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Design of an Online COD Detection System for Water Quality

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Abstract

In response to the issues of low detection accuracy and inconvenient manual sampling associated with traditional water quality COD detectors, this paper presents the design of an online automatic detection system for chemical oxygen demand (COD) in water quality using rapid digestion spectrophotometry. The system is centered around the STM32F407 microcontroller, based on the Cortex M4 core. It is capable of automatically detecting COD content in water samples and communicating data. It can detect water quality status in real-time and help relevant departments obtain water quality information in real-time to prevent water pollution accidents. The test results show that the system has successfully performed various functions for online detection of COD in water quality. The error in COD detection indication within the range of 15 mg/L to 2000 mg/L is less than ± 5%, meeting the technical requirements of relevant standards. It has good application prospects and practical value.

Keywords

Chemical oxygen demand, water quality testing, rapid digestion spectrophotometry, STM32F407, photoelectric detection

1. Introduction

With the rapid development of industrialization, the surface water pollution of the surface of my country is very severe. Organic pollution in the river generally exists, water pollution is becoming increasingly serious, and the water body is rich in nutrition [1]. The timely, accurate, and comprehensive reflection of the quality and pollution of the water environment can save at least 40%of the cost of water environmental governance in the later period, and it can also prevent the occurrence of water pollution accidents. Therefore, it is extremely important to monitor early pollution monitoring of water quality. Chemical Oxygen Demand (COD) is one of the important indicators to determine whether the water quality is contaminated [1]. The main source of pollution, so COD can be used as a comprehensive indicator of organic matter content. However, due to the high price and high maintenance cost of COD detection instruments abroad; there is still some gap in domestic water quality monitoring in terms of performance [2]. Therefore, designing a high measurement accuracy, low price, convenient detection, and environment-friendly water quality COD online monitoring. The device controller is of great practical significance for preventing water quality pollution.

2. Basic principles

This design compares multiple water quality COD detection methods and finally chooses the fast-elimination of optical lighting method as the detection method of this system. The measurement principle of the instrument measurement of water quality COD is used quickly to detect the optical lighting method. The basic principle is to apply Langbeier's Law to the measured water quality. Chemical oxygen demand is the consumption of strong oxidants under special conditions in special conditions. Fasting and solving the lighting method is based on its characteristics, adding potassium chromate solution to water samples, silver sulfate solution, mercury sulfate solution, concentrated sulfuric acid solution after the chemical reagents are fully mixed, heated to the high temperature of 165 °C, keep it for 10 minutes, so that the solution is fully reacted. After the reaction is over, the optical sensor measurement reaction is over [3]. The content of chromium ion reflects the consumption of strong oxidants in water quality, which is the content of COD. The three-valent chromium ion has an absorption effect on the light of a specific wavelength, so the absorption of the three-valent chromium ion is measured, and the content of the COD is then obtained. The absorbance of a three-valent chromium ion is found through the Langbeier Law. The formula of the Langbeier Law is as follows:

$$A = -\log_{10}\frac{I_t}{I_o} = \log_{10}\frac{1}{T} = K \cdot l \cdot c \quad (1)$$

In the formula, A is the absorbance; I_0 is the incident light strength; I_t is the transmission light strength; K is the light absorption coefficient; C is the solution concentration; $l$is the thickness of the solution [4]. Through this form, it can be concluded that the COD concentration is proportional to the absorbance of light absorption in water quality, so when we are equipped with a batch of standard concentration COD solutions and measure the absorbance of its COD, we can get the linear relationship between them.

The solution adopted by this design is to choose the light-emitting diode that can emit specific wavelength light as a luminous component device. After the transmitted light is transmitted through the solution in the elimination tube, the light is used to receive the light battery receiving through the light. After the light battery is illuminated, its surface will have electron flows to form a current. By capturing this change, after a certain calculation process, the corresponding light intensity is obtained. In the specific detection process, the water quality COD detection device will have one step gap test, so as to obtain a value of light intensity as I_0, which is used as the light intensity of the light. During the subsequent testing process, the test process to participate in the water sample is to be measured. The value measured by the optical battery is the light intensity I_t. In this way, in the actual detection process, according to the measured light strength I_0 and transmitted light strong i, you can calculate the COD value of the wwater-basedtest. Use two silicon light battery receivers to receive the light of the specific wavelength emitted by the emitting diode, transform the received light signal through the sensor into an electrical signal, and filter and amplify the collected electrical signal, so that the electrical signal is converted into the electrical signal into it into a transformer into the electrical signal [5]. The standard voltage value received by the industrial control motherboard simulation input module, the voltage value of the road is used as a strong incident light I_0, and the other road voltage value is used as the transmission light strong I_t. According to the Langbeier Law, the content of COD in the water quality can be obtained.

3. System overall solution

The water quality COD automatic online monitoring system designed in this article is mainly used by the main control circuit, high-precision AD conversion circuit, liquid level detection circuit, photoelectric conversion amplification circuit, temperature detection and control circuit, data storage circuit, and RS485/4-20MA communication circuit these seven parts. The system structure box diagram is shown in Figure 1.

The system is based on the STM32F407 microcontroller based on the Cortex M4 kernel, which is responsible for the control and data processing of each functional module of the system. Through the system software controls the automatic detection operation process, the water sample and dosage of the liquid device, the temperature detection and control of the elimination tank, the COD photoelectric signal collection, and AD conversion, the COD value calculation, the 4-20mA current ring, and the RS-485 communication, etc. The PT100 temperature sensor is used to detect the temperature of the anti-solution tank, and the reaction temperature can be controlled by the PID algorithm through the PID algorithm to quickly and accurately reach 165°C. A 24-bit AD converter ADS1256 is converted to the photoelectric detection signal of the elimination solution to obtain the optical value and then calculate the COD value based on the linear relationship between the optical value and the COD value [6]. COD detection values are calibrated through two groups of standard liquids known as standard concentrations to improve detection accuracy. The final COD detection results were uploaded to the data collection instrument through a 4-20mA current ring or RS-485 communication method.

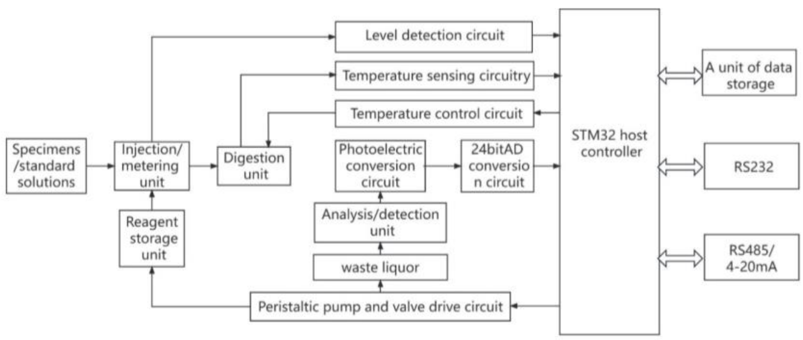

Figure 1. Water quality COD online detection device controller structural box diagram.

Water quality COD online monitoring device controller system work is to have the following workflow:

(1) Starting device: When the detection cycle comes or the upper machine starts the COD monitoring device;

(2) Elimination and cleaning: After the device is started, the creep pump is working on the work through the control circuit. The waste liquid in the discharge and eliminates the waste liquid in the pool will be continuously cleaned for at least 6 minutes to avoid the effect of the last detection of the residual liquid on the test results, and then increase the increase. Large errors; then make the peristaltic pump reversed, empty and eliminate water samples in the pool, clean the waste liquid;

(3) Water inlet sample: Start the peristaltic pump main control chip to compare the liquid level of the solution with the set threshold. If the water level reaches the threshold, turn off the peristaltic pump and start washing the metering tube; after the end, the water sample is sent to the elimination pool;

(4) Reagent 1 (mercury sulfate): Anti-blowing water sample tube to eliminate waste liquid; then enter the reagent, and send it to the elimination pool after obtaining a quantitative reagent;

(5) Reaging reagent (Silver sulfate of potassium chromate): Blow the air into the elimination pool before moisturizing, make the reagent 2 mix with the water sample, and then moisturize the water-like tube. After quantitative reagent 2, send it to the elimination pool, and then blow into the air to make it fully mixed;

(6) Heating: When the temperature measurement circuit detects the temperature does not reach the threshold, the heating device is activated to make it the best temperature of the reagent and water sample response, and then the reaction temperature remains unchanged so that the two react fully. After the response, start the relay to turn on the fan, cool down and cool down;

(7) Data processing: After the optical path module, I/V conversion module, and A/D conversion module, the light signal is converted to the light absorption value. Due to the linear relationship between the light absorption value and the water quality COD value, the main control chip can COD data obtained by the linear relationship between light absorption and COD;

(8) Device cleaning: After obtaining COD data, empty the waste liquid in the pond, at the same time enter the water sample, blow the air into the elimination pool, and clean the water sample tube and the elimination pool.

4. System hardware design

4.1 Main controller circuit design

Using ST Company's STM32F407zet6 microcontroller, the microcontroller contains three 12-bit sampling rates with a maximum of 2.4msps, as many as 15 communication interfaces including 3 I2C interfaces, 4 USART interfaces, and 3 SPI (42Mbits/s) interface, twelve general 16-bit timers, operating frequency is as high as 168MHz, rich resources on the film, large storage space, and rich serial resources.

4.2 COD optoelectronics detection module circuit design

The COD optoelectronic detection module circuit is a key constituent structure of the entire COD detection system. The optical path module is mainly used to transform the radial beam of the light source and transform it into a parallel light vertical emission through the absorbent in the pond water sample. In the process of the entire chemical reaction, the light signal received by the optoelectronics diode is very small, which makes the current generated by the optoelectronics diode extremely small. It must be converted to the voltage signal and amplifier processing through the I/V conversion circuit and then amplifier processing [7]. The A/D conversion circuit is used to collect the signal that is enlarged by I/V, and then process it through the MCU. As shown in Figure 2, it shows the light diagram of the circuit structure of the detection module.

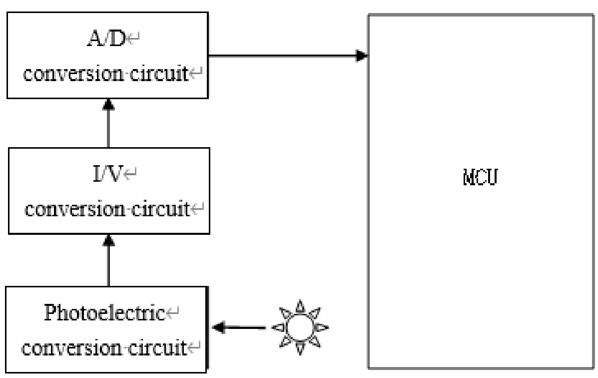

Figure 2. Detection module circuit structure brief diagram.

4.3 A/D conversion circuit design

The 24-bit A/D conversion chip ADS1256 produced by the Texas Instrument (TI) company is used. Its collection rate can be 30KSPS and the accuracy can reach±10uV. The main role is to collect the voltage signal converted from the degree of light, so as to correctly obtain the concentration of the COD. The A/D conversion circuit diagram is shown in Figure 3.

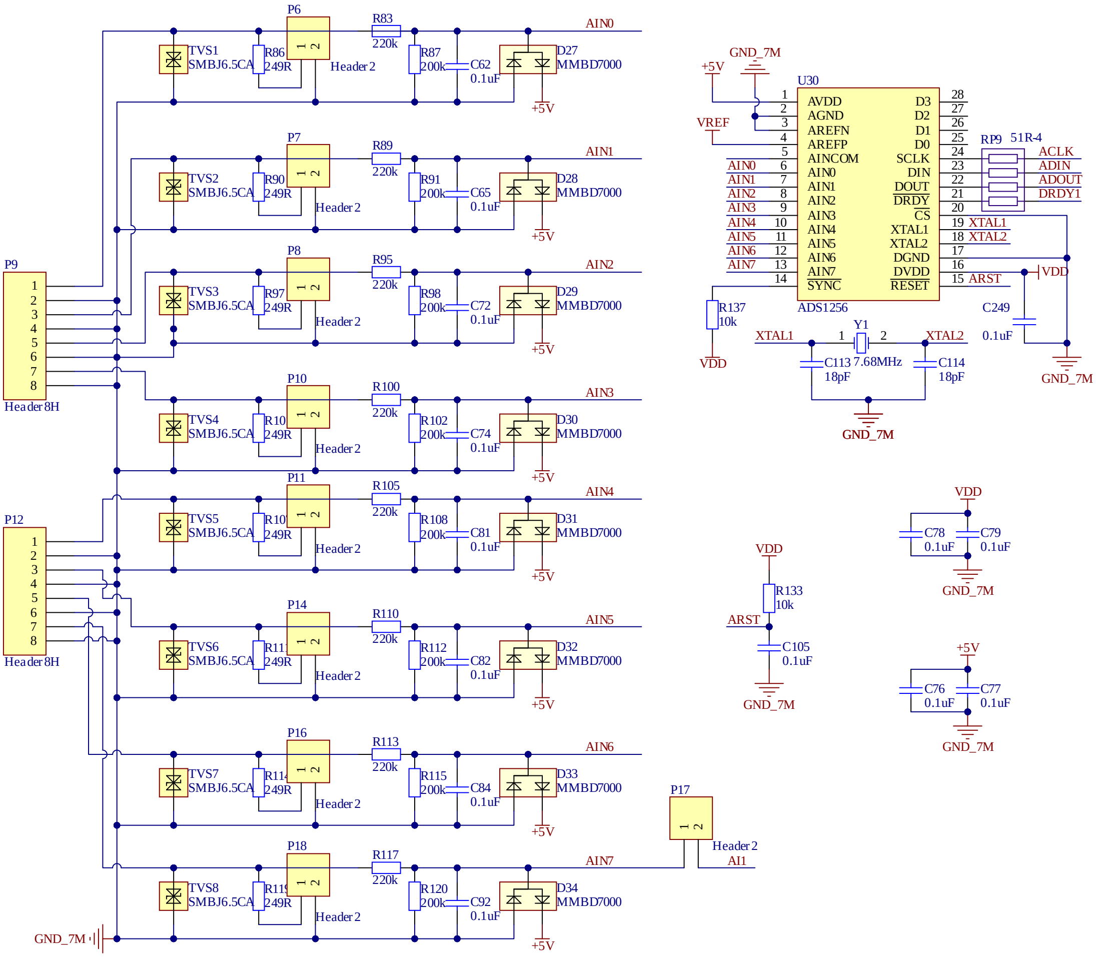

Figure 3. A/D conversion circuit diagram.

4.4 I/V conversion and amplification circuit design

The main function of the I/V conversion circuit is to convert the light value to current and voltage signals. The main solution is to convert the current of the optoelectronics diode into a voltage that can be collected through an operational amplifier as a current-voltage conversion. The I/V conversion and amplifier circuit diagram is shown in Figure 4. The P19's 2-pin is connected to the optoelectronics diode. The 3 pins are connected to the AD1256. After the STM32 micro-controller is collected and processed by the ADS1256, the light value can be obtained at this time.

The water quality COD detection module is based on the rapidly solving lighting method. First of all, the LED light with a wavelength range of 440nm ± 20nm is used as a point light source, and the luminous mirror of the quartz material (glass material absorbs the light of the light below 340nm. Focus the point light source into parallel light spots (the diameter of the light spots is less than the diameter of the filter), and then generate a single wavelength with a wavelength of 440nm ± 20nm through the 440nm ± 20nm filter, and then illuminates the double -pass quartz that needs to be measured in water samples to test the water sample. After absorbing the reduction pond, the reducing substance in the water sample was absorbed and finally shot to the optoelectronics diode, which converts the optical signal to the electrical signal from the optoelectronics diode.

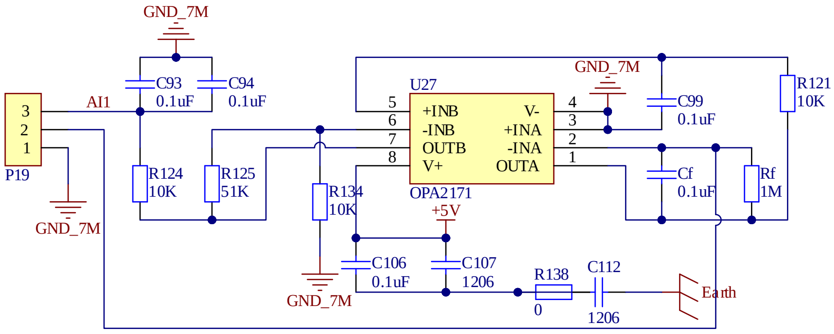

Figure 4. I/V conversion and amplification circuit diagram.

4.5 Temperature detection circuit design

Temperature detection and control circuits are used to detect the temperature conditions of the reaction pool, ensure that the reagent and water sample can react normally, and avoid affecting the measurement results due to temperature [8]. The temperature detection circuit is shown in Figure 5. The PT100 sensor+AD623 amplifier is used to form a temperature detection circuit. P1 connects the PT100 sensor. After AD623, the current temperature is collected and processed by the internal AD of STM32.

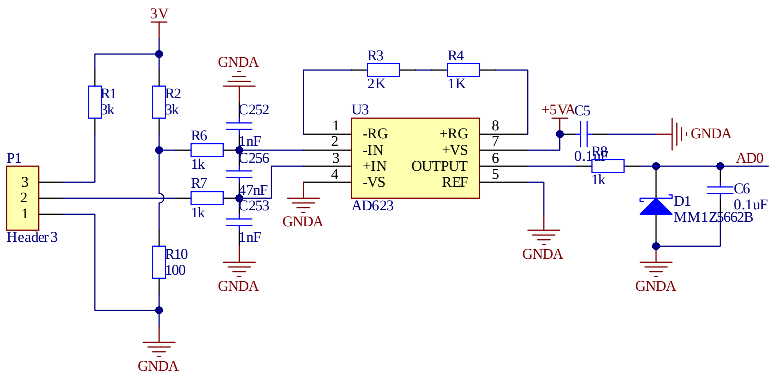

Figure 5. Temperature detection circuit diagram.

At 0 degrees Celsius, the resistance value of PT100 is 100 ohms, and its resistance value increases approximately uniformly with temperature. Therefore, by measuring the change in its resistance value, it can be converted into the corresponding temperature. In order to improve the accuracy of measurement, a three-wire system is selected. The advantage of the three-wire connection method is to add equal wire lengths on both sides of PT100 to the bridge arms on both sides, which eliminates the wire resistance and reduces measurement errors.

This article uses a bridge method to measure the resistance of the PT100 with temperature changes. The current requirements of the PT100 are less than 1mA. In order to facilitate the collection, try to make the current flow through the PT100 near 1mA. The working principle of the bridge is to compare the voltage value in the middle of the two voltage resistors [9]. As shown in the figure, when R1 = R2, at this time, only when RPT = R10, the bridge is balanced. The resistance value of the R10 is the resistance value of the RPT. At this time, essence use a dedicated instrument to calculate the amplifier AD623 for differential release. The voltage calculation formula output after the bridge and the computing amplifier is shown in the formula:

$$\left(\frac{R_{10}}{R_{10}+R_2}-\frac{R_{PT}}{R_{PT}+R1}\right)\times VDD\times A=\frac{ADC}{ADC\_MAX}\times VDD \tag{2}$$

Among them, VDD is the reference voltage of the bridge voltage and AD, A is the amplification multiple of the amplifier, ADC is the current AD measurement value, and ADC_MAX is the maximum range of ADC; theoretically, the current RPT resistance value can be directly calculated through the formula [10]. Then check the table according to the resistance value to get the current temperature value.

AD623 is an integrated single-power precision Instrumentation amplifier, that can achieve rail-to-rail output under a single power supply (+3V to+12V), and it allows gain programming with resistors of different resistance values, which is more flexible. When there is no external resistance, AD623 is set to unit gain by default; After the external resistor is connected, the AD623 can be programmed to set the gain, which can reach a maximum of 1000 times depending on the resistance value of the external resistor. It gains:

$$G = \frac{100K}{R_G} + 1 \tag{3}$$

In this article, the selected 3K resistance of RG, that is, its gain is 34 times, which can be effectively collected by AD and the error is small.

4.6 Storage circuit

A device AT24C02 supports bus data transmission protocol I2C. Set the 0.1UF capacitor C186 as a filter capacitor to filter high frequency. Set up 4.7kΩ resistors R228 and R229 as the upper pull resistance to maintain the IIC communication line free and high-level state. However, although the main and from the device can be used as a transmitter or a receiver, it can only be controlled by the main device to control the data (sending or receiving) mode. It can achieve up to 8 AT24C02 device addresses, so it can be connected to the bus up to 8 AT24C02, and the choice device is used through the address of different configuration devices. The storage circuit is shown in Figure 6.

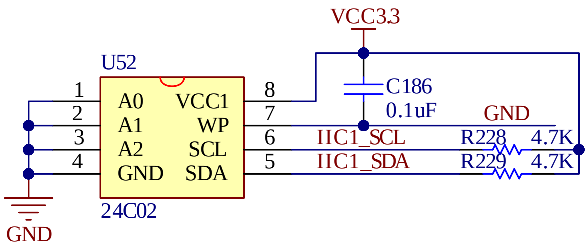

Figure 6. Storage circuit.

4.7 Expressive pump drive circuit design

In the COD detection device, the peristaltic pump as the core device of the water sample acquisition module requires it to be able to turn on and reverse under the control of the main controller to achieve water pumping and drainage function, so as to realize the automatic sampling of the COD detection system Function. The design of the speed drive signal circuit of the stepper motor is shown in Figure 7.

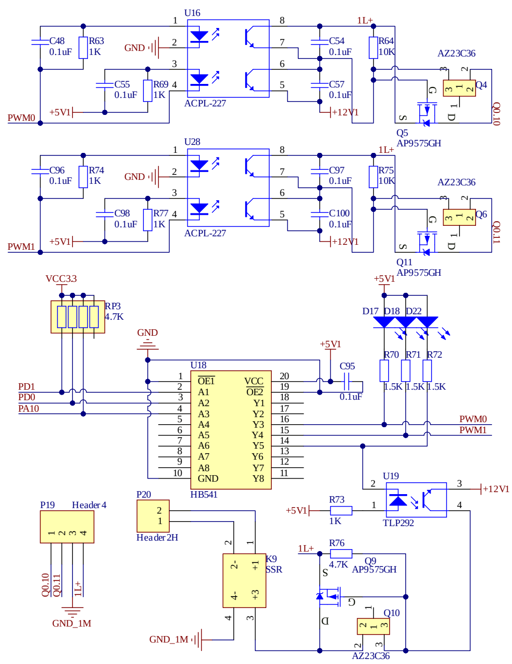

Figure 7. High-speed PWM signal output circuit.

4.8 Communication module circuit design

4.8.1 RS485 circuit design

The RS485 communication circuit is the output unit of the COD detection device. It communicates with the data acquisition instrument [11]. It can transmit the collected data to the data collection instrument and then upload it to the data terminal.

The RS485 communication circuit uses SP485 communication chip. SP485 communication chip can be used to change the hardware protocol that changes serial communication. The RS485 communication circuit is shown in Figure 8.

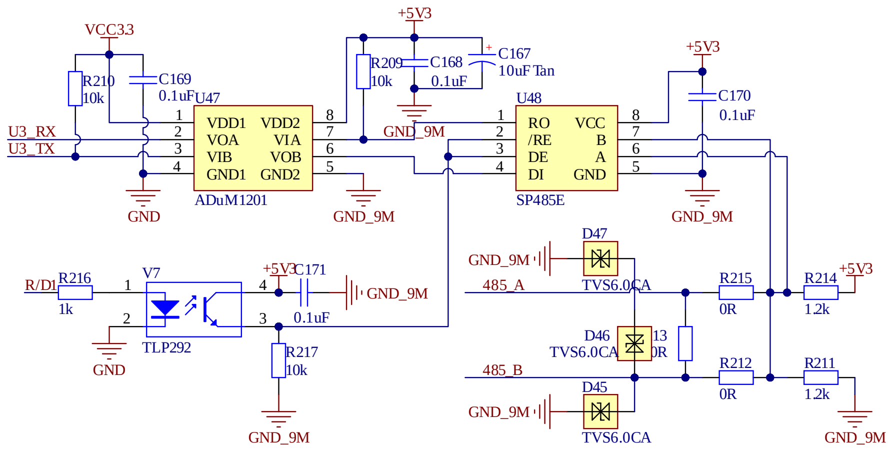

Figure 8. RS485 circuit design.

4.8.2 RS232 circuit design

In order to monitor and control the operation of the COD detection device in real time, compared with the use of standard serial port TTL to connect with the touch screen, RS232 is more suitable for communication between devices and devices. The COD detection device designed in this article perform data communication between point-to-point data between the touch screen. Its transmission speed is faster than the UART interface, and the use of a pair of twisted cables as the connection line that receives and send can improve the reliability of data communication. The RS232 communication circuit is shown in Figure9.

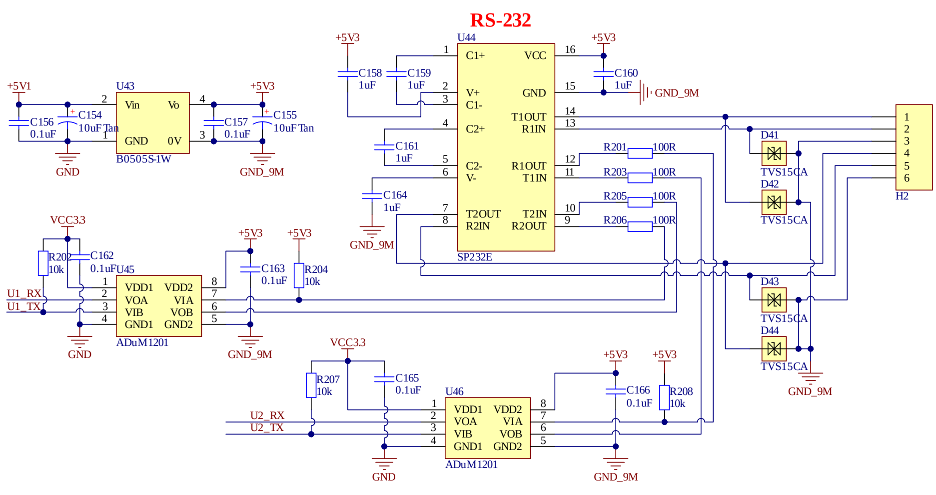

Figure 9. RS232 circuit design.

4.8.3 4-20mA communication circuit design

The COD monitoring device communicates with the 4-20mA current generated by the device to communicate with the data collection terminal. 4-20MA communication circuit uses an independent DAC chip DAC8563 to generate input voltage driver XTR111 output 4-20mA current. XTR111 is a precise V/I converter, designed for standard 0MA-20MA or 4MA-20MA analog signal. The XTR111 circuit is shown in Figure 10.

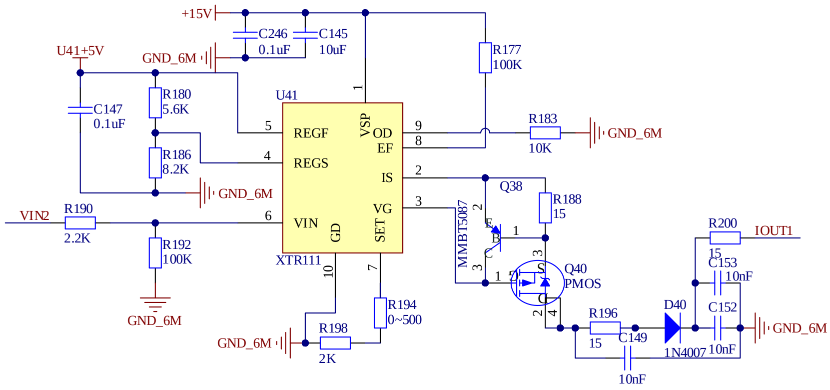

Figure 10. XTR111 Circuit Design.

5. System software design

After the COD automatic detection device is turned on, the main control chip starts the initialization program automatically by automatically resetting and then detects the parameters and initialization data of each module through the subroutine [12]. If the system parameters are wrong, the parameter calibration program is automatically entered.

The correction data is obtained from the Flash inside the main control chip. After the correction is completed, the parameter detection program is re-entered until the parameter is correct and enters the next execution program. This system can achieve water quality COD 24h fully automatic detection. When the upper machine sending starts to detect instructions or time reaches 1h, the system starts to perform the detection program, the peristalsis pump is turned on, washed side by side, and the baseline calibrates to determine the light source. Then the quantitative water sample, reagent, and reagent second rows are entered into the elimination pool, and the temperature control detection and control will be activated to maintain the temperature of the anti-solution tank at 165 ° C 15min [13]. Ponds and data processing get COD value. The continuous COD detection program flowchart is shown in Figure 11.

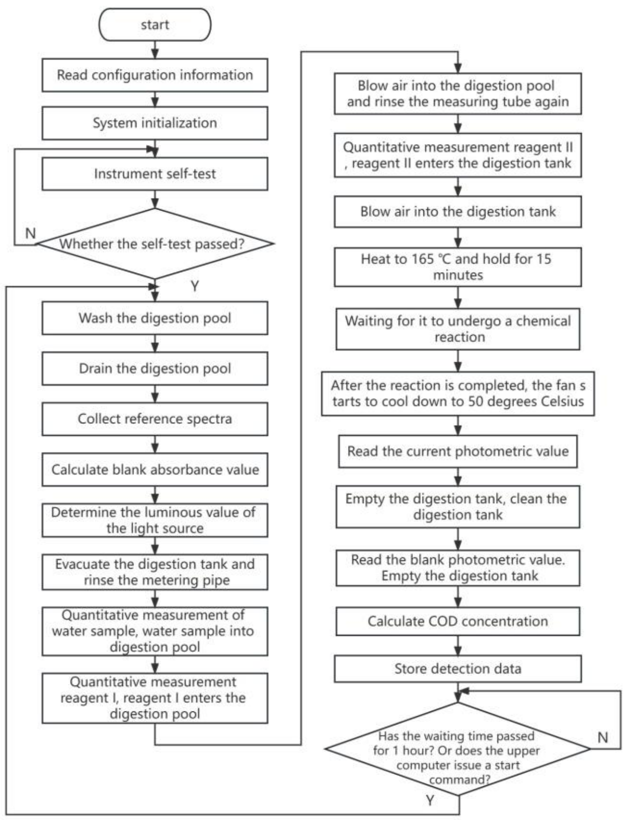

Figure 11. COD detection program flowchart.

6. System test

The three groups of standard water samples with different concentrations of COD are detected separately through the water quality COD online detection device designed herein to compare and organize the measured COD concentration data with the standard concentration data. The statistics of the error are shown in Table 1.

Table 1. COD test analysis results

Standard concentration	Results of testing						
(mg/L)	Group one	Error	Group two	Error	Group three	Error	Average error
15	14.38	-4.13%	14.33	-4.47%	14.30	-4.67%	-4.43%
30	29.14	-2.87%	29.35	-2.17%	28.88	-3.73%	-2.92%
50	48.83	-2.34%	49.36	-1.28%	49.09	-1.82%	-1.81%
100	98.56	-1.44%	98.33	-1.67%	99.03	-0.97%	-1.36%
200	198.74	-0.63%	198.62	-0.69%	198.66	-0.67%	-0.66%
300	297.97	-0.67%	298.15	-0.62%	298.13	-0.62%	-0.64%
500	497.36	-0.53%	496.63	-0.67%	496.91	-0.62%	-0.61%

As shown in Table 1, the comparison between the COD value measured using the water quality COD automatic online monitoring system and the standard COD concentration of sample reagents is based on the analysis of test results. It is less than 5%, which is smaller than the national standard HJ377-2019 for chemical oxygen demand in online automatic monitoring regulations, meeting the design requirements. The accuracy requirements of traditional water quality COD detection devices are within 8%, and this design will increase accuracy by 3%.

7. Conclusion

Based on the basic principles of the rapid solution of the spectrophotia method, this article designed a water quality COD online detection system based on STM32. This system realizes the function of automatic detection of water sample COD content and data communication. It also performs practical verification. The results show that the accuracy of this design has been significantly improved compared to the traditional water quality COD detection device. In addition, this design adds peristaltic pumps, which can achieve automatic extraction and detection of water-like, solve the problem of artificial sampling and cleaning in most domestic water quality testing instruments, and achieve remote online control. The speed of water quality detection allows relevant departments to obtain water quality information in real time to prevent water pollution accidents.

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