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Research on the Current Status of Urban Drainage (Stormwater and Sewage) Pipeline Network and Intelligent Diagnostic System

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Abstract: As an important component of urban infrastructure, the urban drainage (rain and sewage) pipeline network directly affects the ecological environment and residents' quality of life of the city. This article systematically analyzes the current construction and management status of urban drainage networks, and points out the problems existing in traditional operation and maintenance models, such as low detection efficiency, lagging data processing, and insufficient intelligence level. Based on this, a digital diagnostic system framework has been proposed, aiming to achieve real-time monitoring, intelligent diagnosis, and precise maintenance of drainage networks through the Internet of Things, big data analysis, and artificial intelligence technology.

Keywords: Drainage Pipeline Network, Rainwater and Sewage Diversion, Digitized Diagnosis.

1. Introduction

With the significant acceleration of urbanization, the burden on drainage network systems is increasingly heavy, posing unprecedented challenges. The limitations of existing traditional management models further exacerbate the severity of this issue. Research indicates that the challenges currently faced by drainage systems are primarily manifested in three aspects: first, the inadequacy of pipeline construction; second, the lack of operational and maintenance management efficiency; and third, the insufficiency of emergency response mechanisms. Such problems directly trigger a high incidence of urban flooding, significantly impacting residents' quality of life and public safety levels. In this context, the rapid development of digital and intelligent technologies has brought unprecedented innovative solutions for improving the efficiency and effectiveness of drainage network management.

The development of an intelligent diagnostic system has demonstrated significant value and contributions in both theory and practice. It can substantially enhance the operational efficiency of urban drainage management systems, thereby achieving more effective management and allocation of urban water resources. By leveraging the integration of sensor technology and the maximum flow algorithm for efficient data processing, it enables real-time monitoring of pipeline network operating conditions and the swift identification and localization of potential fault areas.

2. Analysis of the Current Situation

2.1. Pipe Network Construction and Layout

Through the collection, organization, and preliminary analysis of on-site survey results, pipe network data, and related materials, a foundational data support is provided for subsequent work. The main data includes the location distribution and attribute information of drainage networks and ancillary facilities, key node information such as outlets, interception and storage facilities, pumping stations, and sewage treatment plants, as well as water-related materials such as river systems and development plans. The focus is on analyzing the structural relationships of the network, the inflow and outflow conditions of key nodes such as outlets, pumping stations, and sewage treatment plants, and rationally dividing drainage zones according to the objectives and scope of pipe network research diagnosis, laying the groundwork for the scientific formulation of online monitoring schemes and subsequent monitoring and testing.

According to the survey data, the coverage ratio of stormwater networks in a certain area is approximately 70%, while the coverage ratio of sewage networks is about 80%. In areas where a separated system has been implemented, the allocation ratio of stormwater to sewage is typically around six to four. In practice, due to some residents illegally connecting sewage to stormwater networks, along with frequent occurrences of stormwater outlets being blocked by garbage, causing stormwater to flow into sewage networks, the effective implementation of separation is significantly disrupted, leading to considerable fluctuations in the actual separation ratio. In the core urban area of this region, a relatively complete drainage network system has been established, comprising two main components: stormwater and sewage networks. The stormwater network is laid along urban roads, aiming to efficiently collect surface runoff from road surfaces and specific areas and redirect it to nearby rivers or water bodies, thereby maintaining the normal operation of the urban drainage system and the ecological balance of the environment. This process is crucial for maintaining urban public health and ecological balance.

From a structural perspective, the existing drainage network often exhibits a characteristic of material diversification. For instance, reinforced concrete pipes are widely used next to main roads due to their low cost and high pressure resistance, while the use of brick pipes can still be sporadically observed in some early-developed areas, exacerbating the overall frequency of network failures. These factors have made the maintenance and upgrading of the existing network structure a key issue that urgently needs to be addressed.

2.2. Existing Problems and Challenges

The main issues with the urban drainage (stormwater and sewage) network include aging, blockage, leakage, and low management efficiency. These problems not only affect the normal operation of the network but also have a significant impact on the urban environment and residents' lives. A study analyzing CCTV inspection data from a district in Shanghai found that the distribution pattern of pipe defects has important guiding significance for planning and repair work. Aging of the network, outdated design standards, and untimely maintenance are also significant reasons for low operational efficiency. Research indicates that in a city in Guangdong, issues such as pipe leakage, backflow from rivers, and severe sedimentation have resulted in low-quality influent water at sewage treatment plants, affecting treatment efficiency and threatening environmental health. The existing management model lacks intelligent means, making it difficult to achieve precise monitoring and rapid response.

The increasing frequency of extreme weather further exacerbates the pressure on the network, highlighting the inadequacy of traditional systems in coping with complex conditions. Studies show that in small and medium-sized cities, problems such as incomplete drainage facilities, inadequate drainage networks, and low drainage standards become more apparent during heavy rainfall, easily leading to urban flooding. In such cases, traditional management models often struggle to respond in a timely manner due to a lack of intelligent means. Therefore, to enhance the operational efficiency of the network and reduce environmental risks, the introduction of an intelligent diagnostic system is particularly necessary.

3. Digital Intelligent Diagnostic System

The intelligent diagnostic system for urban drainage (stormwater and sewage) networks is a comprehensive platform driven by data, integrating advanced technologies such as the Internet of Things and artificial intelligence to achieve intelligent monitoring and diagnosis of drainage networks. The main functions of the system include three modules: data collection, analysis processing, and decision support. Specifically, the system collects operational status information of the network through a sensor network and utilizes advanced algorithms to deeply analyze the data, thereby providing accurate decision-making support for operational personnel.

The introduction of the intelligent diagnostic system can significantly enhance the operational efficiency of the drainage network and effectively reduce environmental risks caused by flooding. Recent urban flooding events such as the Zhengzhou "7·20" incident and the Wenshan Qiubei "5·27" mountain flood incident have fully exposed the shortcomings of traditional management models in the face of extreme weather. In contrast, the intelligent system, with its real-time data processing and image recognition capabilities, can provide early warnings of potential problems before disasters occur, thereby optimizing resource allocation and minimizing losses.

The intelligent diagnostic system has many advantages, but it still faces some challenges in practical applications. Some studies have pointed out that due to the complexity of water quality conditions in urban drainage networks, the accuracy of existing prediction models still needs improvement. The issue of insufficient data coverage may also affect the overall performance of the system. Therefore, future research should focus on improving algorithms and expanding data sources to further enhance the reliability and applicability of the system.

4. Research Framework

4.1. Data Collection Layer

The data collection layer is responsible for collecting multi-source heterogeneous data, and its design needs to deeply consider the characteristics of urban drainage networks. The rationality of sensor layout is directly linked to the reduction of the defective pipe inspection area. Therefore, the data collection phase must balance the collection of single indicators while emphasizing multi-dimensional information collaborative analysis, so as to lay a solid foundation for subsequent data processing work.

4.2. Data Processing Layer

The data processing layer specializes in data cleaning and intelligent analysis, serving as the critical core of the system. Relying on advanced algorithms and technological means, this layer can deeply extract the value of collected data, assisting operational personnel in making precise strategies. Data analysis and processing technologies thus become a necessary pillar in the system architecture.

The formulas are as follows:

$$\min\left(\frac{1}{T}+e\right)\sum_{j\in J} C_{1,j}\, L_j$$

$$s.t.\begin{cases}\sum_{\mathrm{i}\in N(\mathrm{j})} X_{\mathrm{i}} \le \beta D_{\mathrm{j}}^{\frac{8}{3}}, \quad \mathrm{j}\in \mathrm{J} \\ \sum_{i=k} X_i = Q(k), k\in K \\ C(k) = \Psi_k q F_{K,} k\in K \\ Q(k) = C(k), k\in K\end{cases}$$

The first constraint aims to ensure that the total number of drainage paths through the j-th pipe does not exceed its maximum carrying capacity. The second constraint guarantees the maximum drainage capacity of the K-th node, which is defined by the maximum flow value in the flow collection starting from the K-th node and traversing the entire drainage network. The third constraint ensures the determinacy of the drainage area of the K-th node, which is influenced and constrained by three key parameters: the area governed by that node, the runoff coefficient, and the intensity of heavy rainfall. The fourth constraint explicitly states that under ideal conditions, the maximum drainage capacity of the K-th node per unit time is equal to the amount of water collected per unit time under extreme rainfall conditions. Based on the initial settings of the first and second constraints, xi and Dj are two variables.

4.3. Decision Support Layer

The decision support layer provides operational optimization suggestions, with its function designed for short, medium, and long-term improvement plans. This phased implementation strategy helps flexibly respond to operational needs under different scenarios, ensuring the long-term stable operation of the system. This layer also needs to integrate water quality detection and CCTV pipeline structure inspection methods to comprehensively assess the current status of the network and propose targeted improvement suggestions.

4.4. User Interaction Layer

The user interaction layer meets the operational needs of different roles, emphasizing the visualization and variability of information. By integrating Revit's building information modeling capabilities and Dynamo's flexible programming capabilities, the user interaction layer achieves full-process automated operations from component library establishment to parametric modeling, greatly enhancing the system's practicality and user experience.

The overall architecture of the intelligent diagnostic system ensures seamless connection and information sharing between various layers through a layered design approach. This design not only addresses the efficiency issues of traditional management models but also provides strong technical support for the construction of smart cities.

5. Key Technologies of the Intelligent Diagnostic System

5.1. Data Collection Technology

Data collection is the foundational link of the intelligent diagnostic system, and its design must closely integrate with the characteristics of urban drainage networks. The use of “hook-shaped” and “linear” layouts for flow sensors effectively narrows the inspection scope of defective pipes. This layout strategy fully utilizes the topological structure characteristics of the network, providing theoretical guidance for reasonable sensor positioning. In practical applications, various factors such as the complexity of the network, the direction of water flow, and the distribution of potential failure points must also be considered.

In actual deployment, data collection technology must also balance cost-effectiveness with application needs. Excessively high construction costs may hinder project promotion, while overly simplified solutions may impact system stability. Therefore, flexible implementation plans should be formulated based on specific application scenarios. Research indicates that pipeline inspection technology in high water level scenarios can combine sonar and CCTV to reduce the additional burden posed by traditional methods. This innovative approach provides a solution path for similar problems, thereby laying a solid foundation for subsequent data analysis and processing, and promoting the comprehensive implementation of the intelligent diagnostic system.

5.2. Data Analysis and Processing Technology

Data analysis and processing technology, as a core component of the intelligent diagnostic system, directly determines the performance quality of the system. In practical applications, data cleaning and preprocessing are indispensable first steps. Research has successfully identified issues such as inflow infiltration, sedimentation, and overflow in drainage networks by constructing a monitoring and diagnosis system centered on data statistical analysis, significantly reducing problem investigation costs. Therefore, data cleaning must address these issues existing in multi-source heterogeneous data to improve data quality.

The optimization of intelligent diagnostic algorithms is the key to achieving precise predictions and decisions. Similarly, in drainage network systems, selecting suitable intelligent diagnostic algorithms is crucial for improving operational efficiency. The performance of algorithms may vary under different working conditions, so optimization based on actual situations is necessary. This optimization method not only enhances computational efficiency but also ensures the reliability of results. Data analysis and processing technology plays a vital role in the intelligent diagnostic system. Through data cleaning, feature extraction, and optimization of intelligent diagnostic algorithms, the overall performance of the system can be effectively improved.

6. Conclusion

As an important facility for the normal operation of cities, drainage networks play a crucial role in the discharge of urban stormwater runoff, sewage overflow from pipe networks, and flood warning. Due to deficiencies in planning, construction, and management maintenance of the networks, urban wastewater overflow and flooding disasters occur, even leading to environmental pollution and infrastructure damage. Overflowing sewage may also pose a threat to public health. The intelligent diagnostic system for drainage networks not only serves as an essential indicator of the operational state of urban drainage networks but also plays a significant role in reflecting flood prevention, flood control, and water resource management in environmental fields.

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References

[1] Tang Shengli, Zheng Hui, Song Huamin, et al. Construction and Application of Intelligent Information for Urban Drainage Systems-A Case Study of the Nansha Drainage Pump Station in Guangzhou. China Informatization, 2024, (12): 111-114.

[2] Li Guo. Statistical Analysis and Repair of Defects in Urban Drainage Pipelines. Special Structures, 2024-10-28.

[3] Hu Weiqiang, Han Huili. Research on Quality Improvement and Efficiency Enhancement Strategies for Drainage Networks in a City in Guangdong. Leather Manufacturing and Environmental Technology, 2024-12-15.

[4] Hu Weiqiang, Han Huili. Research on Quality Improvement and Efficiency Enhancement Strategies for Drainage Networks in a City in Guangdong. Leather Manufacturing and Environmental Technology, 2024-12-15.

[5] Xue Jun, Shi Chenlei. Research on the Emergency Management Framework for Sudden Flood Disasters-Based on Typical Case Analyses of Urban Flooding and Mountain Floods. Journal of Yunnan Administrative College, 2024-11-15.

[6] Wu Dijie, Zhang Shi'an. Research and Application of Urban Flooding Monitoring and Early Warning Prediction. Proceedings of the 2024 (3rd) Academic Seminar on Urban Water Conservancy and Flood Prevention, 2024-12-13.

[7] Fu Xingwei, Zhang Tiantian, Li Ming, et al. Research on Monitoring Point Layout Methods for Urban Drainage Networks. Water Supply and Drainage, 2023-06-30.

[8] Gong Rui. Research on Urban Drainage Management Issues-A Case Study of District B in Shenzhen. Central South University, 2022-06-01.

[9] Zhao Congcong, Zhao Yunfei, Ren Ziyuan. Application of Water IoT Monitoring Technology in the Diagnosis of Drainage Network Problems. Environmental Engineering, 2023-11-13.