Design and Realization of Online Remote Measurement and Control System for VOCs Terminal Treatment

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Abstract. Using PIC16F1939 microcontroller, Siemens S7-200PLC and ESP8266 module, a cost-effective and online measurement and control system of VOCs terminal treatment is constructed. This paper introduces the system construction and control scheme, and designs the communication protocol between MCU and PLC, MCU and ESP8266 module, and describes the specific implementation process of the system software. The system integrates the analog acquisition function of the microcontroller, the stable control function of the PLC, and the convenient network access function of the ESP8266 module, which realizes detection of System operation status, and solves the problem of high cost of the PLC analog acquisition capability, and complicated network access of the PLC.

Introduction

According to the definition of the World Health Organization, VOCs are compounds with a boiling point of 50-260°C at atmospheric pressure [1]. Many VOCs are toxic, and some are considered to be carcinogenic, mutagenic, or teratogenic [2]. However, the most significant problem related to the emission of VOCs is centered on the possible production of photochemical oxidants, for example, ozone and peroxyacetyl nitrate [3]. Therefore, the treatment of VOCs has received more and more attention from various countries. Many countries have issued corresponding laws and regulations to limit the emission of VOCs, which has become a focus on air pollution control [4].

In recent years, air pollution has become increasingly serious, and bad weather such as haze is frequent. At present, more VOCs terminal treatment systems have been applied to practice at home and abroad. However, in most VOCs terminal treatment systems, there are one or more following problems. First, the high cost of system, resulting from the high cost of system analog acquisition, cannot meet the needs of small businesses with limited economic capacity. Moreover, without monitoring the running state of the system, it is difficult to understand the real operation state of the system, which is easy to cause safety accidents. Finally, the network access of systems is complicated.

In view of the above problems, this paper designs a VOCs terminal treatment on-line measurement and control system. The system has low cost, convenient access to the network, and can monitor the real operation state of the system in real time.

System Introduction and Control Scheme Design

System Introduction

The construction of the VOCs terminal treatment online measurement and control system is based on a VOCs processing process, which is shown in Figure 1. The process includes three parts: pre-washing, compound processing, and post-washing. The exhaust gas passes through the pre-washing tower, the composite processing device, and the post-washing tower in turn, and meets the discharge standards. The system is provided with two sets of VOCs sensors for detecting the concentration of VOCs in the exhaust gas to be treated and the concentration of VOCs in the exhaust gas that have been treated; the front washing tower and the rear washing tower are provided with
detecting devices such as temperature, humidity and pressure sensors, and actuators such as water pumps. The detecting device is used for detecting the environmental parameters in the washing tower, the actuators are controlled by the system according to the environmental parameters; the compound treatment device is equipped with processing equipment, such as plasma equipment, for treating VOCs exhaust gas; the draft fan is after the rear washing tower.

Figure 1. VOCs Processing Flow.

Figure 2. Terminal Treatment Device of VOCs.

This process is widely used in some industrial production of VOCs for terminal treatment, such as the packaging and printing industry. As shown in Figure 2, it is a terminal treatment device of VOCs for a printing company.

The system monitored through the touch screen uses low-cost small PLC (Siemens S7-200) as the control core, controls the water pump, fan, plasma power supply, etc. Using PIC microcontroller with analog acquisition function to collect sensor data such as pressure sensor, humidity sensor, VOCs sensor, temperature sensor, and ESP8266 module to realize system network access, the data collected by PIC microcontroller send to PLC in real time. The block diagram of the system is shown in Figure 3.

Figure 3. The Block Diagram of System.

Operational Sequence Control

Operational monitoring is a key measure to ensure the operation and safety of equipment, and sequential operation is an important part. Improper operation may cause a safety hazard. Figure 4 is a photo of an accident scene of a VOCs processing equipment in a certain place. In order to ensure the safe operation of the system, it is necessary to strictly control the operation sequence of each part of the system.
During the system shutdown, there may be accumulation of VOCs on the plasma device. In this case, if you run the plasma device, it may cause an explosion. Therefore, it is necessary to turn on the fan to remove this accumulation before the plasma is operated. When shutting down, you also need to turn off the plasma device and then turn off the induced draft fan. If the fan is turned off first, the concentration of the exhaust gas in the plasma processing unit may rise to the explosion range. In summary, the starting sequence is: an induced draft fan->washing tower->composite processing device; the system shutdown sequence is: a composite processing device->washing tower->induced draft fan.

**Induced Draft Fan Air Volume Control**

The system will adjust the air volume of the induced draft fan according to the environment. The common methods for controlling the air volume of the fan include the damper control and the frequency control. Compared with the damper control, the frequency control is more flexible and more energy-saving. The system adopts frequency control. The inverter is Siemens MM420. Considering the complex environment of the industrial site and the requirements of the system, the multi-band control method with strong anti-interference and fast response speed is adopted.

As shown in Table 1, PLC combines the output ports Q1.0, Q1.1, Q1.2, and divides the induced draft fan air volume into 7 files.

<table>
<thead>
<tr>
<th>Q1.2</th>
<th>Q1.1</th>
<th>Q1.0</th>
<th>Fan status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>OFF</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>First gear</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>Second gear</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Third gear</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>Fourth gear</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Fifth gear</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>Sixth gear</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Seventh gear</td>
</tr>
</tbody>
</table>

**Communication between the MCU and the Slave**

The MCU in the system must communicate with the PLC and the ESP8266 module. Therefore, the master-slave communication mode is adopted, in which the MCU communicates with the PLC and the ESP8266 module, the PIC MCU is used as the host, and the PLC and ESP8266 modules are the slaves.

The ESP8266 module is directly connected to the PIC microcontroller, and the level between the USART port of the PIC microcontroller and the RS-485 port of the PLC is different. It cannot be directly connected and requires a level conversion module [5]. The level conversion module uses the MAX485 chip as a conversion chip, and the hardware connection is shown in Figure 5.
The microcontroller must determine the slave status before sending the data packet. The MCU actively sends a communication request command to the data bus, and the slave mounted on the data bus determines whether to respond to the host command. If a slave responds to the host request command, the host receives the slave response command, indicating that the slave is already ready. The host sends the data; if a slave does not respond to the host command, it indicates that the slave is not communicated, and continues to wait for the connection. The format of host request instruction frame and the slave response frame is same. One frame instruction contains two bytes, the first byte is the slave address, the second byte is the function code, and the format is as shown in the Table 2.

<table>
<thead>
<tr>
<th>Name</th>
<th>First byte</th>
<th>Last byte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Slave address</td>
<td>Function code</td>
</tr>
</tbody>
</table>

The microcontroller adopts the USART module asynchronous mode, the PLC adopts the free port mode [5], and the ESP8266 module adopts the UART asynchronous mode. The sensor data packet sent by the microcontroller is in the same format as the status data packet fed back by the PLC. The specific format is: the first byte is the slave address, the bytes from second to the penult byte is the data to be sent, and the last byte is the end flag. The format is shown in Table 3.

<table>
<thead>
<tr>
<th>Name</th>
<th>First byte</th>
<th>(n-2) bytes</th>
<th>Last byte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Address</td>
<td>Data</td>
<td>End byte</td>
</tr>
</tbody>
</table>

**Table 2. The Format of Communication Request Command.**

**Table 3. The Format of the Sensors Data Packet.**

### Software Design

The MCU program is developed with the Mplab IDE. The compiler is HI-TECH PICC; the PLC program is developed with STEP 7-MicroWin; the WiFi module software utilizes a dedicated development platform. As shown in Figure 6, it is the monitoring panel of the system.

### Main Program Design

In this system, the MCU needs to communicate with two slaves, while the PIC16F1939 MCU has only one serial port, so the idea of time-multiplexing is adopted in the program design. The main
program is an infinite loop. First, the MCU communicates with the slave PLC, after which the MCU communicates with the slave ESP8266 module, and then enters the next cycle.

The main program mainly realizes the communication between the master and slaves, and the AD data acquisition. The main program flow is shown in Figure 7 (ADflag, sPLCflag, sWiFiflag are the data acquisition completion flag, PLC communication ready status flag, ESP8266 module communication ready status flag). Start the program and initialize. If ADflag is 1, AD acquisition is performed. When AD acquisition is completed, ADflag is cleared. Then the host sends a slave (PLC) communication request. When the slave PLC responds, sPLCflag is set. Then the host sends the data packet to the PLC, and the PLC feeds back its status data. The host packs sensors data and the feedback data of the slave and clears the sPLCflag. Then the host sends a data packet to the WiFi module. When the data transmission ends, the sWiFiflag is cleared, and the ADflag is set. Finally, program returns to AD acquisition. Else if the ADflag is 0 before the above AD acquisition, the module returns to initialize. When the PLC does not respond to the host and does not time out, it returns to AD acquisition; otherwise an alarm is issued. When the ESP8266 does not respond the host and does not time out, it returns to AD acquisition; otherwise an alarm is issued.

**PLC Control Program Design**

The PLC control program mainly receives the data packet from the MCU, and parses the data packet to perform the corresponding operation. The program flow is shown in Figure 8. Start the initialization, the serial port waiting, if there is no timeout and the receive interrupt flag is 1, the receive interrupt subroutine is executed, receiving and parsing packet. When the communication request sent by the host is parsed, the request is responded and waited; when the sensor data sent by the host is parsed, the data is saved and the status data is fed back to the host, and finally returns to wait. Else if it times out, issue an alarm.

**Communication Program Design between MCU and Slave**

The communication between the MCU and the slave is realized by this program. The program flow is shown in Figure 9. Start the program, initialize, the host sends a communication request, the slave responds, and the host establishes communication between the slaves. If the slave responds with a timeout, an alert is issued, otherwise the host sends a request and waits for the slave to respond.
Summary

This system integrates the powerful analog acquisition function of PIC microcontroller with the stable control function of PLC and the convenient network access function of ESP8266 module to build a set of VOCs online measurement and control system with high cost performance. The communication protocol between MCU and PLC, MCU and ESP8266 module is designed. A low-cost PLC analog acquisition method and a convenient system access method are proposed to make the VOCs terminal treatment system automatic and intelligent. The main functions are as follows:

a) Online monitoring function of VOCs with lost cost;
b) Monitoring function of System operation status;
c) Multi-machine communication of PIC microcontroller;
d) Communication function between PLC and PIC microcontroller.

References


