Design of remote wireless cylinder pressure control system

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Abstract. Pressure is an important object monitored in the modern industrial production safety. Aiming at the present situation of pressure monitored, combined with wireless communication technology, this paper puts forward a scheme which monitored the pressure by wireless technology based on Zigbee protocol. The scheme puts the cylinder pressure as a controlled object, selects Zigbee protocol chip CC2530 as the main control device, to achieve control of the pressure regulating valve based on PID algorithm, and realized the pressure control. Through the simulation and experiment it shows that the scheme can realize the wireless remote control of cylinder pressure, and meet the intelligent demand of control system.

1. Introduction
Pressure is a very important physical quantity [1-5], which reflects the working state of an object in real time. In many fields such as industrial automation production, defense aerospace applications and daily life, pressure parameters are often monitored and controlled to ensure production and Personal safety. In many industrial processes, maintaining a constant pressure or a certain degree of vacuum is a necessary condition to ensure the quality of its products and production safety. In addition, many chemical reactions also require a constant pressure physical environment, therefore, constant pressure control is often required.

At present, there are two main methods for monitoring and controlling pressure: one is through online monitoring of pressure instruments and the on-site manipulation of workers [2]. This traditional pressure monitoring and control method has the disadvantages of low real-time performance, unsafe operation, and large loss of human resources, high production cost, and low safety factor. The other is to form a remote distributed monitoring system through the bus to realize real-time monitoring and regulation of pressure. However, this method requires wiring at the production site, which is difficult to construct, high in cost, and has a certain time lag. Therefore, taking the cylinder pressure as the monitoring object, this paper proposes a design scheme of remote wireless pressure control system based on Zigbee protocol, and discusses its specific implementation process.

2. Overall system design
According to the actual application of cylinder pressure monitoring, the whole system adopts closed-loop control, which consists of on-site acquisition control node, wireless master control node, wireless transceiver module, remote control terminal and wireless gateway. Its overall composition block diagram is shown in Figure 1.

Among them, the wireless gateway realizes the conversion of the Zigbee protocol and the WIFI, and realizes the access of the wireless local area network. The remote control terminal is implemented by a PC. The field acquisition control node consists of: microcontroller, button, display module, data conversion module, pressure transmitter, and regulating valve. The overall control acquisition control block diagram is shown in Figure 2.
The working process is: using a pressure sensor to collect the cylinder pressure (to simplify the design difficulty, the pressure sensor uses a digital pressure sensor), and send it to the microcontroller. The microcontroller processes and judges the obtained data according to a certain control algorithm, when the pressure is less than the set value, a control command is issued to open the air supply of the air valve; when the pressure is greater than the safe value, the air valve is closed or the air supply amount is reduced, so that the cylinder pressure is controlled within a certain range. In addition, the field acquisition and control node transmits the collected data to the master node and the remote control terminal which as a result can monitor the cylinder pressure in real time through the wireless transceiver module. And the master control node and the remote control terminal can transmit the control command to the field acquisition control node through the wireless gateway and wireless transceiver module to achieve the remote regulation and control of the cylinder pressure[6].

3. Hardware design of remote wireless pressure control system

According to the above, the remote wireless pressure control system is composed of a field acquisition control node, a wireless master control node, a wireless transceiver module, a remote control terminal, and a wireless gateway. In the text, the wireless gateway selects the finished WGT2420Z-W, and the remote control terminal selects the PC with wireless WIFI, so the text will not go into details here. This article focuses on the implementation process of the field acquisition control node and wireless transceiver module.

In this paper, the wireless transceiver technology adopts the zigbee protocol [7-10], and the chip that processes the zigbee protocol integrates the microcontroller to simplify the system structure and reduce the cost. In this paper, zigbee protocol chip CC2530 of TI Company is selected as the microcontroller. In order to ensure the reliability of the system, network topology structure is adopted and multicast mode is used for communication. Its composition principle is shown in Figure 3.
The key input CC2530 regulates valve air cylinder liquid-crystal display

![Figure 3](image)

**Figure 3.** Schematic diagram of composition of field pressure acquisition control node with wireless communication function.

The CC2530 chip is a true system-on-chip solution for zigbee communication technology. The peripheral circuit of CC2530 chip adopts Balun transform impedance matching network. The specific application circuit diagram is shown in Figure 4.

![Figure 4](image)

**Figure 4.** Simple peripheral application circuit of CC2530 chip.

According to the device manual, in order to increase the stability of the 1.8V regulator in the CC2530 chip, a decoupling capacitor is required, so a capacitor with a capacity of $1 \mu F$ is to the 40-pin of the chip. The 32, 33 and 22, 23 pins of the chip are used for external crystal oscillators and capacitors to form an oscillation circuit of $32.768$ kHz and $32$ MHz, respectively. When Pins 25 and 26 input differential signals and selected an unbalanced monopole antenna, a Balun matching circuit is used for impedance matching. In the design, discrete inductors and capacitors are used to form an impedance conversion circuit[8].

In the design, considering the design cost and difficulty, the pressure transmitter uses the digital pressure sensor SP12T. The SP12T is a piezoresistive sensor with a pressure range of 50-1400 kPa and a temperature measurement range of -40-125 °C. The internal AD converter is used to output data from the SPI bus to the CC2530. The application circuit diagram of SP12T is shown in Figure 5.
4. Software design of remote wireless pressure control system

The working process of the cylinder pressure detection and control system is as follows: firstly, the cylinder pressure detection module is started by the host machine awakening or timing awakening to reduce the power consumption; then the sensor module (SP12T) receives the sampling command of CC2530, starts sampling and completes analog-digital conversion, and transmits the data to CC2530 through SPI bus. CC2530 conducts calculation and analysis, controls the action of the regulating valve, and realizes the adjustment of cylinder pressure. At the same time, CC2530 packs the data obtained from the sensor and sends it to the host receiving module through Zigbee wireless technology to complete remote cylinder pressure detection.

The system design adopts the mesh networking topology structure. The wireless master control node equipped with the wireless gateway is started as the Coordinator, and the on-site pressure collection control node module is started as the Router. By setting the parameter of DEFAULT_CHANLIST, the system select the channel with the least interference and avoid the conflict with WIFI. The software system of the on-site pressure collection control node is composed of a main program, a wireless communication program, a display program, an alarm program, a data acquisition process, and a control program. The control program, display module and alarm module are relatively simple. The main program, wireless transceiver communication program and data acquisition and processing program are mainly introduced in this paper.

4.1. Main program design of on-site pressure acquisition control node

The main program mainly performs initialization of the system, starts ZigBee's protocol stack, collects cylinder pressure data, and compares the temperature value with a preset limit value to determine whether to control the valve and send an alarm signal, and then the data is displayed and sent to the master control node and the remote control terminal. The flow of the main program is shown in Figure 6.

4.2. On-site pressure acquisition control node wireless transceiver communication program

When the on-site pressure collection control node is powered on (the router or coordinator or terminal device starts normally), the ZDO_STATE_CHANGE event is automatically triggered[11-12]; when the pressure acquisition control node receives the OTA message, the AF_INCOMING_MSG_CMD event is triggered, and then the pressure acquisition and control program is invoked according to the pre-negotiated event handling mechanism at design time. If the pressure collection control node does not receive the command from the master node and the remote control terminal after the Router is successfully started, it will automatically perform pressure acquisition and data processing, and implement the cyclic update the data which collected by the sensor in the buffer by periodically transmitting the periodic signal, and then sent the data to the master node and the remote control terminal. The sending process is simple, and the receiving program flow is shown in Figure 7.
4.3. Data acquisition and processing program of on-site pressure collection control node
The reading and writing of the digital pressure sensor SP12T is carried out by the SPI bus communication protocol, and the SPI bus communication can be realized by operating the pins (NCS, SCLK, SDO, SDI). In order to complete the operation of sending commands and reading data to SP12T, the program flow is shown in Figure 8.

In order to realize the constant adjustment of cylinder pressure, the control and adjustment of cylinder pressure is realized by PID arithmetic[13-15].

5. Simulation and experiment
The control and adjustment of cylinder pressure is realized by PID formula. The calculation formula is shown in equation 1:

$$\Delta u_n = u_n - u_{n-1} = K_p (e_n - e_{n-1}) + K_p \frac{T}{T_p} e_n + K_p \frac{T}{T_d} (e_n - 2e_{n-1} + e_{n-2})$$

$$= K_p (e_n - e_{n-1}) + K_p e_n + K_p (e_n - 2e_{n-1} + e_{n-2})$$

$$= P_p + P_i + P_d$$

(1)
In equation 1: \( P_n = P_e + K_P (P_e - P_e) \)

\[ P_I = K_P \frac{T}{T_s} e_n - K_e e_n \]  

\[ P_D = K_P \frac{T_D}{T} (e_n - 2e_{n-1} + e_{n-2}) = K_D (e_n - 2e_{n-1} + e_{n-2}) \]

Obviously, the calculation of \( \Delta u \) requires only \( e_n, e_{n-1} \), and \( e_{n-2} \). When programming the initial value of the program is initialized zero.

In the closed-loop control system, the pressure in the cylinder is a very sensitive factor as a control variable, which is susceptible to interference from the external environment. Therefore, in the design, an ideal mathematical model is selected to compare its change. In this paper, the first-order inertia link is selected as the mathematical model of cylinder pressure change:

\[ G(s) = \frac{ke^{-\tau s}}{ts + 1} \]

In equation 5, \( k \) is the proportional amplification factor; \( \tau \) is the system pure lag time; \( t \) is the process time constant. It is obtained by experiment, taking \( k = 1, \ t = 8, \ \tau = 0 \). Therefore, Equation 5 can be rewritten as

\[ G(s) = \frac{1}{8s + 1} \]
The mathematical model of the PID regulator used in the design of the system is:

\[ Ge(s) = Kp + \frac{Ki}{s} + KdS \]  

(7)

Equation 7 is the transfer function of the PID regulator. In Equation 7, \( Kp \) is the proportional parameter, \( Ki \) is the integral parameter, and \( Kd \) is the differential parameter. In this design, the sampling period is selected to be 1 second, and \( p = 13.76, i = 7.38, D = 2.52 \), using MATLAB software to simulate the pressure change in the whole system, assuming that the cylinder pressure system requires overshoot \( \leq 15\% \), adjustment time \( ts \leq 10s \), the simulation system block diagram and simulation diagram are shown in Figures 9 and 10. From Figure 10 it can be concluded that the overshoot \( \delta = 14\% \), rise time \( tr = 1s \), peak time \( tp = 2.6s \), adjustment time \( ts = 8.2s \), meeting the requirements.

Figure 9. PID simulation diagram.

Figure 10. Simulation results.

In order to verify the function of the system, a certain YKZ-II I cylinder pressure was selected as the control object in the design, and the function verification experiment was carried out. For the convenience and efficiency of simulation experiment, when the set pressure exceeds 120kPa, the system prompts the pressure alarm and the measured data. As shown in Table 1. The results show that the system can realize pressure detection, alarm and regulation control. The communication distance can reach 15 meters and the system response time is less than 500 milliseconds. It is feasible to use this method to perform wireless automatic control of cylinder pressure.
Table 1. Test data and results.

| Environmental output | pressure | give an alarm |
|-----------------------|----------|---------------|
| 98kPa                 | 98kPa    | No alarm      |
| 120kPa                | 120kPa   | No alarm      |
| 130kPa                | —        | Pressure alarm |

6. Conclusion
In order to solve the problems existing in the distributed pressure monitoring system in the current industrial production process, such as complex wiring mode, difficult construction, high cost and poor real-time performance, the project designed a novel wireless cylinder pressure control system based on the advantages of Zigbee technology, such as long distance of wireless communication, low cost and long life. In this paper, an implementation method of wireless pressure control system based on Zigbee protocol is discussed. Experiments show that this scheme can realize remote wireless control of cylinder pressure and meet the intelligent requirements of control system. The realization of this scheme provides a reference for further realizing the Internet access of industrial production control, and has certain help for the application of Internet technology into the field of industrial control.

Of course, this scheme also has some shortcomings, such as: the communication range and obstacles in the environment will affect the reliability of the system communication. In the future, the implementation method which the system accesses to the wireless sensor network will need to study and improve its monitoring range and reliability.

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