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Data Analysis System for Sewage Pump Test Bench

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Abstract

With the acceleration of urbanization, the stability and efficiency of sewage pumps are crucial for sewage treatment. This article designs and develops a data analysis software system that integrates state monitoring, fault diagnosis, and trend prediction functions. The system adopts wavelet threshold denoising to optimize data, uses GA-BP neural network model for fault prediction, and combines expert system to improve diagnostic accuracy. The front-end is based on Vue.js, and the back-end uses SpringBoot, combined with Echarts to achieve visual data analysis. This system effectively improves the operational efficiency of sewage pumps and provides intelligent management support for sewage treatment plants.

Keywords

Sewage Pump Test Bench; Fault Diagnosis; Trend Prediction; GA-BP Neural Network.

1. Introduction

In recent years, with the rapid development of China's economy, society, and cities, investment in sewage treatment has been continuously increasing. This has led to an increasing frequency of application of sewage pump test benches in sewage treatment, thereby increasing the demand for operation and management personnel[1]. The traditional management method of sewage pumps mainly relies on manual inspection and regular maintenance, which has problems such as lagging detection, insufficient fault warning ability, and high operation and maintenance costs. Therefore, there is an urgent need for an intelligent data analysis system to improve the operational efficiency of sewage pumps, reduce downtime due to malfunctions, and optimize energy management. Even minor malfunctions can cause data changes, thereby affecting the entire sewage treatment process and results[2]. This uncertainty has had a significant impact on production, including whether production can proceed normally and whether the effluent quality can consistently meet standards. Therefore, establishing a fault diagnosis and expert recommended data analysis software system suitable for sewage pump test benches is crucial for the stable operation of sewage treatment plants.

This article proposes a data analysis software system for sewage pump test bench based on GA-BP neural network and expert system. This system combines wavelet threshold denoising technology, intelligent prediction algorithms, and data visualization technology to enhance the monitoring, analysis, and prediction capabilities of sewage pumps[3]. The system can not only monitor the operating parameters of sewage pumps in real time, but also predict the future operating status through neural network algorithms, and combine with expert systems for intelligent fault diagnosis[4]. The research in this article has important application value for the intelligent operation and maintenance of equipment such as sewage treatment plants and industrial pump stations[5].

2. System Architecture Framework Design

Design the system software hierarchy architecture based on the SpringBoot framework, dividing the system into presentation layer, control layer, business logic layer, data access layer, and storage layer. The system software hierarchy diagram ,see Figure 1.

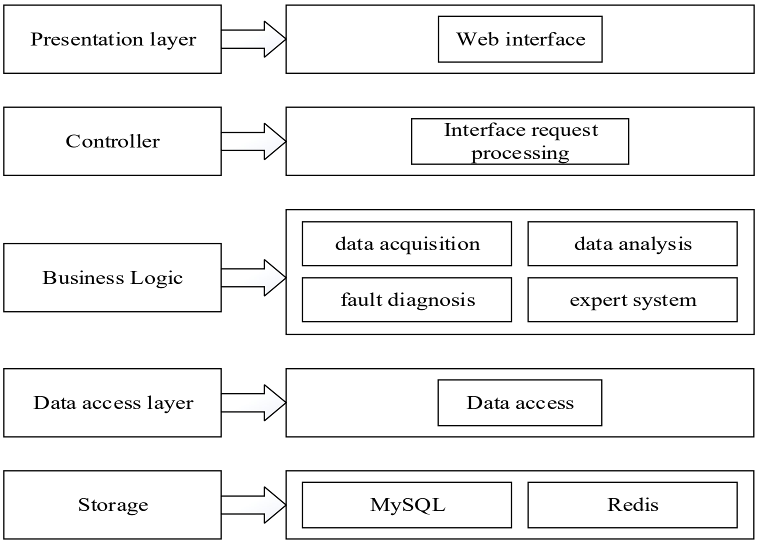

Figure 1. System Software Hierarchical Architecture Diagram

The first layer is the presentation layer, which uses core technologies such as Vue framework, Elements components, and Echarts[6]. This layer mainly implements the display function of front-end statistical views. When users enter the front-end to view statistical data, they obtain statistical data through interaction with the back-end interface and render it. The page design of this system is mainly focused on statistical analysis, and various data statistics are displayed in the form of charts, such as line charts, pie charts, etc., providing users with a visual view of data statistical analysis and bringing them a good experience.

The second layer is the control layer, which mainly processes requests from various users. The control layer is responsible for processing requests sent by the user's front-end. This layer ensures interface security by verifying user login and also logs user operations.

The third layer is the business logic layer, which implements the business logic of various functional modules of the data analysis system. This layer mainly uses the SpringBoot framework to implement the core business logic of the system,see Figure 2.

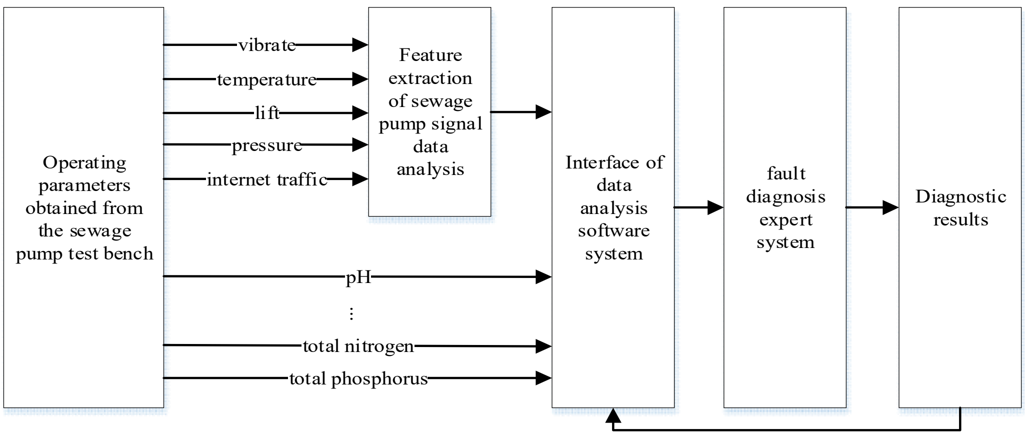

Figure 2. System core business logic diagram

The fourth layer is the data access layer, which is located between the business logic layer and the storage layer. It mainly encapsulates the data in the storage layer to facilitate data interaction with the business logic layer. This layer implements the mapping between database tables and objects. When

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the business logic layer accesses data, it can perform operations such as adding, deleting, modifying, and querying database tables in the storage layer through the data interface of this layer.

The fifth layer is the storage layer, which mainly performs persistent operations on the data of the system. Based on the characteristics of the data in this system, MySQL database is used for data storage. In order to improve user experience, Redis database is used for caching data with frequent queries and calls, sharing database pressure and accelerating response speed.

3. Fault Feature Extraction of Data Analysis Software System for Sewage Pump Test Bench

When a sewage pump malfunctions, it is often inaccurate to determine the fault based on a single characteristic of the signal. Some sewage pumps may malfunction with operating parameters that are within the allowable range, but their operating trends and other characteristics have already become abnormal. Therefore, data analysis of these operating data characteristics is needed. This article uses Python language to extract feature values using wavelet transform.Collect data using head as an example,see Table 1.

Table 1. Head information table

Serial Number	Field name	data type	describe
1	id	int	Primary key
2	lift	float	Head value (m)
3	avg_lift	float	Average head value (m)
4	timestamp	datetime	Collection time

Traditional wavelet analysis usually only decomposes signals without explicit noise suppression, which may increase complexity and uncertainty. Therefore, wavelet thresholding is used to preprocess the running data before feature extraction,see Figure 3.

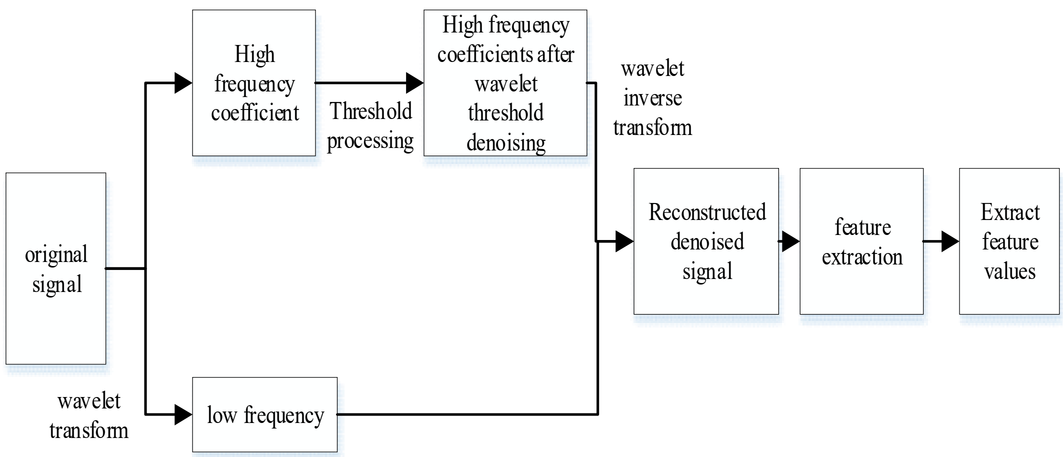

Figure 3. Flowchart for Extracting Feature Values through Wavelet Transform

The process of extracting feature values is as follows:

(1) Firstly, the collected raw signal is decomposed into wavelet coefficients of different frequencies through wavelet transform to represent the signal.

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(2) Use wavelet thresholding to denoise the signal. It utilizes the results of wavelet decomposition by applying threshold functions to wavelet coefficients, zeroing or scaling smaller coefficients to achieve denoising effects. A soft threshold function was used for threshold processing.

(3) Using wavelet inverse transform to reconstruct the processed wavelet coefficients into denoised signals.

(4) Extracting frequency domain features by performing Fourier transform (FFT) on denoised continuous time-domain signals to obtain their frequency domain energy.Taking head as an example,see Figure 4.

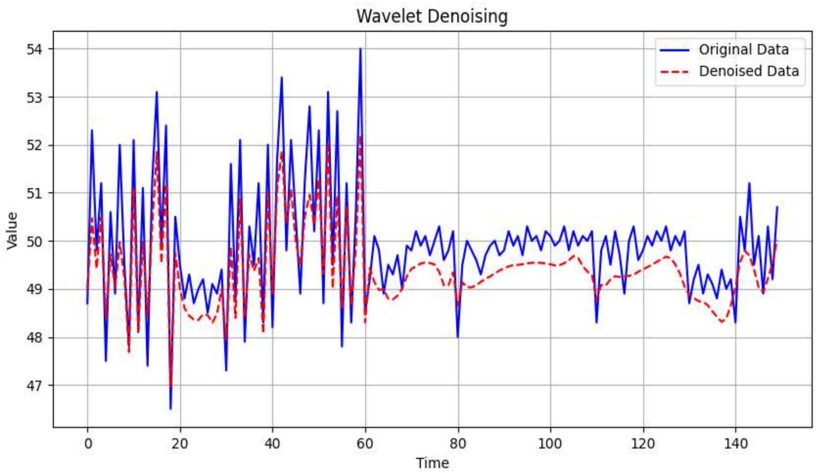

Figure 4. Logic diagram for feature extraction in system fault diagnosis

4. Design of Fault Diagnosis Expert System

By combining the experience and knowledge of domain experts, the diagnostic methods of expert systems are applied to the diagnosis of sewage pump faults, in order to achieve similar decision-making and reasoning abilities as experts to diagnose faults and improve the probability of fault recognition. The expert system established in this article consists of a knowledge base, inference engine, interpreter, database, human-computer interaction module, etc.

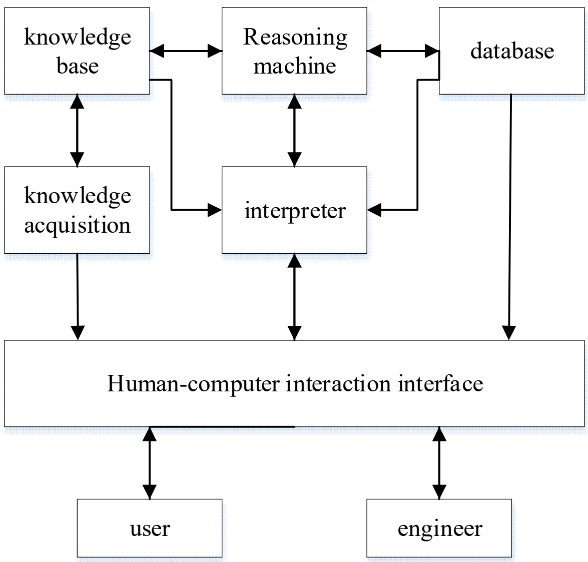

Figure 5. Expert system architecture diagram

The knowledge base mainly manages the collected diagnostic information such as various symptom knowledge and fault knowledge in a unified manner; The inference engine retrieves feature data for diagnosis from the database, infers the knowledge in the knowledge base, and submits the obtained results to the interpreter mechanism; The interpreter is mainly used to provide diagnostic reasoning results and other information output to the human-computer interaction module; The database is used to store various types of state parameter data in the local knowledge base, including knowledge, diagnostic results, and intermediate quantities; The human-computer interaction module can update and modify knowledge in the knowledge base for users, and also provide corresponding human-machine operations for report generation and diagnostic result output,see Figure 5.

4.1 Expert System Diagnosis Process

The diagnostic process of the expert system is as follows: firstly, the fault features are extracted from the data collected by the sewage pump test bench, and different faults are identified and imported into the expert system. Finally, the expert system infers the measured fault signals, fault diagnosis rule base, and knowledge base, and provides fault causes and maintenance suggestions based on the features,see Figure 6.

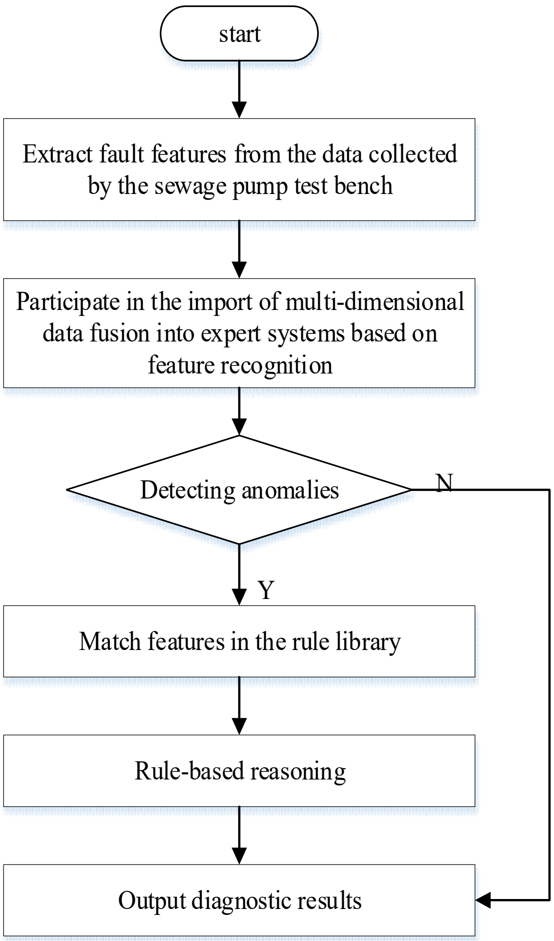

Figure 6. Expert system diagnostic flowchart

4.2 Design of Knowledge Base

Expert knowledge is a prerequisite for system diagnosis, therefore it needs to be summarized and extracted from domain experts or other sources, and transformed into a form that computers can understand according to certain representation methods. Due to the lack of experimental data, automatic knowledge acquisition methods are difficult. Therefore, this article adopts non automatic methods to acquire knowledge, mainly through the following two approaches:

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(1) Firstly, understand the principle, composition structure, and operation process of the sewage pump. Then, analyze the relevant manuals, professional books, management regulations, and other materials of the sewage pump, and organize the knowledge obtained

(2) Inquire with teachers in relevant fields to supplement the knowledge obtained; By integrating two methods of knowledge acquisition, summarize and generalize the collected knowledge to form a knowledge base for fault diagnosis,see Figure 7.

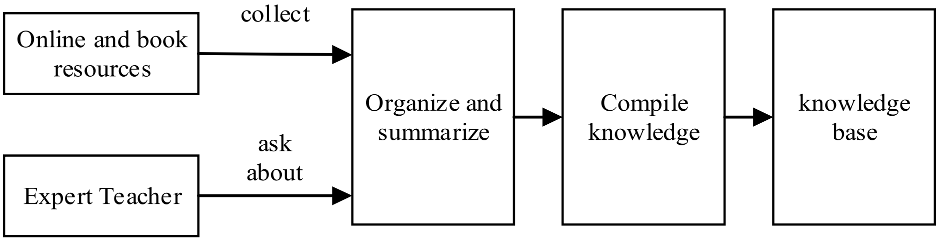

Figure 7. Structure diagram of knowledge base formation

The representation of knowledge is an important step in expert system diagnosis and serves as a bridge between knowledge acquisition and application. Represent the obtained expert knowledge according to the set rules, so that the computer can compile and apply expert knowledge for diagnosis.

5. Implementation of System Scheme

5.1 Online Monitoring Interface Display

The monitoring interface of the sewage pump test bench data analysis system displays real-time data on key parameters such as temperature, head, flow rate, pressure, and vibration during the operation of the sewage pump. The interface uses various visualization methods such as bar charts, line charts, and bar charts to experiment with the operating status of the water pump at different time periods, ensuring clear and easy to read data. The top status indicates whether each parameter is normal, and the line chart and bar chart display trend fluctuations. The bar chart is used for fine comparison, and the continuous curve chart monitors stable operation, which is conducive to real-time monitoring,see Figure 8.

Figure 8. Online monitoring interface

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5.2 Trend Prediction and Fault Diagnosis

By visualizing trend prediction to increase the confidence of fault types, more accurate fault diagnosis can be achieved. The implementation process is as follows:

(1) On the basis of removing noise from the given data through wavelet transform, the training set and testing set were divided, and the dataset required for the trend prediction model was constructed.

(2) A fitness function is defined, which uses MLPRegressor as the prediction model and calculates the mean square error between the predicted value and the actual value as the fitness value.

(3) Optimize the hidden layer size of MLPRegressor using genetic algorithm to obtain the minimum mean square error as the optimal solution.

(4) We reconstructed the MLPRegressor model using optimal parameters and performed trend prediction on the test set.Taking head as an example,see Figure 9.

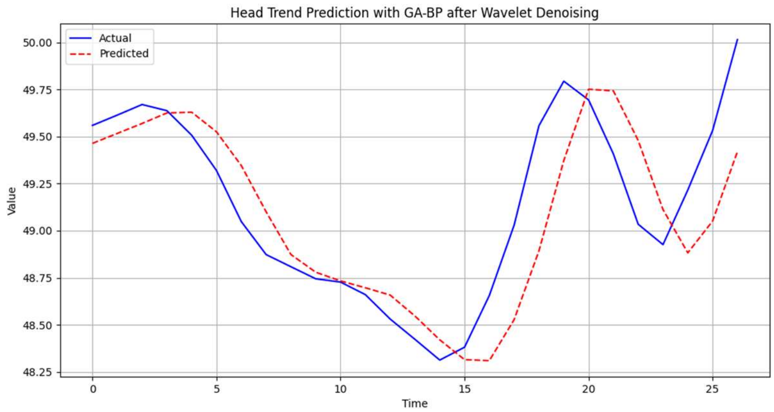

Figure 9. Online monitoring interface

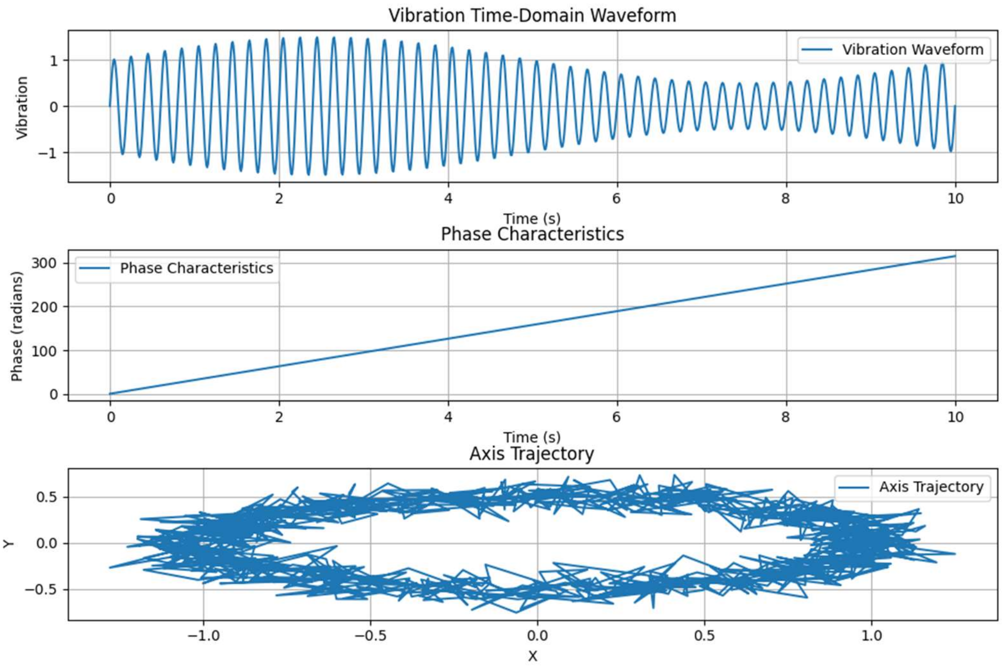

Figure 10. Fault characteristic diagram of flow or pressure reduction during operation

The fault characteristics are the fault symptoms exhibited when a water pump malfunctions, and are the basis for identifying the type of fault. Analyzing and summarizing fault characteristics is a prerequisite for expert systems to diagnose faults. This article uses time-domain waveforms, phase characteristics, and axis trajectories for diagnostic analysis. The time-domain waveforms can reflect the dynamic response of the water pump during operation and help detect instantaneous shocks, mechanical vibrations, and abnormal load changes; Phase characteristics are used to analyze the relationship between pump vibration and rotating components, providing information about system imbalance, bearing damage, or misalignment; Axis trajectory monitoring can reveal potential issues such as rotor misalignment, bearing wear, or structural deformation. By combining these feature analyses, expert systems can more accurately diagnose the types of faults in water pumps, improving the accuracy and reliability of diagnosis.

The expert system will make judgments based on the above characteristics, diagnose and analyze the status of the sewage pump, and ultimately provide diagnostic results to maintain long-term stable operation.

6. Conclusion

A set of online monitoring and fault diagnosis system for sewage pump test bench has been developed to address the operational issues of sewage pumps. The entire system architecture and functional units have been elaborated in detail, and a fault diagnosis design based on expert system has been proposed.

(1) The developed system can display real-time and accurate key parameter information of sewage pumps, which is convenient for staff to monitor.

(2) The designed expert system can effectively extract fault data features, make accurate judgments on faults, analyze the causes of faults based on fault features, and provide suggestions for troubleshooting, reducing system maintenance costs and time and ensuring the smooth operation of equipment.

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