoring of the golden gate bridge', Available at: <http://www.eecs.berkeley.edu/~binetude/ggb/>

[7] Lynch, J. P., Sundararajan, A., Law, K. H., Kiremidjian, A. S., Carryer, E., Kenny, T. W., Sohn, H. and Farrar, C. R. (2003) "Field Validation of a Wireless Structural Monitoring System on the Alamosa Canyon Bridge" *Proceedings of SPIE - The International Society for Optical Engineering*, v. 5057, pp.267-278.

[8] Wang, Y., Loh, K. J., Lynch, J. P., Fraser, M., Law, K. H. and Elgamal, A. (2006) "Vibration Monitoring of the Voigt Bridge using Wired and Wireless Monitoring Systems," *Proc. of 4th China-Japan-US Symposium on Structural Control and Monitoring*, Hangzhou, China, October 16-17.

[9] Lynch, J. P., Loh, K. J., Hou, T.-C., Wang, Y., Yi, J., Yun, C.-B., Lu, K. and Loh, C.-H. (2005) "Validation Case Studies of Wireless Monitoring Systems in Civil Structures", *Proceedings of the 2nd International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-2)*, Shenzhen, China, November 16-18, 2005.

[10] NAMS Group, "N. Z. Infrastructure Asset Valuation and Depreciation Guidelines-Version 2.0", ISBN No:0-473-07235-1. 2006