A Framework for the Intelligent Monitoring System of Stormwater Management Based on the Internet of Things and Wireless Sensor Networks

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Abstract: In the evaluation of stormwater management performance of landscape architecture project, the data acquired efficiently in real time is the basis of quantitative evaluation. The intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks has provided a new technical approach for real-time acquisition of performance data, performance evaluation and post-management of the project. In this paper, a framework for the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks was introduced. The system structure and basic operation mode were described through an eco-road project case in Nanjing, China. The project team implemented the monitoring of the basic data of the rainfall, surface runoff, rainwater collection, soil moisture content, etc. by constructing the intelligent monitoring system of stormwater management for the project, and conducted quantitative analysis and evaluation on the stormwater management performance of the project based on the monitoring data in the last 3 years.

Keywords: Internet of things, wireless sensor networks, intelligent monitoring system, stormwater management performance

1 Introduction

As an evidence-based discipline (BROWN & CORRY 2011), landscape architecture requires data to quantitatively evaluate and verify the performance of landscape architecture projects (LUO 2014). A number of studies have tackled the performance and value of landscape architecture design (YUNING 2017, DEMING & SWAFFIELD 2011, CULBERTSON & MARTINICH 2012). And the accuracy of the basic performance data obtained will directly affect the performance evaluation results of the project (PETSCHEK & WALKER 2008). Stormwater management performance evaluation has always been the key content of quantitative evaluation of landscape architecture projects, and the efficient real-time data acquisition has always been a difficult problem in the quantitative evaluation of stormwater management.

In the past, most of the performance data of stormwater management in landscape architecture practice were acquired through manual sampling, on-site measurement and laboratory testing, etc. The traditional data acquisition methods had the defects of inefficient data acquisition, non real-time data, etc., which could not comprehensively and objectively reflect the performance of stormwater management of project.

In recent years, the development of Internet of Things and sensor technologies has provided new technical possibilities for stormwater management performance evaluation. The real-time, dynamic, efficient and accurate data acquisition method is of great significance for the quantitative studies of landscape architecture performance (HAN et al. 2013).

Journal of Digital Landscape Architecture, 3-2018, pp. 310-318. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-642-0, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537642033.

2 Framework

In the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks, real-time dynamic hydrological data such as water quantity and water quality of sites and landscape facilities were obtained by using Internet of Things and sensor technologies for the stormwater management performance issue of landscape architecture projects. The effect of rainwater collection, surface runoff control, improvement of hydrological effects, greening and water-saving ratio and improvement of water quality were analyzed and represented visually through the client.

2.1 Site Sensor Layer

It was composed of sensors and data acquisition instruments to implement the real-time collection and local temporary storage of project water quantity or quality information. Sensors mainly included water quantity monitoring sensors and water quality monitoring sensors. Key indexes of water quantity sensor monitoring included site rainfall, surface runoff, rainfall collection, soil moisture content, etc. Key indexes of water quality sensor monitoring included TN (total nitrogen) and TP (total phosphorus), pH value, turbidity and suspended matter, etc. For performance monitoring, the selection of sensor types was determined mainly based on the site actual situation and the design problems to be solved. Open design was adopted for the system to flexibly adjust the number and types of sensor interfaces according to the number and types of sensors.

2.2 Network Layer

In the network layer, the performance data collected at the site sensor layer were uploaded to the system cloud platform in real time through the communication launcher. Mobile communication 4G network was shared for the communication upload, and separate network setup was not required. Data upload interval could be set in the communication launcher flexibly based on the project stormwater management monitoring data needs as once a minute, once a day, etc.

2.3 Data Application Layer

The data uploaded by field sensors and data acquisition units were integrated to form the rainwater performance management database, and generate various kinds of statistical tables and reports and trend charts for visualization. At the same time, rainwater management performance analysis and evaluation such as the effect of rainwater collection, surface runoff control, improvement of hydrological effects, greening and water-saving ratio and improvement of water quality, etc. could be implemented using the data in the database through the developed client software.

3 Case Study

In this paper, through the case study of Nanjing Tianbao Street eco-road engineering system designed by the Institute of Landscape Architecture Planning and Design, Southeast University, the application of the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks in practical projects was introduced. Due to space limitations, only a brief introduction of the project and technology application was made in this paper.

3.1 Project Overview

Nanjing Tianbao Street Eco-road Engineering System was located in Hexi New City, Nanjing, Jiangsu Province, China. The full length of the road was about 600 m, the cross section of road segment was 45 m wide, with bi-directional four lanes, medium separation greening belt 5-8 m wide, utility tunnel laid underground with the covered depth of 4.0 m, and side separation greening belt 2 m wide. Starting from solving the stormwater problem of urban roads systematically, permeable pavement, catch ditch, natural infiltration storage box and other artificial intervention technologies similar to nature were adopted according to the local conditions in the project based on the idea of restoring the urban natural hydrological cycle according to the regional precipitation, different underlying surface types of the road and groundwater level, etc., endowing the road with rainwater infiltration, rainwater collection, rainwater storage and utilization, habitat optimization and multiple other functions concurrently.

Fig. 1: Eco-road system diagram of Nanjing Tianbao Street

Nanjing Tianbao Street eco-road project consisted of four parts: Pavement rainwater infiltration system, rainwater collection and distribution system, rainwater storage and utilization system and rainwater performance monitoring system (Refer to Figure 1 for all parts of the system configuration. In view that mainly the composition and application of the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks were discussed in this paper, two papers *A novel stormwater management system for urban roads in China based on local conditions*.YUNINGCHENG & RUIJUNWANG 2017, *Being both Opposite and Complementary: Urban Road Sponge System Practice Based on Digital Technology – Taking Nanjing Tianbao Street Ecological Road as the Example*.

YUNING CHENG & MINGKUN XIE 2017) could be referred to for the detailed planning and design strategies and technologies of the project). By constructing a complete stormwater management system for urban roads, multiple design goals including surface runoff control, rainwater collection and resource utilization, habitat optimization, etc. were achieved in Tianbao Street project. The response and coordination at all levels of rainwater collection, storage, infiltration, purification, discharge, utilization and management were achieved, which solved the drought and waterlogging problem in urban roads systematically, enhanced the capacity of the road system to handle rainfall itself, and embodied the concept of sustainable design.

3.2 Stormwater Management Performance Monitoring System

Through the application of the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks, real-time monitoring of the whole process of site rainfall, rainwater collection effect, surface runoff, hydrological effect improvement monitoring, greening and water-saving ratio was implemented. Management personnel could keep abreast of the real time hydrological data of urban roads at any time through computer client, mobile APP and other terminals, to achieve quantitative and visualized management of urban road water environment.

Fig. 2: Site photo of the intelligent monitoring system of stormwater management in Tianbao Street eco-road project in Nanjing

The monitoring objects of rainwater management in Tianbao Street eco-road included three main indexes, i. e. regional rainfall, rainwater box water level and soil moisture content in different soil depths. Rainfall data collection was completed by tipping-bucket rain-gauge, and the time interval for cumulative rainfall statistics could be adjusted as needed.The water level change in the rainwater collection and storage box was acquired by hydraulic pressure water level sensor, which was placed at the bottom of the box and could convert water pressure difference into water level change value for output. It was mainly used for monitoring rainwater collection on the road, storage, infiltration and utilization. The principle of electromagnetic pulse was adopted in the soil moisture sensor to obtain the volumetric water content of soil media, which is mainly used to monitor the moisture content of soil, which was mainly used for monitoring the soil moisture content in the road greening belt. To facilitate the objective evaluation of stormwater management performance, two sets of sensor devices with the same settings were buried in the road segment where technical measures for eco-road engineering were implemented and in the road segment where technical measures for eco-road engineering were not implemented, to compare and analyze the performance of eco-road projects subsequently (Figure 2 and Figure 3).

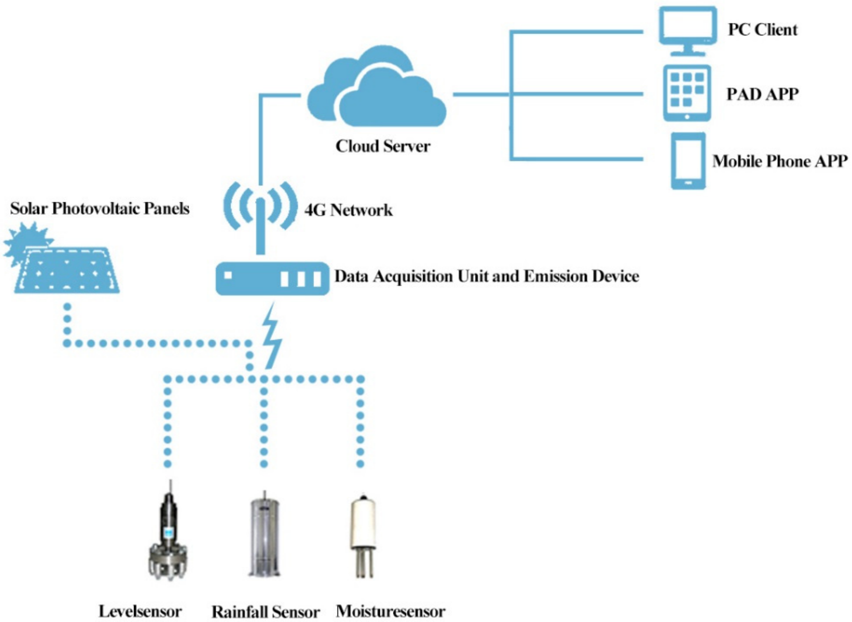

Fig. 3: The Framework for Intelligent Monitoring System of Stormwater Management in the Ecological Road of Tianbao Street, NanJin

The data information collected by each sensor was initially processed by the field devices and then transmitted to the cloud for further processing and storage through the wireless signal transmitting device. The client could logon to the server via the Internet for real-time query of the related information. The Digital Landscape Architecture Laboratory of Southeast University specifically developed a performance monitoring platform mobile APP for this project (Figure 4). The performance monitoring platform mobile APP was constructed based on the performance data set and B/S architecture (Browser/Server mode), including 9 toolboxes, i. e. map monitoring, data visualization, data query, data analysis, alarm management, evaluation and analysis, etc. Authorized users could browse and download data remotely through mobile phone APP and PC client.

Fig. 4: Stormwater Management performance mobile APP developed by Digital Landscape Laboratory of Southeast University

In addition, in terms of system energy supply, renewable energy was adopted for the sensors, data acquisition units and launchers, i. e. the devices were powered by site solar photovoltaic panels, thus ensuring the long-term stable and effective running of the system and low maintenance requirement.

3.3 Stormwater Management Project Performance Statistical Analysis

We comprehensively analyzed the rainwater management performance of Nanjing Tianbao Street eco-road in from three aspects, i. e. surface runoff control, rainwater collection and resource utilization and system habitat optimization, etc.

1) Surface runoff control performance

Through the data statistics of 24-hour daily rainfall and liquid level change of the water storage box acquired by the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks in the past three years, the results showed that when 24-hour rainfall in Tianbao Street design area ≤ 116.6 mm, the sponge system of the eco-road could achieve 100 % local consumption of rainfall. When 24-hour rainfall > 116.6 mm, excessive rainwater could be discharged quickly combined with the gray system (Figure 5).

2) Rainwater collection and resource utilization performance

From January to December 2015, the regional total rainfall in Nanjing Tianbao Street eco-road was 1,312.2 mm, the annual total water volume in the pavement range was 11,808m^3, the annual rainwater collection in water storage box was 4,807 m^3, and the annual rainwater collection and utilization rate was 41 %. From July 2016 to July 2017, the regional total rainfall in Nanjing Tianbao Street eco-road was 1,052 mm, the annual total water volume in the pavement range was 9,468 m^3, the annual rainwater collection in stormwater collection box was 4,865 m^3, and the annual rainwater collection and utilization rate was 51 % (Figure 6).

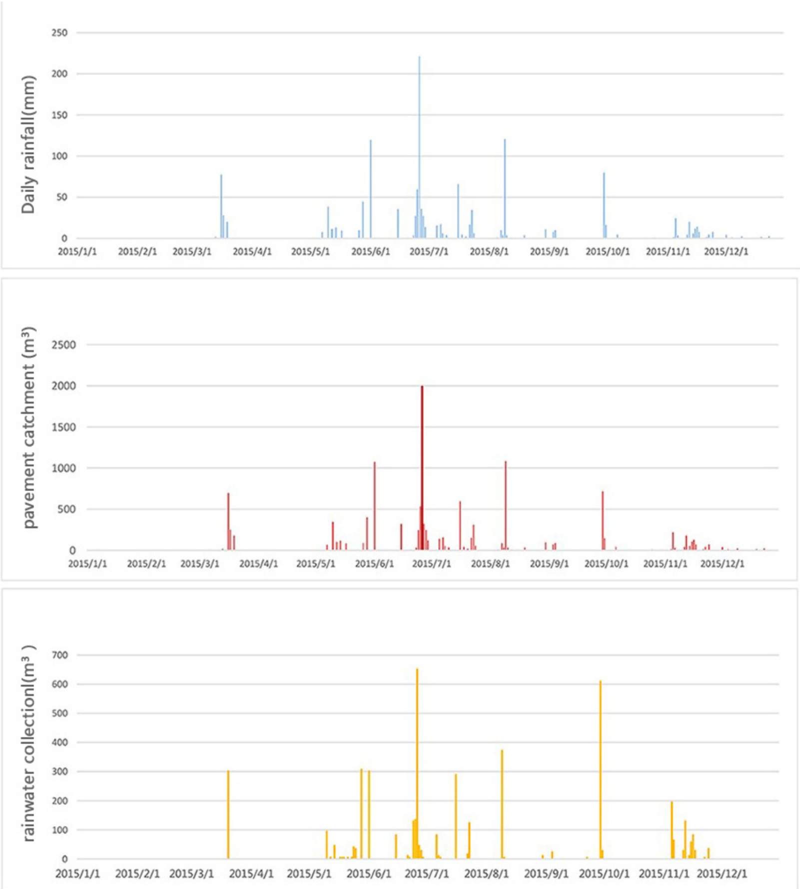

Fig. 5: Statistics of site daily rainfall, pavement catchment and rainwater collection from July 2016 to July 2017 in Nanjing Tianbao Street eco-road

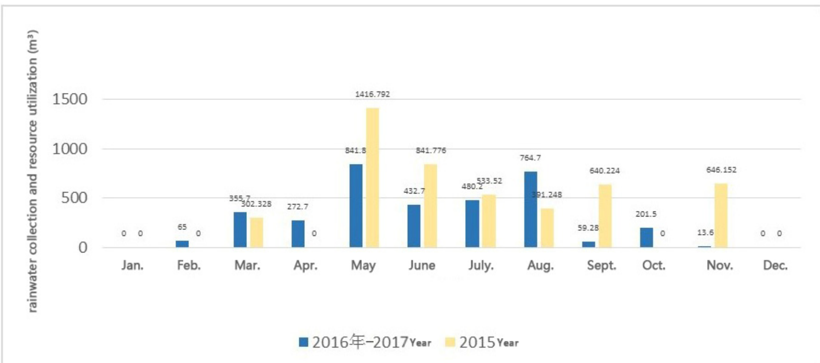

Fig. 6: Statistics of rainwater collection and resource utilization in Nanjing Tianbao Street eco-road

In the test segment of Nanjing Tianbao Street eco-road, the medium separation greening area was 3,384.8 m^2, which required about 6,768t (2 $t/m^2 \cdot year$) of water annually for irrigation. Calculated based on mean annual precipitation in Nanjing City, 3,224 m^3 of irrigation water was still required every year. The annual average water collection in the 600 m water storage box of the eco-road system test segment was about 4,334 m^3, which could basically meet the green irrigation water needs of the medium and side separation greening belts of the test segment.

3) Soil habitat optimization performance

The monitoring data showed that the sustained release effect of rainwater in water storage box could basically last throughout the year. In autumn when there was relatively water shortage in plants, the soil moisture content at 2.4 m in the test segment could still maintain above 30 %. Under the condition that artificial greening irrigation was maintained in the contrast segment, the soil moisture content of the test segment was still more than 10 % higher than that of the contrast segment (Figure 7). (Roots of trees in urban road green belt were mainly distributed in the depth of 1-2 m, and roots of shrubs were mainly in the depth of 0.45-0.6 m. Considering the embedding depth of water storage box, relatively high moisture content maintained in the 2.4 m soil layer had little effect on the root respiration, and would not lead to water accumulation and rotting roots. Due to the capillary effect, when the soil was dry, part of the water would rise to the upper layer of soil for plant root absorption).

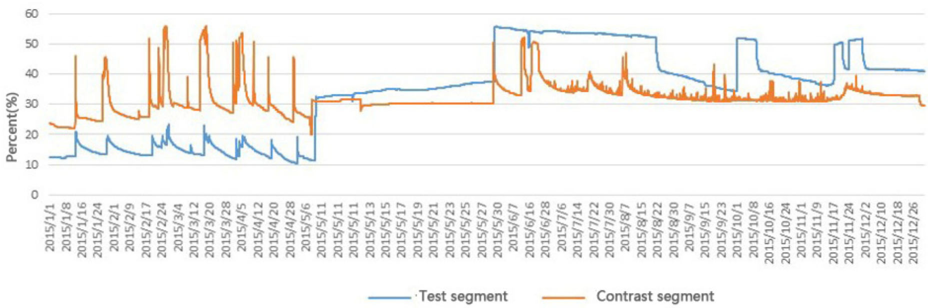

Fig. 7: Comparison of soil moisture content at 2.4 m between the test and contrast segment of Nanjing Tianbao Street eco-road in 2015

4 Conclusion and Outlook

In this paper, by introducing the composition and characteristics of the intelligent monitoring system of stormwater management based on the Internet of Things and wireless sensor networks, the possibility of applying Internet of Things, sensors and other technologies to the performance evaluation of stormwater management in landscape architecture projects was explored combined with the application instance in Nanjing. The system provided accurate basic data and technical support for stormwater management performance monitoring of landscape architecture projects, effectiveness verification of planning and design as well as improvement and upgrade, post maintenance management of projects,etc. The application results of the intelligent monitoring system in practical engineering project showed that, the system could meet the continuous monitoring of the dynamic process of rainwater in the engineering project, so as to obtain highly efficient real-time data and properly meet the needs of performance studies. Similarly, Internet of Things and wireless sensor network technologies could also play an important role in landscape architecture project planning and design, performance evaluation and project management and other areas, such as key plant and soil parameters required for the measurement in plant and soil studies, analysis and evaluation of physiological limitations of landscape architecture planning and design elements, impact of climate change on landscape architecture projects, and improvement of site microclimate conditions by landscape architecture planning and design, etc.

Acknowledgements

This paper is supported by:

1) The National Natural Science Foundation of China, the project name: Research on Parametric Design of Water Environment in Landscape Architecture (51608108).
2) The Research innovation program of academic degree graduate students in Jiangsu Province. the project name: Study on Design method of Natural Landscape Water system based on Digital Hydrological Analysis(KYLX15_0056).
3) The Fundamental Research Funds for the Central Universities.

References

Brown, R. D. & Corry, R. C. (2011), Evidence-based landscape architecture: The maturing of a profession. Landscape and Urban Planning, 100 (4), 327-329.

Culbertson, K. & Martinich, M. (2012), A holistic approach to sustainability: Lessons from the Lafitte greenway in New Orleans, Louisiana. Edinburgh Architectural Research Journal, 33, 1-14.

Deming, E. & Swaffield, S. (2011), Landscape Architectural Research: Inquiry, Strategy, Design. John Wiley & Sons, New York.

Han, J. C., Wang, H. W., Gao, X. L. & Liu, Y. (2013), The discussion on application feasibility of "internet of things(iot)" in the urban stormwater intelligent management. Journal of Fudan University.

Luo, Y., Ming-Han, L. I., Duan, S. L., Zhang, X. W., University, T. T. & Aamp, T., et al. (2015), Landscape performance of built projects: comparing landscape architecture foundation's published metrics and methods. Landscape Architecture, 52-69.

Petschek, P., Walker, P. & Read, J. (2008), Grading for Landscape Architects and Architects. De Gruyter, Basel.

University of St. Gallen, ETH Zurich, MIT.Internet of Things (2008), International Conference for Industry and Academia Retrieved March 26, 2008.

Yu-Ning, C. & Ming-Kun, X. (2017), Being both Opposite and Complementary: Urban Road Sponge System Practice Based on Digital Technology – Taking Nanjing Tianbao Street Ecological Road as the Example. Chinese Landscape Architecture, 5-13.

Yu-Ning, C & Wang, R. (2017), A novel stormwater management system for urban roads in china based on local conditions. Sustainable Cities & Society.
http://www.the-internet-of-tings.org/iot2008/.