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Sewage Discharge Monitoring and Management System Based on K-Means Algorithms

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ABSTRACT

In order to effectively monitor and manage the discharge behaviour of enterprises to avoid water pollution and improve environmental quality, it is proposed to develop and design a sewage discharge monitoring and management system which meets the practical needs. The sewage discharge data management module, monitoring and management module, early warning management module, data statistical analysis module and system query function module are designed and developed. In addition, the development and design process of the functional module of the system is described by means of example diagram and time sequence diagram. On the basis of system function design, language and database technology are applied to realize the functional modules of the system. The function test and performance test of the system are discussed and analysed, and a sewage discharge monitoring and management system that meets the actual needs of the sewage discharge monitoring department is developed. The results show that the sewage online monitoring and management system has the functions of real-time reception, treatment, analysis and early warning. Therefore, the system can help to make up for the loopholes in the sewage discharge monitoring and management of enterprises, effectively standardize the sewage discharge behaviour of enterprises, and then improve the environmental pollution caused by excessive sewage discharge.

INTRODUCTION

The total amount of water resources in China is relatively abundant, but due to the influence of climate conditions and vast land area, there are serious regional and temporal differences in precipitation in China, which also makes the precipitation in the vast northern and inland areas less. Moreover, the overall precipitation in China is mostly concentrated in summer, it causes serious water shortage in many areas of China. Therefore, it is of great practical significance to strengthen the monitoring and management of sewage discharge and control the pollution of water resources. It is also an important measure to alleviate the shortage of water resources in China.

Judging from the current domestic sewage discharge situation, although China has more detailed standards for enterprise sewage discharge, the phenomenon of enterprise sewage stolen discharge is very serious. The main reason is that the supervision department lacks effective monitoring of enterprise sewage discharge, which provides an opportunity for enterprise stolen discharge. In the view of the sewage discharge supervision department, it is difficult to collect discharge data for enterprises because of the lack of complete information management tools. At the same time, due to the large number of enterprises and the complex types, it lacks effective monitoring and management of enterprise sewage discharge information, which makes the sewage discharge monitoring and management work have larger loopholes. In view of this research background, the design and implementation of sewage discharge monitoring and management system is studied. It is hoped that this study will improve the environmental pollution caused by serious sewage discharge and inadequate sewage discharge monitoring in enterprises, and effectively standardize the sewage discharge behaviour of enterprises. Implementing immediate punishment to enterprises violating regulations can effectively manage sewage and protect the ecological environment.

EARLIER RESEARCH

In order to achieve sustainable economic development, many researchers at home and abroad are beginning to intensify the work of sewage discharge supervision and continue to develop and explore automated systems and supporting equipment with independent intellectual property rights. In 2015, a study designed the upper computer application program of sewage treatment system based on Visual Basic software (Ong et al.

2015). Finally, the field operation test of the control system was carried out. The test results show that the system can meet the requirements of sewage treatment control with high reliability and stable operation. Li et al. (2015) put forward a design and research of solar heating anaerobic wastewater treatment system in cold area based on the research on solar heating treatment of anaerobic wastewater at home and abroad. The design scheme of distributed control system for municipal sewage treatment automation system was proposed by Zhang et al. (2015). Its main function is to monitor subsystems of municipal sewage treatment through configuration software WinCC and Siemens S7-300 programmable logic controller (PLC). Based on these shortcomings, combined with the development of wireless sensor networks, Von (2015) designed a wireless sensor network monitoring system which can simultaneously monitor various parameters. The system has the advantages of high reliability, easy expansion and low power consumption. It has been implemented in a sewage treatment plant and achieved good performance. A research adopted S7-200 series PLC provided by Siemens as controller and used three-dimensional force control configuration software and GPRS RTU transparent transmission function to realize remote monitoring of the process, parameters and operation status of the main equipment of rural domestic sewage treatment (Kong et al. 2015). A study applied Siemens S7-200 PLC to sewage treatment system by analysing various control parameters of sewage treatment system and comparing different automatic control modes (Tian et al. 2015). In 2017, recent study developed and evaluated a small package sewage treatment system that combined the commercial needs of the market with current and future environmental legislation in the UK (Basrawi et al. 2017). Zhou et al. (2017) applied artificial intelligence control technology to sewage treatment plant. Fuzzy control method was used in sewage treatment process, and on the basis of dynamic fuzzy control of water quality, the software design and upper control of automatic control system for parameters of sewage treatment process were completed. In 2018, a research put forward an implementation strategy of embedded sewage treatment control system based on real-time kernel and described the functional requirements, hardware and software design and implementation strategy of the system (Song et al. 2018).

MATERIALS AND METHODS

The supervision of sewage discharge has always been the focus of environmental protection departments. At present, the traditional way of environmental protection work has been difficult to meet the needs of modern environmental protection work. Therefore, in order to promote the efficiency of environmental protection work, in modern environmental protection work, to better strengthen the attack on enterprises' covert sewage discharge behaviour, and effectively improve the effectiveness of sewage discharge management, in the current information age era, strengthening the construction of the sewage discharge supervision system is particularly necessary.

To better strengthen system development and design, it is supposed to pay attention to the analysis of system function and performance. This needs to strengthen the investigation of the use of the monitoring system, and grasp the needs of users and performance, so as to better ensure that the designed monitoring system is more practical. In the process of investigation, it is necessary to master the requirements of the environmental protection department for the use and function of the system (Table 1).

Data management module is one of the main modules in the whole system function. Its main purpose is to better supervise the sewage discharge data, so as to better store the sewage discharge data in the system, and at the same time to analyse the water quality, so as to provide scientific and detailed basis for decision-making of environmental protection managers (Fig. 1). The function of early warning management module is mainly to alarm and notify abnormal sewage discharge behaviour. Therefore, in order to meet the needs of system functions, efforts should be made in early warning maintenance of receiver's information, the configuration of early warning parameters, and the processing of early warning data. At the same time, early warning query function should be provided. In the monitoring and management module, it mainly detects and manages sewage discharge data. Specifically, it closely combines the data detected by the system, and effectively strengthens the analysis and processing of the data, so as to judge whether there is illegal sewage discharge in enterprises.

Table 1: Feasibility analysis of online monitoring and management system.

Serial number	Classification	Make a concrete analysis		
1	Economic feasibility	The cost of system development is reasonable	Personnel cost arrangement in place	Reduce unnecessary waste
2	Technical feasibility	Developing technically reliable personnel	Excellent managerial ability	The necessary equipment of the system
3	Feasibility of management	Efficient	Reliable management	Government support is strong

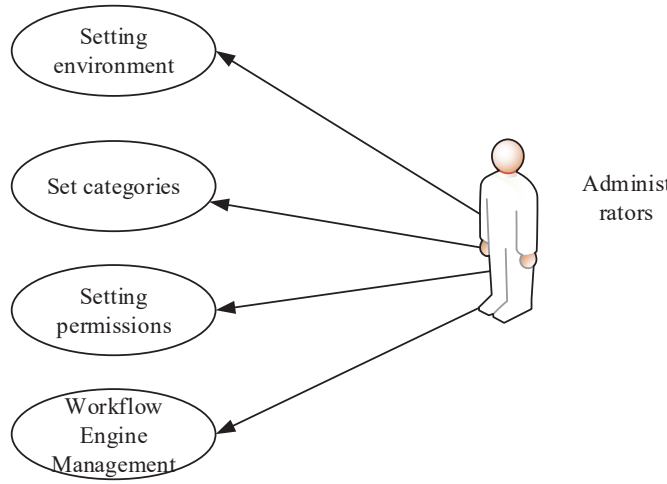

Fig. 1: User use case diagram of system settings function.

RESULTS AND DISCUSSION

Clustering technology for over-standard degree of factory sewage discharge: Partitioned clustering algorithm is used, among which K-means is the most widely used clustering technology. It is an unsupervised learning model based on prototype. Through K-means algorithm, it can be found that the number of clusters specified by users (k) is represented by the centroid. It has many advantages, such as fast convergence speed, easiness for understanding the principle, and suitability for a variety of data types. However, there are several problems in applying K-means algorithm to clustering of over-standard degree of factory sewage discharge: first, k value needs to be determined beforehand as parameter input; second, centroid selection is the most critical step in k-means, and clustering results are often different when choosing different centroid; third, K-means applies an iterative method to update centroid continuously, and each iteration not only calculates the value of clustering criterion function (target), but also recalculates the centroid of the next round.

Due to some problems in the application of K-means algorithm to over-standard clustering, appropriate improvements are made to these problems in combination with the characteristics of sewage data. In order to better adapt to the clustering of over-standard degree of factory sewage discharge, the key points of K-means algorithm improvement are as follows: The K-means algorithm is mainly aimed at the calculation of the distance between two data points. Before analysing how to simplify the calculation of the distance between two data points, a data point x, $x = (x_1, x_2, \ldots, x_i)^T$ is studied first. x_i represents the proportion of the i^{th} index exceeding the national standard, and i represents the total number of sewage indicators to be monitored, which is also the dimension of data points. Because the selection of centroid has a great influence on the final clustering result, manual selection of centroid is used when initializing. After the above analysis, each data point has its corresponding value, and the two data points represented by the maximum value and the minimum value can be regarded as the initial centroid. For the final cluster number k, the clustering operation is meaningful only when it is greater than or equal to 2. In summary, the initial centroid value is:

$$V_{Sj} = \begin{cases} \min\{V_{xi}\}, (i = 1,2,L,N; j = 1) \\ V_{S1} + \dfrac{V_{sk} - V_{S1}}{K - 1}, (1, < j < k) \\ \max\{V_{xi}\}. (i = 1,2,L,N; j = k) \end{cases} \quad \ldots(1)$$

In the above formula, x represents all data points, i.e. all sewage data to be input for clustering. x_i represents the i^{th} data point, that is, a specific sewage data.

Real-time monitoring of factory sewage discharge: In the clustering analysis above, not only the degree of over-standard pollutant discharge from factories is obtained, that is, each cluster, but also the centroid of each cluster. Therefore, to judge the degree of over-standard sewage data in a factory at a certain time, it is only necessary to calculate the distance between the data point and which centroid is the shortest, that is, the closest over-standard degree. The over-standard sewage discharge from the factory represented by the shortest centroid can be considered as the over-standard degree of sewage discharge from the factory at that time. The flow chart of the algorithm is shown in Fig. 2.

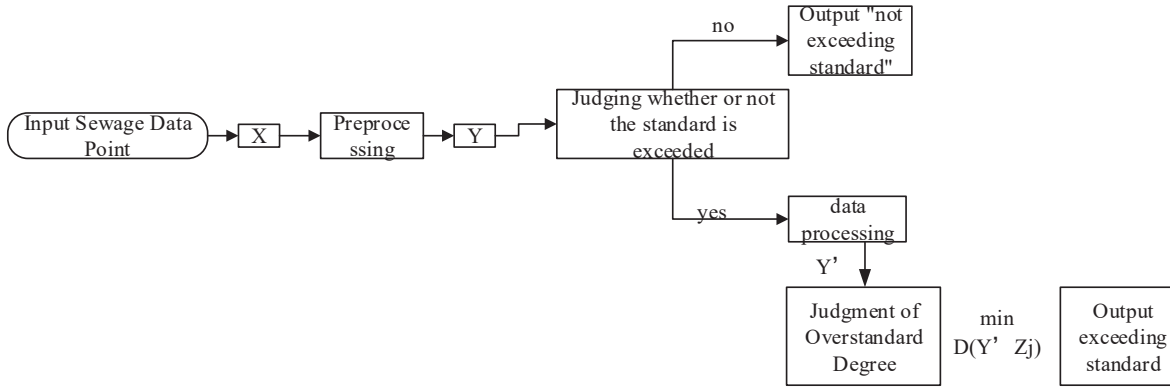

Fig. 2: Flow chart of over-standard monitoring algorithm.

Input sewage data point X of a factory at a certain time:

$$X = \left(x_1, x_{2,}, \cdots, x_w\right)^T \quad \ldots(2)$$

After data pre-processing, Y is obtained:

$$Y = \left(\frac{x_1 - S_1}{S_1}, \frac{x_2 - S_2}{S_2}, \cdots, \frac{x_w - S_w}{S_w}\right)^T = \left(y_1, y_2, \cdots, y_w\right)^T \quad \ldots(3)$$

Formulas (4) and (5) are used to judge whether the standard is exceeded or not.

$$\forall j\left(y_j \le 0\right) \in \text{Not exceeding standard}, \left(j = 1, 2, \cdots, w\right) \quad \ldots(4)$$

$$\exists j\left(y_j > 0\right) \in \text{Exceeding standard}, \left(j = 1, 2, \cdots, w\right) \quad \ldots(5)$$

If it does not exceed the standard, output "does not exceed the standard" and end. If it exceeds the standard, the data is pre-processed to judge the degree of exceeding the standard, and Y' is obtained:

$$Y' = \left(y'_1, y'_2, \cdots, y'_v, ID\right)^T, \left(1 \le v \le w\right) \quad \ldots(6)$$

Demand analysis and outline design of sewage discharge supervision system: Specific functional requirements are as follows: receiving and analysing large sewage data; analysis and detection of large sewage data; over-standard monitoring of sewage discharge; storage of large sewage data; prediction and warning of sewage discharge; demonstration of data and research results. In addition to functional requirements, the implementation of sewage monitoring system should also meet the following requirements: design of friendly interface, scalability, high reliability.

According to the demand analysis, a four-tier framework is designed for sewage discharge supervision system. These four layers are application layer, business layer, middle layer and model layer from top to bottom, as shown in Fig. 3. The application layer is the closest to users, including the interface display of basic query data, the drawing of prediction curve etc. The business layer is between the application layer and the middle layer. On the one hand, it collects the output results of all the algorithms in the middle layer. On the other hand, it provides corresponding service interfaces according to the specific needs of the application layer. The middle layer mainly implements the algorithms studied in the system, and separates them into one layer, which not only reduces the coupling between layers, but also improves and updates the algorithms in this layer. The model layer includes the addition, deletion and modification of stored data, as well as the persistence of query results.

The sewage discharge system is divided into five modules: data receiving and analysis module, data analysis and processing module, data storage module, data query module, and alarm module, as shown in Fig. 4.

Detailed design of sewage discharge supervision system: At present, socket communication is used between the cloud platform processing layer and the lower layer. After binding the ports, the lower layer ports are monitored. If the data are received, the data are transmitted to the analysis module for processing. After receiving the data, it is parsed according to the defined protocol format. If the parsing fails, it will be discarded without further processing. If the parsing succeeds, it will show that the data format conforms to the specifications and is the data needed by the system. Data analysis and processing module is mainly divided into three small modules, sewage indicators detection module, standard exceeding monitoring module, and prediction module. The format conforms to the specifications and is the data needed by the system.

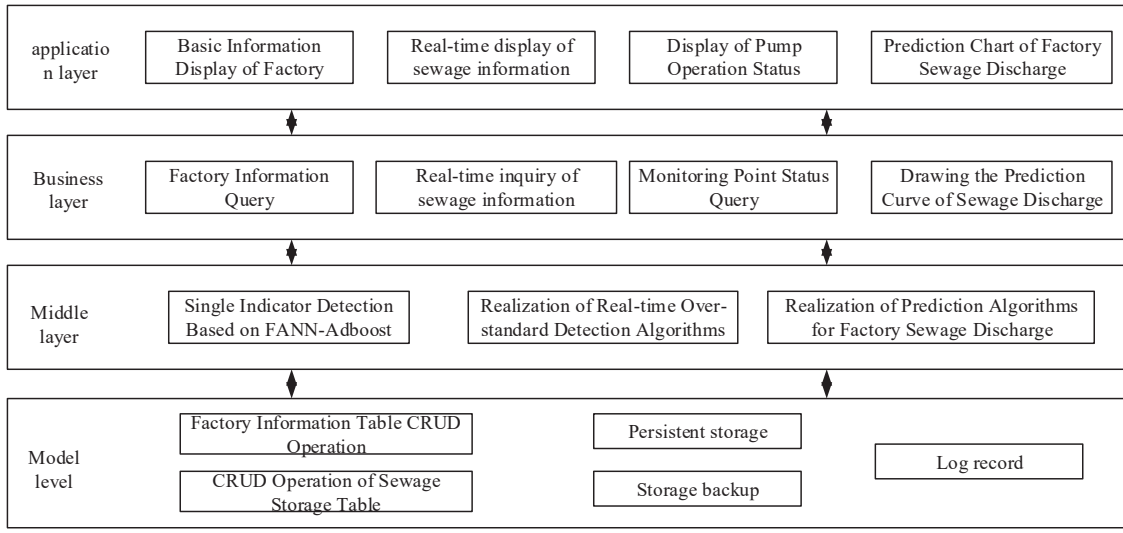

Fig. 3: Logical structure.

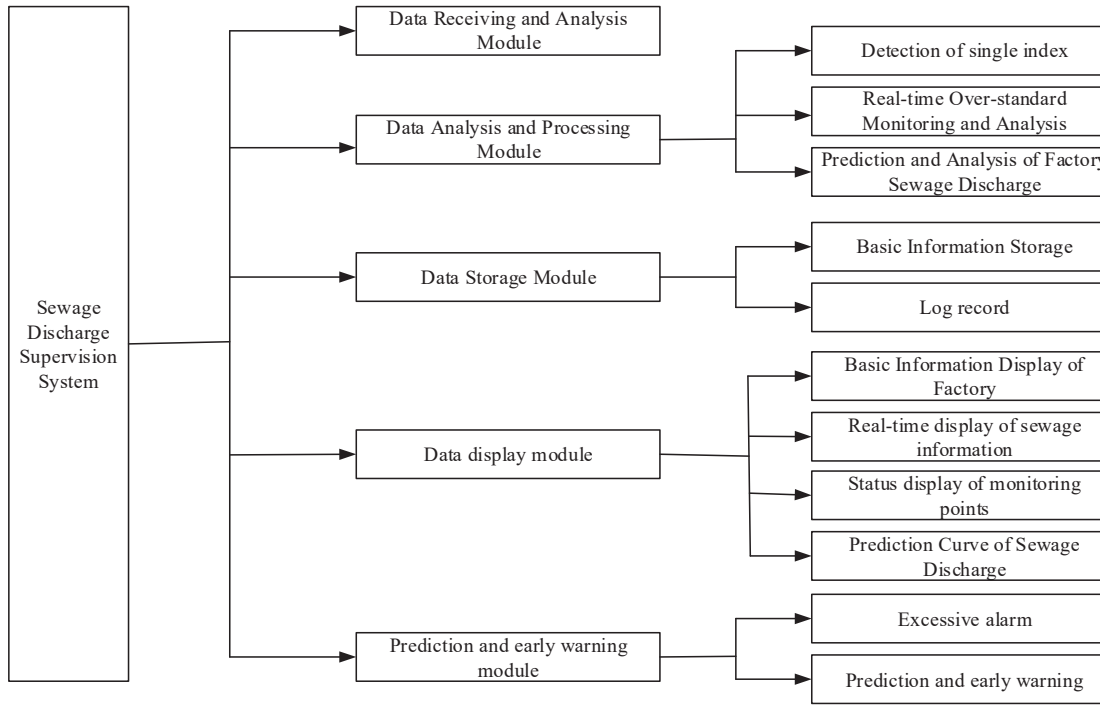

Fig. 4: Function module design.

The data display module adopts B/S architecture, so that users can browse the pages of sewage monitoring system through both PC and mobile clients. All display interfaces are implemented using HTML, JSP, JavaScript and other technologies, and eventually released and deployed to Apache Tomcat server. The data display module is divided into the main interface, the basic information interface of the factory, and the sewage discharge display interface.

First, the main interface is presented to the users. On the main interface, the list of all cities is displayed through the drop-down menu, and users can choose to view all the

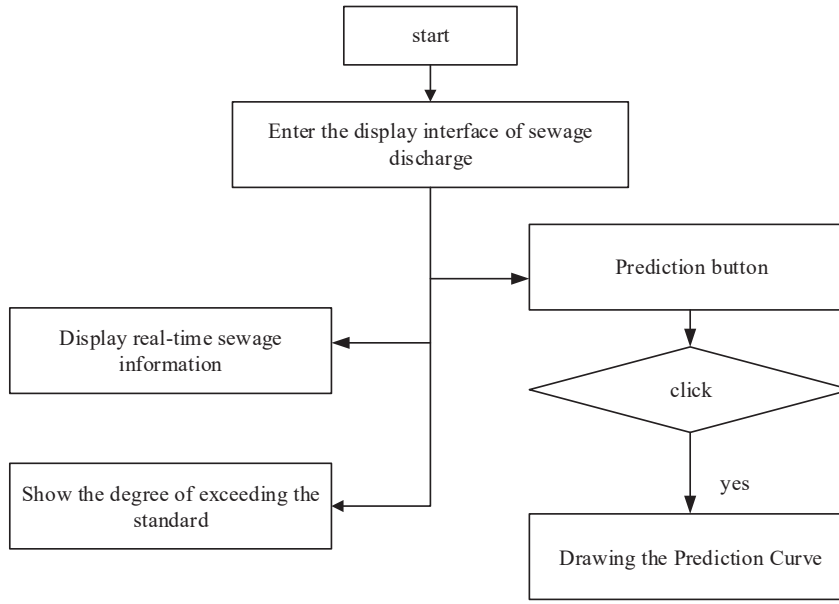

Fig. 5: Demonstration process of sewage discharge.

regulatory factories in the city. When clicking on a factory, it jumps to the basic information interface of the factory. In the basic information interface of the factory, users can see the name of the factory, the city where the factory is located, the brief introduction to the factory, the number of monitoring points and the list of all monitoring points of the factory. All monitoring points arranged by the factory will be presented to users in the form of a list. If users need to check the operation status of a monitoring point, they can click on the monitoring point. After entering the sewage discharge display interface, users can not only see all the real-time wastewater indicators, including pH, water temperature, COD value, etc., but also see whether the wastewater at this monitoring point of the plant exceeds the standard at the moment. If it exceeds the standard, it will show the corresponding degree of exceeding the standard. Users can click on the "Prediction" button to view the sewage discharge curve of the plant in the past month and the trend in the next few days. The specific process is shown in Fig. 5.

CONCLUSION

The sewage discharge monitoring and management system is mainly studied. In the process of research, starting from the process of sewage monitoring and management of the management department, a sewage discharge integrated management system is developed and designed by using programming language and database technology, which meets the actual needs of sewage discharge monitoring and control. The complete process of sewage discharge data management, sewage discharge monitoring and early warning is controlled. And the sewage discharge data management module, monitoring management module, early warning management module, data statistical analysis module and system query function module are designed and developed.

In the actual application process, the realization and implementation of the system will effectively supervise the sewage discharge situation of sewage discharge enterprises, improve the drawbacks of the original monitoring system which cannot be monitored immediately, improve the speed of information flow, ensure the timely development of sewage monitoring work, and lay a solid foundation for the improvement of the supervision effect and environmental protection benefits of environmental protection departments. The system plays an important role in standardizing the behaviour of enterprise sewage discharge, improving environmental pollution caused by serious sewage discharge and inadequate monitoring of sewage discharge, and promoting the development of environmental protection in China.

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