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Research on the Monitoring System of Multi-Sensor Based Sewage Treatment Process

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Abstract: This article puts forward a multi-sensor data collection and the methods on the real time control of the sewage treatment process. The three layer distributed control system and parallel sensor integration scheme are designed according to the needs of the sewage treatment process, then the model selection is made on the hardware of the sensors and control module according to the needs of the sewage water quality monitoring and process control and hardware configuration distribution is conducted according to the distribution, types and information of the monitoring points, control points and data points and finally corresponding procedures are prepared and the relevant test is conducted as well according to the target sewage treatment process. *Copyright © 2013 IFSA.*

Keywords: Multi-sensor, Sewage treatment, Real time monitoring, Data integration, Intelligent control.

1. Introduction

The sewage system has the instability and uncertainty with the features of multivariable, nonlinear, time variant and random treatment process [1-2]. Therefore it is relatively hard to set up an accurate mathematic model. At the same time, the control of the sewage treatment system is the multi-objective control so it is hard to reach the control requirements with the traditional control method [3]. However, the intelligent control system, with the functions of self-study, self-adaptation and self-organization is particularly suitable for the control of the dynamic process of complex sewage treatment [4-5]. In the recent years the intelligent control has been successfully used in the feed water treatment, sewage water treatments, physical and chemical sewage water treatment in US, Europe and Japan. Presently, there are numerous projects that are being investigated and developed [6]. The intelligent control has been the research hotspot and leading subject in the area, demonstrating a greatly wide application prospect [7].

2. System Design

2.1. Distributed Control System

There are several typical forms for the computer control system as follows: operation guidance control system, directly digital control system, monitoring control system, distributed control system and Field

bus Control System, etc. Distributed control system, based on the Microcomputer Technology, carries forward the unit aggregated instruments and the advantages of the computer system and makes full use of the achievements of control technology, computer technology, communication technology and image display technology, forming the computer integrated control system that has been concentrated the continuous control, order logical control and data collection function. Distributed control system is generally divided into comprehensive management level, centralized operation monitoring level and process control level with the system structure drawing shown as follows in Fig. 1.

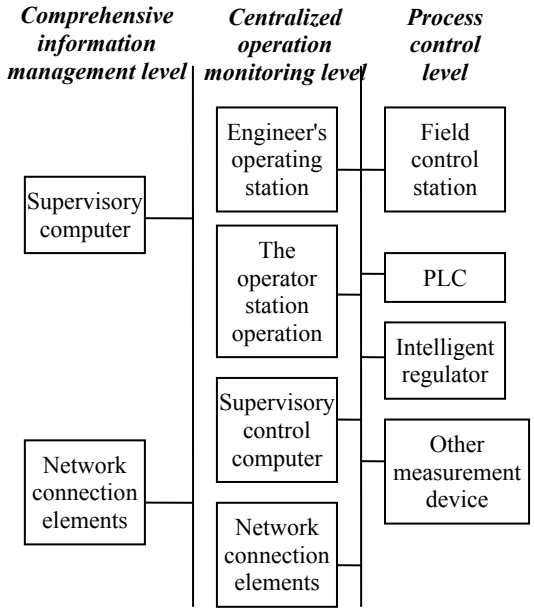


Fig. 1. Normal structure of distribute control system.

With respect to the features of BCFS$^{\circ,R}$ process studied in this topic and the relevant requirements, a three layer distributed monitoring control system has been designed with the overall structure shown as follows in Fig. 2.

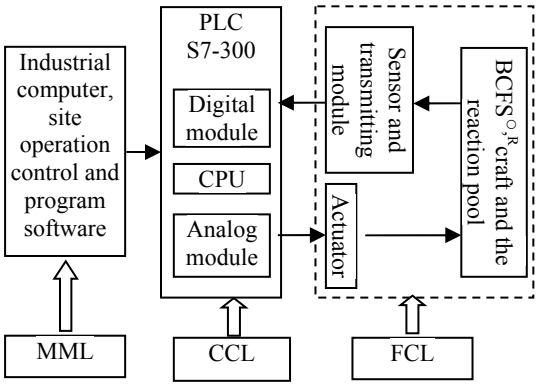


Fig. 2. BCFS$^{\circ,R}$ structure of control system.

The monitoring management layer (MML) is an industrial control computer, which can functions as conducting the field the monitoring and system programming and debugging, at the same time it can realize the remote control and management of the computer, analysis and treatment, storage display on the data collection and be responsible for the database, knowledge base management, log, statement and operation conditions, etc so as to real time filed monitoring.

Centralized control layer (CCL) can function as controlling the field actuator and realize the communication between the field equipment and monitoring management layers. It includes Siemens S7-300 PLC controller, field control station consisting of various auxiliary modules and can realize the functions of data collection and filed equipment control, etc.

Field control layer (FCL) consists of data collection and control execution system. The data collection system mainly includes the sensors and signal transmitting equipment. The control execution system refers to executive components, such as pump, blender and aerating apparatus. The field control layer is the lowest layer that can realize the data collection and process control of the technological process.

2.1. Distributed Control System

Parallel multi-sensor integration means all the output information from all the sensors is inputted into the same multi-sensor integration center. At this moment, the information stored in the sensor can be synchronized or non- synchronized; the sensors can be of same kinds or not be of same kind and the information can the information sent by the same sensor at the different moments or the information sent by the same sensor at the same layer or different layers. Parallel sensor is more suitable for space time multi-sensor integration. But to the large input information, it is required that more sensor integration center should process the information quickly. The parallel multi sensor integration structure can be shown in Fig. 3. It is known from this figure that when the parallel multi sensors are being integrated, the output of the various sensors is not affected. The integration center can conduct the comprehensive treatment to the various types of data in a proper method and the outcomes have been outputted finally.

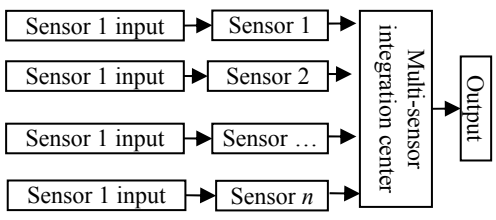


Fig. 3. Structure of parallel fusion pattern.

3. Selection and Design on Hardware

3.1. Sensor and Execution Unit

Field Control Unit belongs to the third layer in the system, field control layer. There are two kinds of data collection sensor: water quality sensor and flow sensor. The execution system mainly consists of pump, solenoid valve and air compressor and blender. The pump is controlled by the special input module and the blender and air compressor are controlled by electromagnetic switch.

After making an overall comparison on different parameters such as the performance, price, working environments and ion disruption, the number and types of ORP, DO, PH, NO_3^-, NH_4^+, PO_4^{3-}, COD, TP and TN sensors have been identified; In total, there are 31 data collection points, including the flow sensor system. The output signal is analog quantity signal ranging from 4 to 20 mA. The basic information can be shown as in Table 1.

Table 1. Statistics of sensors and executing elements.

No.	Name	Type or specification		Qty.
1.	DO sensor	Sensor electrode	MV3030	2
		Transmitter	MF41	
2.	ORP sensor	Sensor electrode	MV3015	3
		Transmitter	EMC173-K030-F-P	
3.	PH sensor	Sensor electrode	MV3010	1
		Transmitter	EGA173-K030-F-P	
4.	NO_3- sensor	Sensor electrode	MV3016	3
		Transmitter	$NO_3$1508	
5.	NH_4+ sensor	Sensor electrode	MV3016	3
		Transmitter	$NH_4$1508	
6.	PO_4^{3-} monitor	Phosphax Compact PO_4		6
7.	TN monitor	NPW-150		2
8.	TP monitor			2
9.	COD monitor			2
10.	Flow sensor	LWGY-40A		7
11.	Solenoid valve			2
12.	Electromagnetic switch			5
13.	Pump	BT300-1F		7
14.	Agitator			4
15.	Air compressor			1

According to the test need, the extraction of the sewage and sludge can be completed with peristaltic pump with external control function. The pump speed can be controlled by inputting 4-20 mA DC signal and the start up and stop of the pump can be controlled by inputting the data quantity signal through the external control interface and external control modules. Besides the current equipment that is used in the blender and air compressor, the types of the other equipment can be shown as follows in Table 1.

3.2. Central Control Unit

Central control unit belongs to the third layer: central control layer. It includes CPU, power source, memory card, communication module and digital and analog module, guide track and communication cable and wiring connector, etc. Its functions are to realize the signal input and output transformation of the field process objects and send the collected data to the upper computer and output the control signal from the upper computer to the executive components at the same time.

After conducting the statistics on the input and output quantity of the system, the obtained I/O point statistics of the system can be shown as in the Table 2. To ensure that the good extension performance of the system, there should be room left for input and output of the digits and analog quantity when designing the hardware.

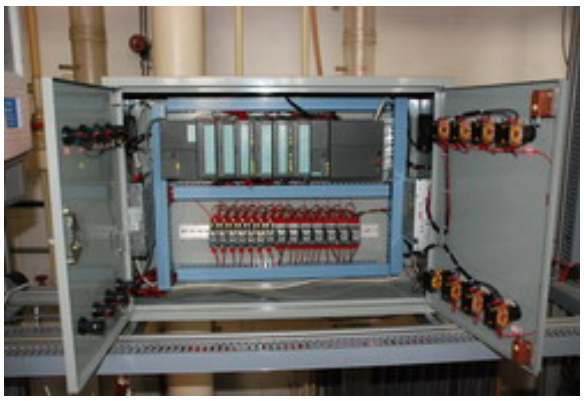
Table 2. I/O points TAB in the control system.

No.	Signal Type	Total points
1.	Digital input	28
2.	Digital output	63
3.	Analog input	31
4.	Analog output	7

After making comparison on many aspects, the Siemens PLC series with reliable and stable performance are selected. According to the needs of the system, a determination has been made to select S7-300 series CPU315-2DP of PLC. 4 pieces of analog quantity input modules SM331 (inputting analog quantity by 8 routes) can realize the data collection and pump flow and pump flow monitoring of 24 sewage water quality parameter collection points. 2 pieces of analog quantity output modules SM332 (outputting analog quantity by 4 routes) can realize the rotation speed control of 7 pumps. 1 piece of the digital quantity input module SM321 (inputting by 32 routes) and 2 pieces of analog quantity output modules SM322 (outputting by 32 routes) can realize the control of the start up and stop of pump, air compressor, aeration electromagnetic valves and blender motors and the control on the operation status indicator lamp of the equipment. As CPU315-2DP has been integrated as PROFIBUS communication port, CP5611 modules that can support PROFIBUS communication is selected so as to realize the communication and exchanges between industrial personal computer and PLC. The hardware required in FCU can be shown as follows in Table 3.

3.3. Connection Diagram of Hardware System

The actual connection diagram of the hardware can be shown in Fig 4. Fig. 4 (a) is the physical connection diagram of PLC, Fig. 4 (b) is the physical connection diagram of water quality sensor and Fig. 4 (c) is the physical connection diagram of the monitoring on sewage water treatment process.



(a)

(b)

(c)

Fig. 4. Physical hardware connection diagram.

4. Software and Programming Design

4.1. Distribution of Data Collection Points and Control Points

Through the research on the BCFS^{O,R}process, it is preliminarily confirmed that there are 24 water quality parameters needed to be collected in total. The monitoring parameters on the input and output of water and various reaction tanks can be shown as follows:

Water inlet R0: COD, TP, TN, NH_4^+, PO_4^{3-};

Anaerobic tank R1: PO_4^{3-}, ORP;

Oxygen deficit tank: NO_3^-, PO_4^{3-}, ORP;

Anaerobic /aerobiotic tanks R4: DO, NO3-, ORP;

Aerobiotic tank R5: DO, NO_3^-, PO_4^{3-};

Sedimentation tank (water inlet) R6: COD, TP, TN, NH_4^+, PO_4^{3-};

Phosphorus sedimentation tank.

The explanation on the distribution on the main actuators such as pump and motors in BCFS ^{O,R} process can be shown as follows:

1. Peristaltic pump can be used to control the water flow in the seven points: inflow, backflow A, B and C, phosphorus sedimentation tank inflow, phosphorus sedimentation tank backflow and sludge backflow. The start up and stop and the rotation of each pump should be controlled and the flow sensor is set in the pump outlet to conduct the flow monitoring.

2. There is one aeration valve in Anaerobic /aerobiotic tanks R4 and aerobiotic tank R5 and there is one piece of air compressor in the laboratory. The start up and stop of aeration valve and air compressor is controlled by the digital quantity.

3. A blender controlled by the motor is set in each tank from R1 to R4. The blender motor is always in the working condition and the start up and stop of it can be controlled by the digital quantity.

4.2. Hardware Configuration Design

Hardware configuration means to designate what kind of hardware modules can be used in the system and what kinds of addresses can be used to visit such modules. The features of the modules can conduct the valuation with the parameters. Hardware configuration has designated the configuration and parameters setting of the system hardware, for instance the parameters of CPU and I/O address allocation, etc. Because 8 signal modules, functional modules and communication processing modules at most can be installed in the frame of the installation modules, there are 8 signal modules and 1 communication module in the system. The interface of the hardware configuration of the communication system can be shown in Fig. 5.

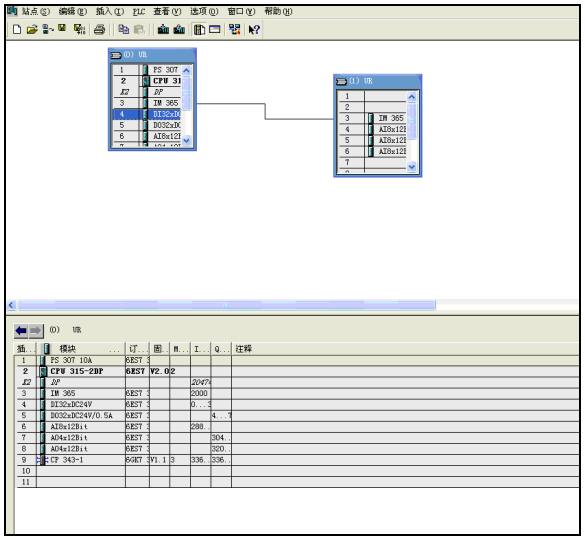


Fig. 5. Communication system hardware configuration interface.

4.3. I/O Distribution of System

After completing the hardware configuration and before conducting the programming, the control content, control flow and various collected signal of the system should be confirmed firstly. Then PLC I/O distribution table is worked out according to the actual connection of PLC. The digital quantity input and output, PLC address of analog quantity input and output, input signal introduction in the system should be set according to the variables displayed on the upper monitoring interface correspondingly.

PIW is the analog quantity input, PQW is analog quantity output and MW is the intermediate value. The address distribution of the main hardware can be shown in Table 3.

Input this address into STEP7. In the SIMATIC300, CPU and CP can automatically appear. In the symbols under CPU procedure input the address information and then prepare I/O distribution table well, input the relevant various with STEP7 symbolic editors, which can be used as the basis for preparing the system control programs. Variable table is a tool used to modify and monitor the variables. The monitoring on the variables can update the variable value at each period. Through the monitoring the variable, the control data transmitted to the upper computer can be tested at any time so as to realize the real control on the field executive components.

After preparing I/O distribution table well, input the relevant various with STEP7 symbolic editors, which can be used as the basis for preparing the system control programs. Variable table is a tool used to modify and monitor the variables. The monitoring on the variables can update the variable value at each period. Through the monitoring the variable, the control data transmitted to the upper computer can be tested at any time so as to realize the real control on the field executive components.

Table 3. The main hardware address allocation table.

Name	Address
Sensor 1	PIW288
Sensor 2	PIW230
Sensor 3	PIW232
Sensor 4	PIW234
Sensor 5	PIW256
Deliver pump flow sensor	PIW258
Return A flow sensor	PIW260
Return B flow sensor	PIW262
Return C flow sensor	PIW272
Back to the mud sensor	PIW274
Recycling of phosphorus flow sensor	PIW276
Supernatant reflux sensor	PIW278
Deliver pump stop	I12.5
Return A flow stop	I12.6
Return B flow stop	I14.0
Return C flow stop	I14.1
Back to the mud to stop	I14.2
Phosphorus recovery pump stop	I14.3
Supernatant recycling to stop	I14.4
Deliver pump flow	PQW256
Backflow A flow	PQW258
Backflow B flow	PQW260
Backflow C flow	PQW262
Back to the mud flow	PQW320
Phosphorus recovery flow	PQW322
Supernatant recycling flow	PQW324
Mixer 1 open	I12.0
Mixer 2 open	I12.1
Mixer 3 open	I12.2
Mixer 4 open	I12.3
Mixer 5 open	I12.4
Mixer 6 open	I12.5
The red light 1 switch	I4.3
The red light 2 switch	I4.4
The red light 3 switch	I4.5
Green light 1 switch	I4.0
Green light 2 switch	I4.1
Green light 3 switch	I4.2
Bright red 1&green light 1 dark	Q12.7
Bright red 2&green light 2 dark	Q13.0
Bright red 3&green light 3 dark	Q13.1

4.4. Programming Design

Before preparing the program, main program flowchart of the system control process should be drawn as Fig. 6 firstly. There are there types for common PLC program structure: linear programming, modularization programming and structured programming.

To make the program easier and clearer, more organized and convenient to debug, modularization programming is adopted in preparing the program and the fragment programs are divided according to different program.

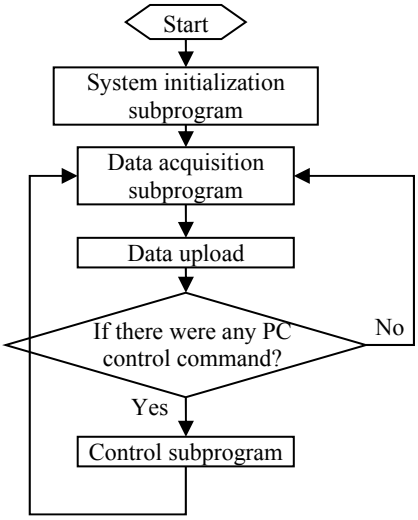


Fig. 6. PLC main program flow chart.

The main programs of PLC consists of initialization subprogram, pump start and stop subprogram, pump flow control subprogram, air compressor and aeration valve starting and turn off subprogram, blender control subprogram and data collection subprogram. The structure of PLC can be shown in Fig. 7 as follows:

a) System initialization subprogram.

When the system starts to work, it is necessary to conduct the system initialization, namely when starting the system, the detection should be conducted to the current working conditions of each part. If there is any mistake, an alarm is given; then the parts of execution components in continuously working should be initialized (such as air compressor, blender and feed pump). Then the initialization treatment is conducted on the data table of the analog quantity (such as speed of feed pump) data treatment with starting value given. The system initialization is realized through calling the subprogram in the main analog quantity.

b) Starting and stop subprogram of pump.

The working condition of a same actuator in the system may be different if it is in the different position, therefore it is required that the starting and stop of pump can be controlled by subprogram.

c) Pump flow control program.

The operation and flow of the pump can be different in different position and at different moment. This part of the program, after receiving the external flow control commands, sends the flow signal to the corresponding pump, but the premise is that the pump is in the working condition.

d) Starting and turning off program of air compressor and aeration compressor.

Starting and turning off program includes the starting and stop of the air compressor and the starting and turn off of the valves, but also the valve starting and turning off of the air compressor in the operation condition. Attention should be paid to this principle in designing the valve starting and turning off program: to the starting condition, start up the system first then turn on the valve, to the turning off condition, turn off the valve first and stop the system.

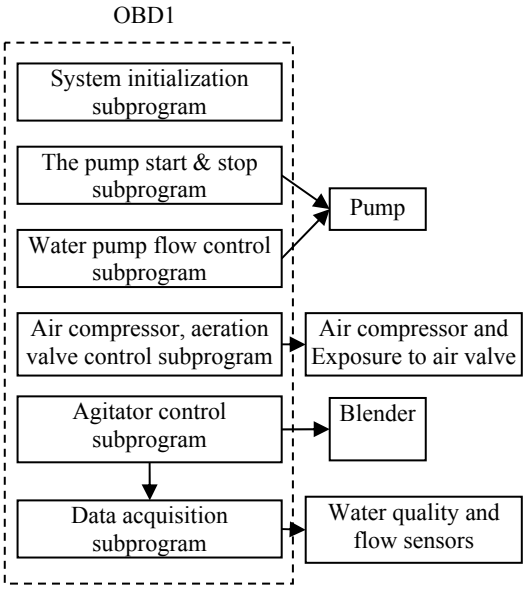


Fig. 7. PLC Program Structure Diagram.

e) Blender control subprogram.

The operation condition of the blender is relatively simple. Start the system first then start it and it will turn off when the system stops. The indicators of the blender operation condition can show the working condition of the blender.

f) Data collection subprogram.

After the upper computer sending out collection command, the data collection subprogram reads the analog quantity output terminal at certain period then transmits the reading to the upper computer.

5. Conclusions

Unmanned, intelligent and automatic features can be served as the future trend for the sewage water treatment process management. The water quality monitoring system put forward in this article can better satisfy the real time monitoring of the distributed sewage water treatment process and the needs of the delicacy management on the sewage water treatment field in the future.

Acknowledgements

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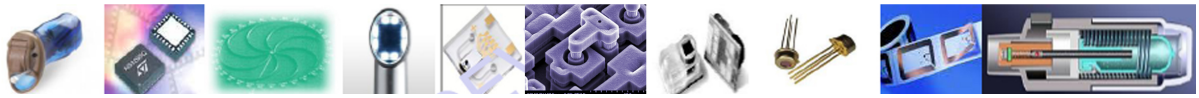
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