Design and implementation of a high-precision turbidity measuring instrument of a mine

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Abstract. In this paper, the principle of turbidity detection based on light scattering principle is expounded, and a design method of high-precision turbidity measuring instrument in coal mine is proposed. The software and hardware design of such turbidity measuring instrument are introduced. The measuring instrument adopts integrated circuit design such as imported photodiode and high-precision operational amplifier. The MATLAB simulation software tool is used to formulate the curve of the turbidity measurement data, and the turbidity measurement value is compensated and corrected to improve the turbidity measurement accuracy. Furthermore, the measuring instrument adopts low-power design, the OLED display technology in particular, to replace the traditional digital tube or LCD liquid crystal; the anti-interference design is applied in the digital interface communication design, and the electromagnetic compatibility test is very suitable for the electromagnetic environment in the coal mine.

1. Introduction
Turbidity refers to the degree of hindrance of the solution to the passage of light, and is an important parameter that can indirectly reflect the use of equipment in the production process of water companies [1]. Especially in China’s coal mining enterprises, the turbidity of mine water is generally large, which makes the management of mine water treatment difficult, and can not guarantee the stability of the effluent, which makes it more difficult to reuse the mine water. With the continuous improvement of coal mine automation level in recent years, underground hydrological monitoring, on-line monitoring of underground water quality, on-line monitoring of mine water quality, on-line monitoring of downhole equipment/cooling water, etc. [2] have been introduced, so a mining turbidity is needed. The detection technology detects the turbidity of underground fire water, downhole equipment cooling water, and downhole spray water, thereby indirectly understanding the use of equipment and adopting different water treatment measures to achieve remote monitoring or further improve the level of automation management.

There are many methods for detecting turbidity, such as transmitted light, ratio method and scattered light type. The transmitted light type has poor detection accuracy for low turbidity concentration; the ratio method is to combine the projection and scattering methods, but the structural design. It is more difficult to implement; the scattering method is relatively easy to implement, and the
measurement linearity is good. It is the preferred measurement method for high-precision performance products abroad. This paper mainly uses the light scattering principle detection method. In order to ensure the design accuracy, the imported high stability is selected. As a light source, the high-intensity op amp and analog-to-digital converter are used to amplify the micro-signal to improve the measurement accuracy. In software data processing, the MATLAB software tool is used to fit the measurement data curve to further improve the turbidity. The measurement accuracy is compared with the American HACH and the domestic mainstream brand turbidity meter. The designed turbidity measuring instrument has high measurement accuracy, good stability and electromagnetic compatibility, and rich output interface. It is suitable for use in the complex electromagnetic environment of coal mines.

1 optical turbidity detection principle

![Figure 1. Block diagram of light scattering turbidity measurement](image)

As shown in Fig. 1, a light source is disposed in the turbidity optical detecting probe, and a silicon battery photodetector is mainly used for receiving 90° scattered light. The turbidity probe is infiltrated in the solution to be tested, the surface of the lens is in contact with the solution to be tested, and the light source emits a fine parallel light having a light intensity of I0 into the solution [3], and has an angle \( \theta \) with the Y axis, which is reached according to the Beer-Lambert law. The light intensity \( I_x \) at B is:

\[
I_x = I_0 e^{-Kx \sin \theta}
\]

(1) where \( T \) is the turbidity value, \( I_0 \) is the light intensity of the light source emitted by the light source, and \( K_1 \) is the absorption coefficient. The light hits the particle and emits a plurality of scattered light, wherein 90° of the scattered light is received by the photodetector through the light decay, and the total scattered light \( I_{ss} \) at \( x_1 \sim x_2 \) is:

\[
I_{ss} = K_{ss} I_0 T \Delta x
\]

(2)

Where \( K_{ss} \) is the scattering coefficient, \( \Delta x = x_2 - x_1 \)

It can be seen that the scattered light intensity \( I_{ss} \) is proportional to the turbidity \( T \) and \( \Delta x \), and the measured turbidity value in the water can be measured indirectly by measuring the scattered light intensity.

2. Design of the mine water quality turbidity measuring instrument

The light scattering turbidity detecting and measuring instrument mainly receives the light intensity signal through the front end silicon battery, and the silicon battery mainly functions to convert the received light intensity value into a collectable electric signal, and the electric signal realizes signal amplification processing through the precision signal conditioning circuit. The amplified electrical signal enters the analog-to-digital conversion chip (A/D) and is converted into a digital signal. The digital bus is used to read the data between the microprocessor and the A/D chip, and the microprocessor calculates and compensates the collected data. Calculate and display the final calculated result on the liquid crystal.
2.1. The hardware design of the Water quality turbidity measuring instrument

The hardware design of the turbidity meter mainly includes the following parts: photoelectric signal conversion and acquisition conditioning circuit, display and communication circuit, power supply circuit, microprocessor and peripheral circuit.

Figure 2. Turbidity meter hardware design block diagram

Figure 3. Main components of the turbidity meter hardware module

Design of light source and signal conditioning circuit

(1) Light source circuit design
The infrared light emitting part adopts the imported infrared LED reflective diode with a wavelength of 860 nm. The light intensity of the light emitting diode is linear with the driving current [4]. The magnitude and stability of the light intensity directly affect the strength of the received signal, and the measurement accuracy of the measuring instrument. The influence is large, so the high-precision constant-current driving circuit is used in the design. In order to ensure the stability of the reference voltage, the micro-power high-precision voltage reference chip LM285-2.5V is selected, and the temperature drift coefficient of the chip is 20ppm [5], which greatly improves the design. The stability of the voltage reference with environmental fluctuations improves the accuracy of the constant current source and reduces the influence of temperature on the turbidity measurement error.

(2) Signal conditioning and processing circuit design
As shown in FIG. 4, the silicon photodiode D13 converts the received optical signal into a weak electrical signal [6]. The diode is designed to operate in a light guide mode and a zero bias state, and convert the received light intensity signal into a photocurrent signal. It can effectively prevent the reverse bias current, meet the weak light intensity signal conversion, improve the turbidity measurement accuracy, and there is a certain drift and error in the data amplification process. In order to improve the measurement accuracy, a compensation capacitor is designed in the design process. C1 reduces drift and suppress current noise.
The latter stage modulates the weak signal, mainly using a current (I) to voltage (V) conversion circuit. Since the generated photocurrent signal is very weak, normally between pA and μA, the latter integrated operational amplifier chip is required to have very low bias current, ultra-low noise, high stability [7], this paper uses a high-precision operational amplifier TLV2372 chip as a signal conditioning amplifier chip [8], the photo-diode generated weak photocurrent signal through the TLV2372. The chip realizes high-precision signal amplification of the current signal to the voltage signal, and the amplified signal voltage amplitude is between 0 and 150 mV, and the voltage signal is converted and processed by the ADS1100 analog-to-digital converter of the PGA programmable amplifier integrated in the latter stage. The microprocessor interacts with the A/D chip through the I2C serial bus, as shown in Figure 4.

![Figure 4. Silicon cell optical signal receiving conversion circuit](image)

In order to meet the special environmental requirements of poor underground coal mine light, the measuring instrument adopts self-illuminating OLED dot matrix liquid crystal screen, and adopts Qingda photoelectric 128×64 dot matrix liquid crystal screen HGS128×647, which has built-in SSD1305 controller [10], through serial. The bus realizes data reading and writing for the microprocessor, and the implementation is simple and reliable. The operating temperature range of the liquid crystal display is wider than that of the conventional ordinary liquid crystal, and the working environment temperature range is -40±85 °C. Since the self-luminous display is adopted, the display needs to be lit. The dot matrix is energized, the other parts are not powered, and the power consumption of the liquid crystal is about 30 mA when the LCD is normally displayed. The low power consumption design is very suitable for the intrinsically safe power supply and transmission requirements of the coal mine.

![Figure 5. RS485 bus interface circuit](image)

The RS485 communication bus interface circuit of the measuring instrument adopts the MAX3072 chip design [11]. As shown in Figure 4, the V7 triode circuit in the circuit is mainly to let the measuring instrument be in the state of receiving data when it is powered on, in order to improve the
anti-electromagnetic interference capability of the bus communication and reach the coal mine. The level 2 electromagnetic radiation required by the measuring instrument design, the 2-stage pulse group resistance and the DC power supply and the signal port level 2 surge (impact) immunity test, to achieve reliable protection of the interface, select three TVS on the bus A, B line The SMBJ17CA implements transient voltage suppression clamp protection, and uses a common mode choke coil to enhance the suppression of common mode interference. The discharge tube is mainly used for overvoltage, lightning and electrostatic protection [12].

The current output interface of the measuring instrument adopts the special current output chip AD5410 integrated circuit design, and the sound and light alarm circuit adopts the dual triode drive control design, as shown in Fig. 6.

![Figure 6. Current output, alarm control circuit](image)

(4)Microprocessor and peripheral circuit design

The measuring instrument microprocessor adopts C8051F340, which is the mixed signal system core SoC [13] of Cygna Company of USA. It is packaged in a small OEM 48-pin LQFP with a supply voltage range of 2.7-3.6 V. This design is powered by a 3.3V power supply. At the same time, the processor chip has high integration, and the I/O port supports programmable adjustment. It can be adjusted according to actual conditions during PCB layout. The processor supports online simulation and debugging, supports C2 simulation interface and offline program download, and is convenient to use. The internal FLASH of the processor integrates the power-down storage rewritable data storage unit [14]. In order to ensure reliable storage data, the peripheral circuit adopts EEPROM memory chip CAT24C02 (N6) to realize double backup of stored data to ensure reliable and secure stored data.

![Figure 7. Microprocessor and peripheral interface circuit](image)

2.2. The software design of the Water quality turbidity meter

The software program design of turbidity meter mainly includes the following aspects: 1) basic parameter configuration of single chip system; 2) A/D analog-to-digital converter configuration, signal acquisition and filtering; 3) data compensation and processing calculation (MATLAB simulation) The calculation formula performs curve fitting on the filtered data; 4) OLED liquid crystal display communicates with the bus; 5) signal and alarm output. The main software flow chart is shown in Figure 8.
3. Measurement data analysis and MATLAB curve fitting

The turbidity measuring instrument designed in this paper is configured to calibrate and verify the measurement accuracy and error by configuring the standard turbidity solution of Formazin. Six kinds of concentration solutions are arranged in the range of 0-1000 NTU, and 0 and 1000 NTU are used before the measurement. The solution is initialized to two points of the measuring instrument, and then the measured measuring instrument is placed in other concentration solutions to measure the data. Under ideal conditions, the light intensity signal should be linear with the turbidity concentration. According to the two-point calibration method, the linear relationship is calculated as: \( y = \frac{x}{15.004} \) (where \( x \) is the intensity of the light intensity signal and \( y \) is the turbidity concentration). The measurement error is found in the experiment, the maximum measurement error is at 400NTU concentration point, and the maximum error value is 44.68NTU. In order to improve measurement accuracy and reduce measurement error, the received light intensity signal value and standard are obtained by MATLAB software tool [15]. The relationship curve of the solution concentration value is fitted, and the light intensity signal value data corresponding to the concentration of the standard solution is corrected and compensated, and the fitting formula is \( y = 0.00000064134x^2 + 0.057443x - 1.98 \) (where \( x \) is the intensity value of the light intensity electric signal, \( y \) is Turbidity concentration), the internal processor of the turbidity meter is processed according to the compensation relationship, and then the measuring instrument designed in this paper is compared with the American HACH turbidity meter TSS Portable and a domestic brand turbidity meter. The test data is as shown in the table. According to the experimental results, the measurement error of the measuring instrument designed in this paper is about 3%, while the error of HACH turbidity meter is about 2%, and the measurement error of domestic turbidity meter is about 3.8%. After the measurement instrument, the measurement error is significantly reduced, which can greatly improve the turbidity measurement accuracy. The measurement data of the original 400NTU standard solution maximum error point measuring instrument is 408.84 NTU, which is wrong compared with the standard solution. The
difference is reduced to 8.84 NTU. The test results show that the measurement accuracy and error of the measuring instrument designed in this paper are obviously better than the performance of the domestic mainstream products tested, but there is still a certain gap compared with imported HACH and other measuring instruments.

Table 1. Comparative analysis of turbidity measurement data of measuring instrument

| Serial number | standard solution (NTU) | standard solution Compensation before the two points method measurement and error (NTU) |
|---------------|------------------------|------------------------------------------------------------------------------------------|
| 1             | 0                      | 0x0000 0.00 0.00                                                                        |
| 2             | 200                    | 0x0d44 216.34 16.34                                                                      |
| 3             | 400                    | 0x1a01 424.68 24.68                                                                      |
| 4             | 600                    | 0x24ad 625.77 25.77                                                                      |
| 5             | 800                    | 0x2f6b 813.32 13.32                                                                      |
| 6             | 1000                   | 0x3a9c 1000.00 0.00                                                                       |

| Serial number | Measured value and error after compensation(NTU) | HACH turbidity meter measurement and error(NTU) | Measurement value and error of a mainstream domestic turbidity meter(NTU) |
|---------------|-----------------------------------------------|---------------------------------------------|---------------------------------------------------------------------|
| 1             | -1.98                                        | 0.00                                        | 2.02                                                                |
| 2             | 200.49                                       | 200.2                                      | 202.54                                                             |
| 3             | 408.84                                       | 403.5                                      | 409.83                                                             |
| 4             | 593.89                                       | 602.4                                      | 609.53                                                             |
| 5             | 791.50                                       | 806.7                                      | 789.82                                                             |
| 6             | 1005.27                                      | 1005.8                                     | 1012.3                                                             |

4. Conclusion
In this paper, a mine water turbidity measuring instrument is designed through the analysis of the working principle of optical turbidity detection. The measuring instrument is mainly based on the principle of light scattering. The measurement error is minor (the accuracy is within 3%), and the front end adopts silicon photoelectric. As a photoelectric conversion component, the diode adopts high-precision operational amplifier circuit and A/D analog-to-digital converter design. It adopts low-power OLED liquid crystal display for human-computer interaction and anti-interference design of digital interface RS485 bus to meet complex electromagnetic interference in coal mine. In terms of the environment and data processing, the MATLAB software simulation tool is used to fit and compensate the measurement data curve, which effectively improves the accuracy of turbidity measurement. Compared with measuring instruments of other brands and the performance of the domestic measuring instruments, the measurement error of the measuring instrument has been greatly improved, but there is still a certain gap between the measurement error of foreign HACH products. Thus, further improvement and optimization in front-end silicon photodiode selection, light source and signal conditioning circuit are needed to improve the performance of the measuring instrument. The turbidity measuring instrument mentioned in this paper has been tested on site in Shenhua Shendong, China Coal Group, Zaozhuang Group and other mines. The work is stable and reliable. The mine water turbidity measuring instrument provides a reliable online monitoring for the water quality of underground equipment. Means, high real-time and effective guidance for daily maintenance of water treatment equipment have greater application and promotion value.

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