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RESEARCH ARTICLE

Design and Implementation of an Automatic Emulsion Dispensing and Remote Monitoring System Based on IoT Platform

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ABSTRACT In order to realize the automatic dispensing and remote monitoring of emulsions in the coal mine production process and improve the efficiency and safety of coal mine production, an automatic dispensing and remote monitoring system of emulsions based on the IoT platform was built. The APRUS X industrial network management adapter in this system is the upper computer of Siemens S7-200SMART PLC and the data transmission hub between the dispensing system and the MixIOT cloud platform, while the MixIOT cloud platform realizes the functions of data visualization and remote control terminal; the PLC acts as the control core and monitors the weight sensors, solenoid valves, DC brushless booster pumps, agitators and other equipment at the same time. The data collected by the sensors are uploaded to the cloud through IOT technology and combined with real-time data to realize automatic dispensing and remote control of emulsion. Meanwhile, remote monitoring is realized through Web page and apps, which is convenient for managers to monitor the production site in real time and realize intelligent production. There are 27 groups of liquid dispensing experiments, and the average relative error of emulsion concentration ratio obtained after 27 groups of tests is 4.8%, and the accuracy requirement meets the actual engineering needs. The research results are of great significance to promote the intelligent production of coal mines and the application of industrial IOT technology, and provide specific reference and references for the research and application in related fields.

INDEX TERMS IoT platform, intelligent mine, automatic emulsion dispensing, Siemens S7-200SMART PLC, remote monitoring, sensors.

I. INTRODUCTION

many hydraulic equipment used as power and lubrication medium is an emulsion, usually made of emulsified oil and water blending, when the two mixed emulsified oil in the form of tiny droplets evenly dispersed in water, forming an emulsion. The quality fraction of emulsion applied in coal mine production should be maintained at 3% to 5%, and its concentration has an essential relationship with the working life of hydraulic pillars [1], [2], [3]. once its concentration is too high, it will cause the following consequences: (1) significantly increase the cost of emulsion. (2) The high concentration of emulsion also reduces its defoaming ability. It increases the swelling of the emulsion on the sealing equipment made of rubber and other materials, which will reduce the service life of coal mining equipment when air bubble cavitation of the emulsion occurs and the sealing equipment is damaged. (3) The main components of emulsified oil are base oil, emulsifier, preservative and other additives, which will cause significant environmental pollution if leakage occurs. When the emulsion concentration is too low, it will reduce the emulsion's stiff water resistance, lubricity, and corrosion resistance, which will accelerate the damage to the hydraulic column and affect the safety of the life and property of

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underground workers [4], [5]. Therefore, the research on how to realize the accurate proportioning and remote control of emulsion with the help of intelligent equipment is crucial for hydraulic equipment [6], [7].

Many experts and scholars have researched emulsion automatic proportioning technology. The UK's Leiper Research Institute [8] mainly adopts a distributed multi-pump superposition method to realize emulsion proportioning, this liquid dispensing method has the advantages of fast dispensing speed and high fault tolerance, but it also has the disadvantage of low accuracy;Germany's Hausinger Research Institute mainly adopts a PC-based control system, the advantage is that the degree of automation is greatly improved, and single pump, group and emergency stop control can be realized, but cannot realize local control of the system [9]; The Kamat Institute in Germany [10] has built on this foundation with a centralized control system that enables both remote control and local control, but limited by the conditions at that time, the stability of remote control signal transmission is poor, and the cost is expensive, which is not conducive to large-scale promotion; The Chinese scholar Su Guoxiu [11] designed a set of automatic proportioning system to optimize the solution of emulsion water-oil uniform mixing, which mainly uses the venturi principle to realize the configuration of emulsion water-oil uniform distribution, the advantage of this system is that it can provide stable emulsion fluid, but it only realizes the field control, and the remote control has not been realized yet; To sum up, this study has improved the above problems, including stable emulsion flow, low error rate of emulsion concentration, high degree of intelligence and stable remote control signal. Because the mine ring network is used, this kind of industrial Internet technology has become more mature, so the deployment cost is low [12], [13]. Before constructing the automatic emulsion dispensing and remote monitoring system on the IoT platform, sufficient research was conducted on the market, including the places where such systems are frequently used; for example, in the process of going to a specific coal mine, the automatic emulsion dispensing equipment in use was carefully observed, and it was found that it had only realized automatic dispensing to a certain extent and did not have the function of remote monitoring and control. Its production status was very backward; for example, emulsified oil needs to be manually carried below the mine and then manually loaded into the emulsion mixing tank, and it can only be monitored at the site, not remotely online, which significantly increases the labor force of workers and insecurity. Its equipment diagram is shown in Figure 1. In the subsequent visits to several coal mines, it was found that similar problems existed, so it is essential to realize the automatic emulsion dispensing and remote monitoring system based on the IoT platform.

Compare all kinds of emulsion dispensing systems, all play a significant role in the specific application context, but at the same time, there are three problems; first is the low level of intelligence of the emulsion dispensing device, emulsion dispensing method from the initial manual to the development of the later mechanical stage and then to the automation stage, has now entered the era of intelligence, the primary automatic dispensing device, the function is relatively single, the level of automation is low. Secondly, the concentration of emulsion dispensing needs to be more accurate. The concentration accuracy obtained is often challenging to meet the site's needs due to the constraints of execution parts and sensors. Lastly, remote monitoring cannot be realized [14]. A mature automatic control system should be able to achieve remote control and on-site control to meeting an increasingly complex control environment and can save resources. The designed system has got rid of complicated manual operation, all operations can realize remote monitoring, real-time inspection of equipment data, making the function more perfect, and using high-precision weight sensor and appropriate mathematical model, which improves the accuracy of liquid preparation; The current system can also realize remote monitoring of mobile phones, which greatly improves the degree of intelligence. This research achievement has optimized the traditional emulsion mixing work by using advanced technical means such as the Internet of things platform, Siemens PLC and high-precision weight sensor, making the emulsion mixing site less manned or even unmanned, which can save resources for enterprises and help realize intelligent mines; At the same time, there are also some defects. For example, there is no small emulsion concentration sensor suitable for laboratory use, so the emulsion concentration measurement method can be further optimized. An IoT platform-based emulsion automatic liquid dispensing and remote monitoring system [15], [16], [17] is designed to respond to the above problems. The APRUS X industrial network management adapter (from now on referred to as ''adapter'') is used as an IoT data collection terminal and information transmission hub to smoothly transmit information to the MixIOT cloud platform via 4G network signals while sending control commands to the PLC, and the MixIOT cloud platform realizes the functions of data visualization and remote control terminal; the Siemens S7-200SMART PLC [18] is used as the central control unit and the lower computer of the adapter to control the operation of the equipment, and the weight sensor is used as the signal input unit. Through the designed control

FIGURE 1. Emulsion dispensing system in use at a mine.

program [19], the weight of the emulsion oil tank, water storage tank, and emulsion tank is dynamically monitored, the initial concentration and target concentration are manually input, and the remote control terminal or on-site touch screen sends control signals to control the start and stop of the pump and solenoid valve, thus realizing the automatic dispensing of emulsion and remote monitoring, the use of high-precision sensors makes the dispensing accuracy has been dramatically improved; advanced Internet of Things technology reduces the involvement of people, so it dramatically reduces the labor force of the workers and significantly improves the safety of the production environment of the workers, and the depth of the research in the same type of research is in a leading position; by the laboratory 27 times of the replenishment and oil replenishment experiments, the final average relative error is 4.8%, which meets the needs of practical engineering. [20], [21].

This thesis is divided into seven chapters. Chapter 1, Introduction, introduces the consequences of inaccurate emulsion concentration, the current research progress of emulsion dispensing system and the results of field research, and summarizes the problems of the existing automated emulsion dispensing system and the ways to improve it from the research progress and the results of the field research; based on which, the overall architecture of the system and the significance of the research are proposed. Chapter 2 mainly discusses the overall design scheme, the workflow of the system and the critical technologies used to realize the system. Chapter 3 discusses the selection of PLC and external wiring methods, and designs the remote detection platform of IOT and analyzes the signal and principle of high-precision weight sensors. Chapter 4 introduces the software part in the process of realizing the system, including the realization of the field control touch screen, the critical liquid dispensing algorithm, and the scale transformation. Chapter 5 conducts a field experiment after assembling the system according to the previous design and analyzes the experimental results. Chapter 6 analyzes the conclusions drawn from this side of the thesis. Chapter 7 describes the limitations of the paper and future research directions for other researchers working on such problems. The research is of great significance for promote the intelligent production of coal mines and the application of industrial Internet of things technology, and provides a certain reference for the research and application in related fields.

II. OVERALL SYSTEM DESIGN AND CRITICAL TECHNOLOGY ANALYSIS

A. OVERALL DESIGN SCHEME

The system includes an emulsion dispensing system and a MixIOT cloud platform. The data channels include an upward channel and a downward channel. The emulsion dispensing equipment terminal collects sensor data and transmits it to the monitoring platform through the upward data channel [22]; the monitoring platform pushes commands to the equipment

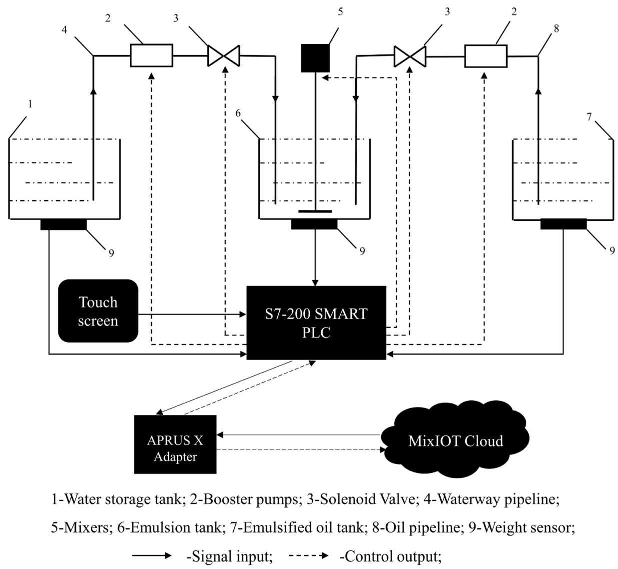


FIGURE 2. System hydraulic principle and hardware structure diagram.

terminal through the downward channel to control the work of emulsion dispensing equipment. The actuator adopts an APRUS-X adapter, DC brushless booster pump with solenoid valve, weight sensor, PLC, and mixer to realize automatic liquid dispensing and remote monitoring function; less electrical equipment means lower cost and failure rate. The weight sensors are installed at the bottom of the water storage tank, emulsion tank, and emulsified oil tank to monitor the weight change of the liquid and transmit the information to the central processing unit PLC, which in turn transmits the information to the APRUS-X adapter via RJ45 interface. The adapter communicates with the cloud server via 4G network signal. The PLC or remote control platform will calculate the required emulsified oil quantity or water requirement based on the initial and target concentrations input by the user and thus control the proportional concentration [23], [24]. The system's hydraulic principle and hardware section are shown in Figure 2, and the system framework is shown in Figure 3.

B. SYSTEM WORKFLOW

To meet the requirement of emulsion concentration in the specified range for the comprehensive mining workforce, the workflow of the automatic emulsion dispensing system is shown in Figure 4. Since most of the concentration sensors are only applicable to the production sites of large enterprises, they are expensive and huge in size, and there is no concentration sensor suitable for laboratory scenarios, a compact and affordable handheld refractometer is used to measure the actual emulsion concentration [25], [26].

After the system gets power, PLC and APRUS-X adapter first run the initialization program. The operations carried out mainly include reading the data from the sensors and processing them in real-time, initializing the PLC data storage area, connecting the adapter to the MixIOT cloud platform,

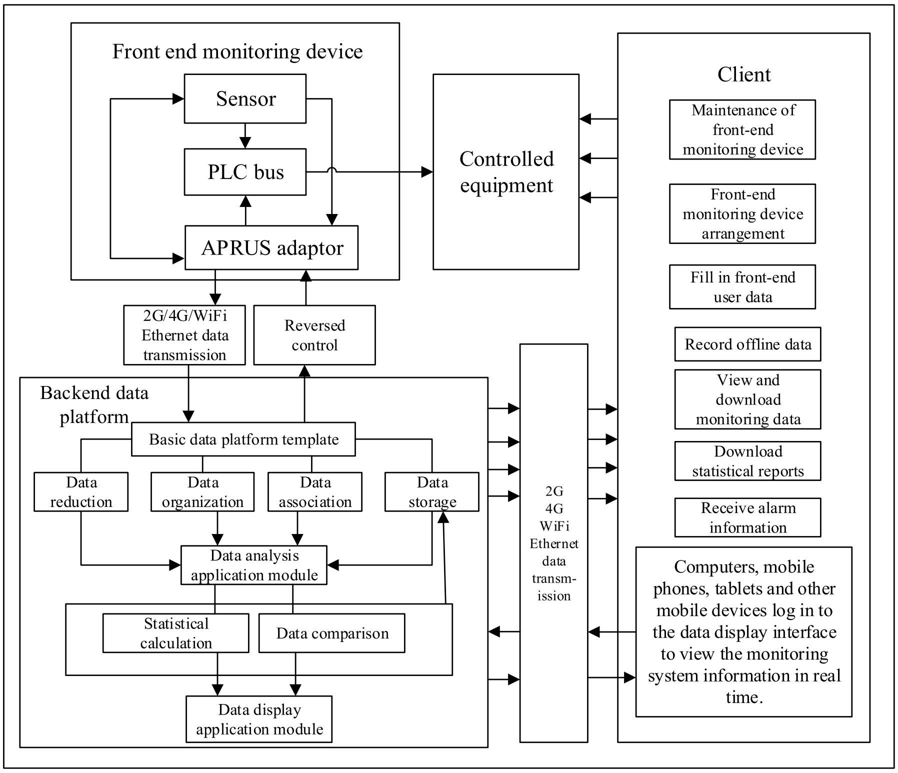


FIGURE 3. Framework of emulsion automatic liquid dispensing and remote monitoring system.

and uploading the data collected by PLC; then judging whether the system is in remote control mode or field control mode [27]; waiting for the user to input the initial concentration and target concentration, and after considering the relationship between the size of the initial concentration and the target concentration, determine whether it is oil replenishment operation or water replenishment operation. Then, according to the information on emulsion weight, initial concentration, and target concentration, it calculates the required water or oil quantity and subtracts the corresponding water or oil quantity from the current water or oil storage tank weight to get the target weight and monitors the weight of water and emulsion tanks after the booster pump and solenoid valve are turned on. Then the user decides on the mixing time and starts the mixer, and after the suitable mixing time, the mixer is closed, and the liquid dispensing is finished, waiting for the user's next liquid dispensing demand [28], [29].

C. ANALYSIS OF CRITICAL TECHNOLOGIES FOR INFORMATION TRANSMISSION

The network communication protocol is a bridge for data transmission on LAN or Internet, which is an important part of the IoT monitoring system construction process, and the communication between the APRUS-X adapter and remote monitoring platform in the emulsion automatic liquid dispensing system requires the selection of communication protocols, which are commonly used in IoT as shown in Figure 5. As a protocol type for transmitting messages, the MQTT protocol is based on the topic subscription model and the message distribution model. The client-server architecture implements the communication function, adhering to the principles of light-star, openness, and simplicity, which is adaptable in both limited device resources and unstable network environments and can provide support for IoT applications. When organizing and transmitting various types of information, it is essential to base the implementation on the hierarchy of subject structures. As a distributor of information, new data will be distributed in the information transmission process. Efficient connection of data and information in the agent. After this, the acquired information is distributed to all clients who have subscribed to the topic by means of the use of an agent. MQTT [30], [31] is a suitable communication protocol for the sensing nodes of the automatic emulsion dispensing system, mainly in the one-to-many data distribution mode, which facilitates multi-sensor data transmission and guarantees the signal stability of the monitoring nodes.

Since Siemens S7 protocol is a non-public protocol, and the system mainly uses Ethernet to communicate with PLC, we focus on the communication method of ISO on TCP and only introduce a little about the protocol of S7. IOS (International Organization for Standardization) International Organization for Standardization has developed OSI (Open System Interconnection) 7-layer model, including the physical layer, data link layer, network layer,

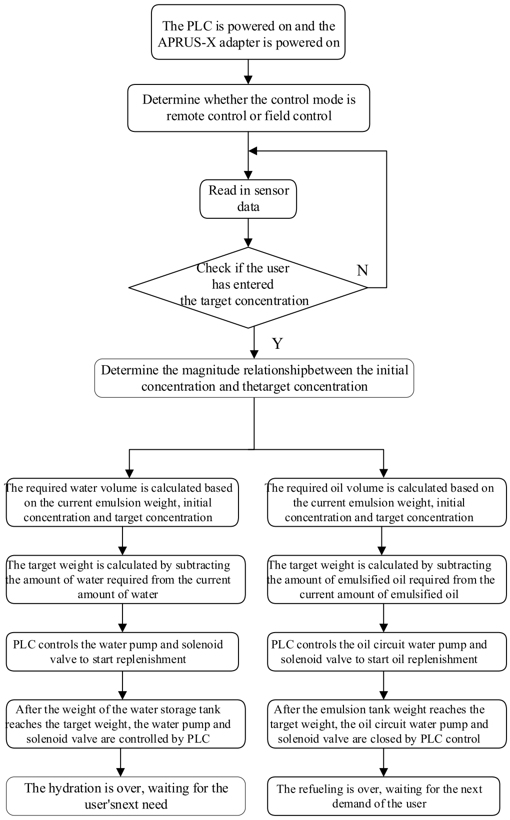


FIGURE 4. System workflow diagram.

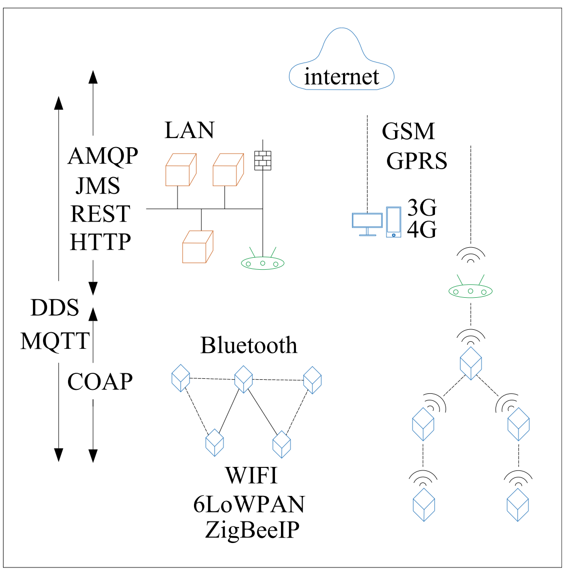


FIGURE 5. Common communication protocols for IoT.

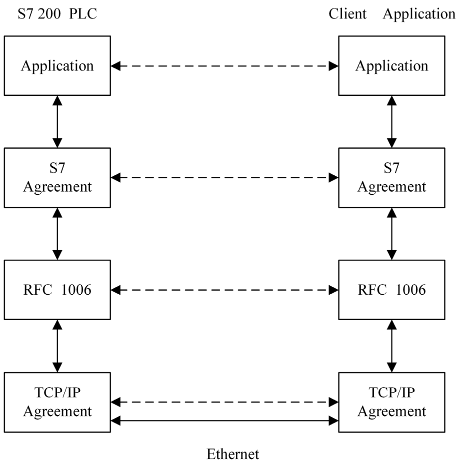


FIGURE 6. S7-200 network communication model.

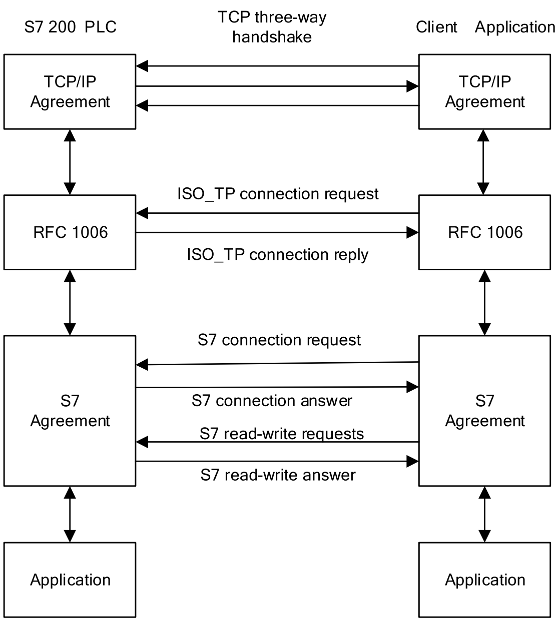


FIGURE 7. S7-200 network communication process.

transport layer, session layer, representation layer, and application layer. Siemens S7-200SMART network communication uses TCP/IP + ISO, and TP + S7 [32] protocol, as shown in Figure 6. The communication process is as follows:

(1) TCP three handshakes to establish communication TCP connection.

(2) ISO_TP connection is established.

(3) S7 protocol connection request and answer to establish a connection.

(4) Implement the S7 protocol to read data. The process is shown in Figure 7.

Data is the basis of an "intelligent mine" [33], [34], [35]. The basic requirement of building a digital mine is to choose a variety of collection terminals for data collection. The data collection process requires various information collection equipment, including information identification equipment, remote sensing equipment, and other sensing equipment [36].

The Internet of Things (IoT) concept has been followed by the rapid development of relevant sensors. As one of the basic units in the IoT architecture, sensors are mainly responsible for inputting monitoring signals to other devices, specifically in converting physical, chemical, or biological quantities of

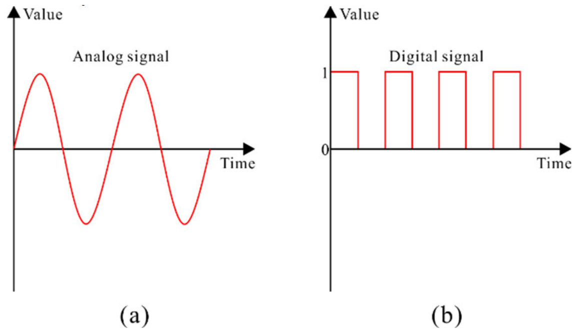


FIGURE 8. Sensor output signal.

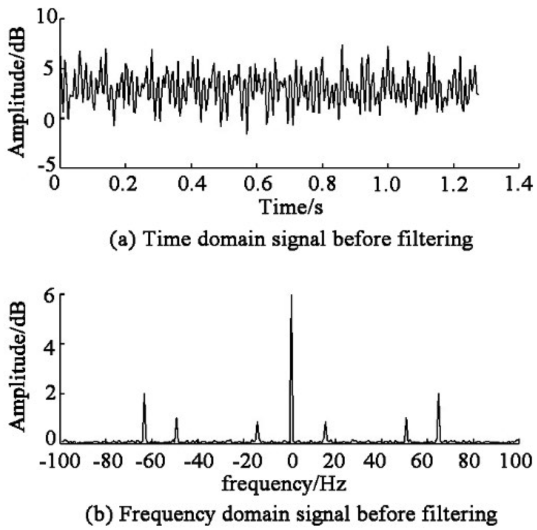


FIGURE 9. Waveforms of output voltage of tension sensor intime domain and frequency domain before filtering.

energy with specific rules. As shown in Figure 8, the output signals of sensors are generally of two types, analog or digital, respectively [37].

By the emulsified oil pumps, pumps, agitators, and other electrical components operating vibration, the pressure sensor output voltage is not a stable DC voltage signal; these vibrations will make the pressure sensor error. The pressure sensor output voltage signal amplified by the conditioning circuit of the time domain and frequency domain signal waveform is shown in Figure 9. Figure (a) in Figure 9 shows the time domain signal before filtering, and (b) shows the frequency domain signal before filtering. From Figure 9, it can be seen that the interference component is the vibration signal whose frequency is not zero.

The stable DC voltage signal can be obtained by filtering out the vibration interference when the pressure sensor works. The FIR technology is used to filter, and the window function is used to add the window processing. The amplitude-frequency curve of the window function is shown in Figure 10(a), and the phase-frequency curve is shown in Figure 10(b).

After the FIR digital filtering of the voltage signal, the time domain and frequency domain signal waveforms are shown

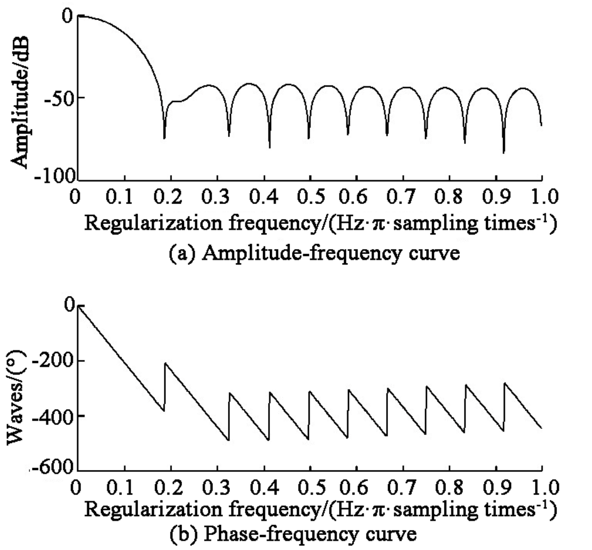


FIGURE 10. Amplitude-frequency and phase-frequencycurves of window function.

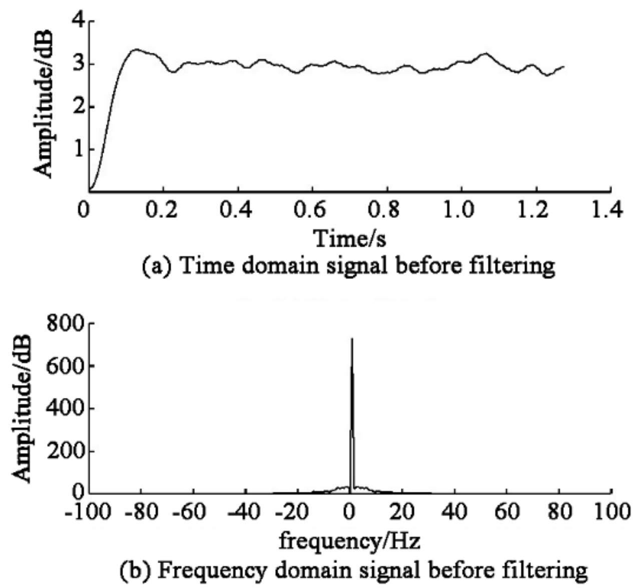


FIGURE 11. Waveforms of output voltage of tension sensor intime domain and frequency domain after filtering.

in Figure 11. In Figure 11, figure (a) shows the time domain signal after filtering, and (b) shows the frequency domain signal after filtering. As known from Figure 11, the high-frequency interference signal brought by vibration has been filtered out, and the DC signal in the filtered signal accounts for the main component, leaving only part of the low-frequency interference.

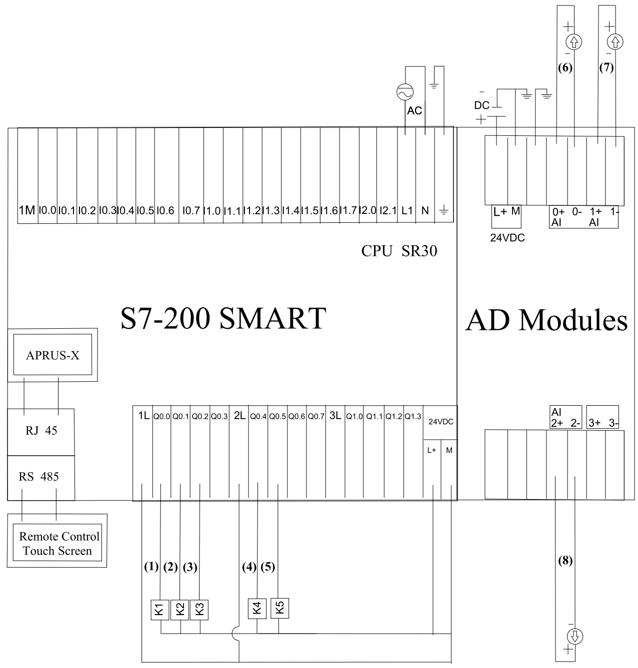
III. HARDWARE DESIGN OF EMULSION AUTOMATIC LIQUID DISPENSING SYSTEM

A. PLC SELECTION AND EXTERNAL WIRING

The central control unit element of the system is a PLC [38] controller. Combined with the market application ratio,

TABLE 1. PLC I/O address assignment.

Serial number	Signal Input		Signal Output	
	Address	Name	Address	Name
1	I0.0	System start-up	Q0.0	Mixers
2	I0.1	System stop	Q0.1	Water storage tank pump
3	I0.2	Mixer start	Q0.2	Water storage tank solenoid valve
4	I0.3	Mixer stops	Q0.4	Solenoid valve for emulsified oil tank
5	I0.4	Inspection signal input	Q0.5	Emulsified oil tank pump
6	AIW16	Water storage tank weight signal		
7	AIW18	Emulsion tank weight signal		
8	AIW20	Emulsified oil tank weight signal		



(1) Agitator control; (2)Water tank pump; (3)Water tank solenoid valve;
(4)Solenoid valve for emulsified oil tank;(5)Emulsified oil tank water pump;
(6)Water storage tank weight collection; (7)Emulsion tank weight collection;
(8)Emulsified oil tank weight collection;

FIGURE 12. PLC external wiring diagram.

the PLC model used for the emulsion automatic dispensing system is the S7-200 SMART series CPU SR30 type PLC from Siemens, Germany, which has an excellent human-machine interface for user operation can be expanded as needed.

After the preliminary demand analysis, the control requirements of the emulsion automatic dispensing system are obtained, respectively, for PLC switch and sensor signal input, PLC control signal output, specific address assignment as shown in Table 1, PLC wiring diagram as shown in Figure 12, where K1∼K5 are intermediate relays.

B. INDUSTRIAL INTERNET PLATFORM DESIGN

Mixlinker network Company from Shenzhen, China, one of the world's leading providers of industrial IoT solutions, aims to solve the problem of protocol conversion of multiple sensor devices with its MixIOT cloud platform for supporting data acquisition work, the platform is responsible for data reception, data storage, data processing, and data application interfaces. At the same time, the platform provides an APRUS-X adapter device, which has a rich data acquisition interface and simple connection and supports compatibility with data acquisition logic and data acquisition protocols through programming. APRUS adapter with interface protocol code written in Lua language can simplify the construction of environmental monitoring systems. The IoT platform has a customized visualization scheme that facilitates the management of sensors and real-time data by managers without programming experience [39]. The MixIOT cloud platform is shown in Figure 13.

APRUS (Advanced Programmable Remote Utility Server) is a programmable adapter with its appearance and interface, as shown in Figure 14. APRUS adapter supports RS485, RS232, and other interfaces and supports configuration compatibility with standard interface communication protocols such as Modbus, CAN, etc. It also supports MQTT, Wi-Fi, and other network protocols for adaptation. Therefore, the APRUS-X adapter is selected as an intermediate hub between the system detection information upstream and signal control downstream, providing the basis for information visualization and remote monitoring of the emulsion automatic dispensing system [40].

C. LOAD CELL SELECTION AND PRINCIPLE ANALYSIS

Load sensors are the most commonly used in production or scientific research and are widely used in various industrial automatic control environments. The resistive strain gauge load sensor is used for the automatic emulsion dispensing and remote monitoring system [41]. The working principle of the

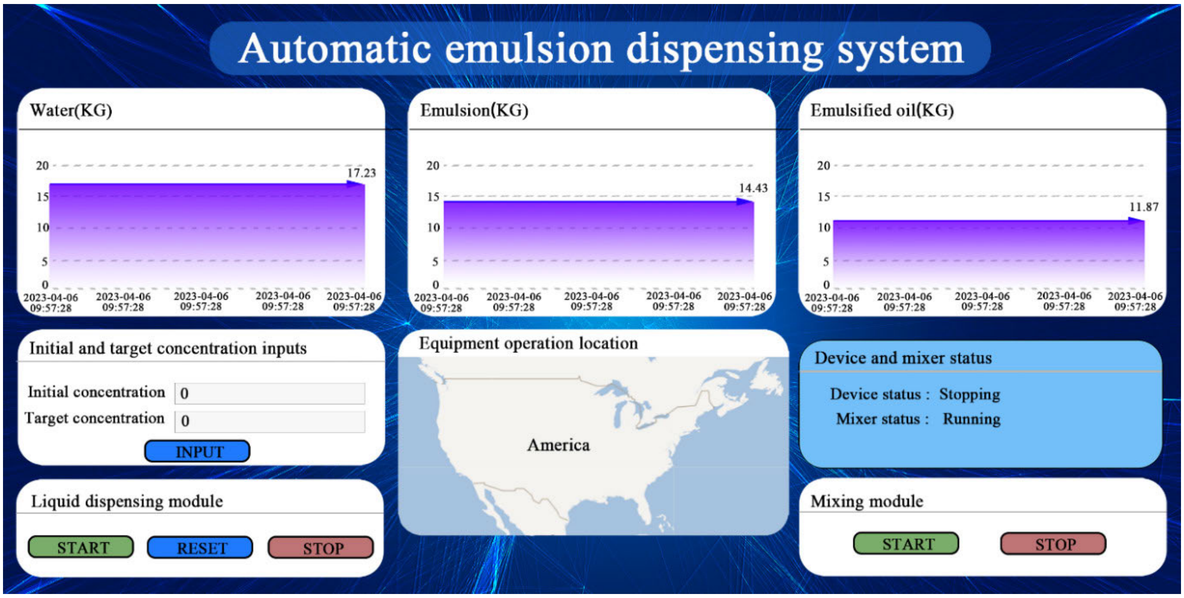


FIGURE 13. MixIOT cloud platform data big screen.

FIGURE 14. APRUS-X adapter.

resistance strain gauge load sensor is that when the elastic element undergoes elastic deformation under the action of external force, the resistance strain gauge attached to the surface of the elastomer is deformed at the same time. After the deformation of the resistance strain gauge, its resistance value changes, and the measurement circuit converts the resistance change of the resistance value of the resistance strain gauge into an electrical signal, thus converting the external force into an electrical signal [42].

When a force deforms a metal conductor, the resistance of the metal resistance wire increases when it is pulled and decreases when it is compressed, the physical phenomenon of the change in resistance value is called the resistance-strain effect of the metal. The evolution of resistance strain gauge is.

$$\begin{cases} R = \rho \dfrac{L}{A} \\ \dfrac{dR}{R} = K\varepsilon \end{cases} \tag{1}$$

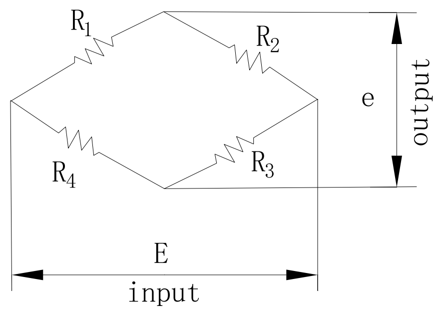


FIGURE 15. Wheatstone bridge.

where: ρ is the resistivity of the metal conductor; A is the cross-sectional area of the conductor; L is the length of the conductor. k is the strain factor or the pressure sensitivity coefficient of the material, also known as the rate of change of resistance. The expression for K yields the sensitivity coefficient when the material is subjected to pressure, which is related to the change in geometry of the material and the change in resistivity of the material after the force is applied.

The Wheatstone bridge circuit is suitable for detecting small changes in resistance, so resistance strain gauge resistance changes can also be detected with this circuit. The Wheatstone bridge circuit, an instrument for accurate resistance measurement, is shown in the Wheatstone bridge diagram in Figure 15.

$$U_0 = \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)} U_i \tag{2}$$

When R1 = R2 = R3 = R4 or R1 *R2 = R3 *R4, the output voltage value e is constant at 0 regardless of the input voltage E. The state of the Wheatstone Bridge at this time is called equilibrium. When the resistive strain gauge

FIGURE 16. Touch screen working interface diagram.

receives an external force to produce strain, the resistance value changes, which changes the output voltage value and, thus, the current value.

IV. SOFTWARE DESIGN OF EMULSION AUTOMATIC DISPENSING SYSTEM

A. TOUCHSCREEN OPERATION PANEL DESIGN

Connect the touch screen and PLC through the RS485 signal line and build the touch screen operating system to realize on-site control; the operation authority of the remote MixIOT cloud platform is higher than the touch screen operation panel to realize secondary control [43]; input the initial concentration and target concentration in the touch screen, click the start button in the concentration proportioning module and the system starts to work, the indicator light of working status is green, the indicator light in the silent mode of the system is to click the start button in the stirring module to start the operation of the mixer, the indicator light is green in the operation mode of the mixer, and the indicator light is red in the silent way of the mixer. The system stops automatically at the end of dispensing. The stirrer needs to be controlled manually because the demand for stirring time differs each time. The date in the upper right corner allows the dispenser to grasp the specific time and control the stirring duration; the touch screen operation panel is shown in Figure 16.

B. WEIGHT DISPENSING METHOD

According to the weight change of water storage tank, emulsion tank and emulsified oil tank for liquid distribution, the weight sensor position is shown in Figure 2, because the initial concentration may be greater than or less than the target concentration when fluid distribution, so when the initial concentration > target concentration, water replenishment operation is carried out, and when the initial concentration < target concentration, oil replenishment operation is carried out, the formula of water replenishment operation and oil replenishment operation are different, so they need to be discussed separately, the water required in water replenishment operation The procedure is shown in Equation (3), and the independent variables are the initial concentration, target concentration and emulsion weight; the formula of emulsified oil required in oil replenishment operation is shown in Equation (4), and the independent variables are the initial concentration, target concentration and emulsion weight, because high-purity emulsified oil is more volatile, flammable and viscosity is not easy to use, so the finished emulsified oil is diluted when it leaves the factory, which leads to the laboratory The concentration of emulsified oil used is not 100%, plus the contact air adsorbs water vapor and carbon dioxide in the atmosphere, so the finished emulsified oil concentration has a certain error, so the oil replenishment operation sets the error coefficient α, α *is* obtained according to the field experiment, to reduce the error formed by the deviation of the emulsified oil concentration and the residual emulsified oil in the oil pipeline, etc. After the experiment, α is taken as 1.05 here, the industrial emulsified oil active substance accounts for 42.2% of the total mass of the industrial emulsified oil.

$$\begin{aligned} \mathrm{C_{tar}} &= \frac{\mathrm{m_1}}{\mathrm{m}_w + \mathrm{m_2}} = \frac{\mathrm{m_2{}^*C}_{ini}}{\mathrm{m}_w + \mathrm{m_2}} \\ &\rightarrow \mathrm{m}_w = \mathrm{m_2}\left(\frac{\mathrm{C}_{ini}}{\mathrm{C}_{tar}} - 1\right) \end{aligned} \tag{3}$$

$$\begin{aligned} \mathrm{C}_{tar} &= \frac{\mathrm{m_1} + \mathrm{m_3}}{\mathrm{m}_o + \mathrm{m_2}} = \frac{\mathrm{m_2{}^*C}_{ini} + \mathrm{m}_o{}^*0.422}{\mathrm{m}_o + \mathrm{m_2}} \\ &\rightarrow \mathrm{m}_o = \alpha\frac{\mathrm{m_2}\,(\mathrm{C}_{tar} - \mathrm{C}_{ini})}{(0.422 - \mathrm{C}_{tar})} \end{aligned} \tag{4}$$

where C_{tar} is the target concentration, C_{ini} is the initial concentration, m_1 is the weight of pure emulsified oil dissolved in emulsion, m_w is the weight of required water, m_2 is the weight of the emulsion; m_3 is the weight of pure emulsified oil in industrial emulsified oil (industrial emulsified oil is added to other solvents in pure emulsified oil to ensure its stable nature for convenient storage and transportation), m_o is the weight of required emulsified oil, and α is the error factor.

C. WEIGHT SCALE TRANSFORMATION

In industrial sites, if the acquired signal is conditioned as a voltage signal and transmitted over a long line, the following problems will arise: first, because the transmitted signal is a voltage signal, the transmission line will be easily disturbed by noise [44], [45]; second, the distribution resistance of the transmission line will generate voltage drops; third, how to provide the operating voltage of the instrumentation amplifier in the field is also a problem. Industrial sites use much current to transmit the signal to solve the above issues and avoid the influence of related noise. The upper limit of 20mA is taken because of the requirement of explosion-proof: the spark energy caused by the current interruption of 20mA is not enough to ignite the gas. In contrast, signal below 4mA and above 20mA is used for the lower limit of alarm of various faults. The reason why 0mA is not taken is to be able to detect a broken line: it will not be lower than 4mA during normal operation, and when the transmission line is broken due to a fault, the loop current drops to 0 mA.

TABLE 2. Experimental data and error of field liquid preparation.

Serial number	Initial concentration（g/100g)	Target concentration（g/100g)	Adding water (KG)	Adding oil(KG)	Temperature (°C)	Humidity（%）	Mixing time（S）	Actual concentration（g/100g)	Error（%）
1	1.8	1	6.4	0	12.7	29	70	1.1	10
2	4.5	2.8	3.38	0	13.1	29	45	3	7.1
3	4.2	3	3.3	0	12.7	29	70	3.2	6.7
4	3.2	1.6	2.94	0	12.7	29	70	1.7	6.2
5	4.1	3	2.7	0	12.7	29	70	2.9	3.3
6	5.8	4	2.26	0	12.7	29	70	4.1	2.5
7	5.3	4.3	1.54	0	12.7	29	70	4.1	4.7
8	6.7	5	1.39	0	13.1	29	30	4.7	6
9	7.3	5.5	1.237	0	12.7	29	60	5.8	5.4
10	3.2	1.6	1.23	0	12.7	29	70	1.7	6.3
11	4.6	3	0.938	0	12.7	29	70	3.2	6.7
12	9.7	8	0.629	0	12.7	29	60	7.5	6.2
13	2.8	5	0	0.1958	13.1	29	134	4.7	6
14	4.5	6	0	0.151	13.1	29	130	5.8	3.3
15	6	7	0	0.1065	13.1	29	95	6.7	4.3
16	3.1	4.1	0	0.25	13.1	29	127	4	2.4
17	4	4.5	0	0.13	13.1	29	100	4.3	4.4
18	3.7	5.2	0	0.093	12.7	29	120	5	3.8
19	5	7	0	0.15	12.7	29	130	6.6	5.7
20	6.5	7.5	0	0.081	12.7	29	120	7.4	1.3
21	7.3	9.5	0	0.201	12.7	29	120	9.7	2.1
22	2.9	4.5	0	0.48	12.7	29	140	4.6	2.2
23	1.8	3.5	0	0.28	12.7	29	130	3.3	5.7
24	3.2	5	0	0.317	12.7	29	130	4.7	6
25	4.5	5.5	0	0.185	12.7	29	130	5.3	3.6
26	0.9	2	0	0.285	12.7	29	130	1.9	5
27	1.6	3.2	0	0.439	12.7	29	130	3.1	3.1
								Average error	4.8%

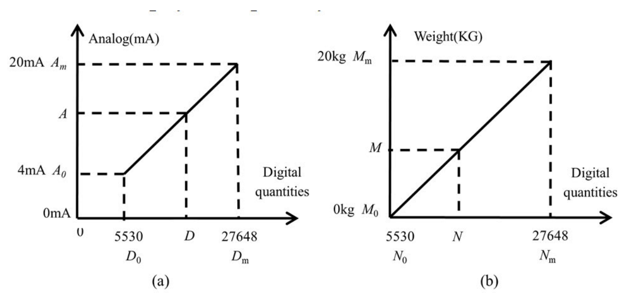


FIGURE 17. Correspondence between analog, digital and physical quantities.

The digital quantity of Siemens S7-200 SMART PLC takes the value range of 0∼27648 because the analog signal is from 4mA∼20mA, so the effective signal range of digital quantity is 5530∼27648 [46]; the correspondence between digital quantity and analog quantity is shown in Figure 17(a), the digital quantity and analog quantity conversion formula are shown in formula (5); the range of the sensor used this time is 0∼20KG, after calibration, 5530 corresponds to 0KG, 27648 corresponds to 20KG, the digital quantity signal conversion real physical quantity formula is shown in formula (6), digital signal conversion real physical quantity correspondence diagram as shown in Figure 17(b).

$$A = \frac{(D - D_0) * (A_m - A_0)}{D_m - D_0} + A_0 \tag{5}$$

$$M = \frac{(N - N_0) * (M_m - M_0)}{(N_m - N_0)} \tag{6}$$

where A is the actual analog quantity, D and N are the actual digital quantity, M is the actual physical quantity, A0 is the lower limit of analog quantity, Am is the upper limit of analog quantity, D0 is the lower limit of digital quantity, Dm, Nm are the upper limit of digital quantity, and M0 is the lower limit of physical quantity.

V. LABORATORY EXPERIMENTS

By setting up the automatic emulsion dispensing system in the laboratory and testing the on-site and remote control, and conducting the dispensing experiments at a room temperature of 13°C and relative humidity of 29%, a total of 27 dispensing experiments were conducted, of which 12 were automatic water addition experiments with the target concentration less than the initial concentration, and the maximum error at the end of the 12 experiments was 10%, the minimum

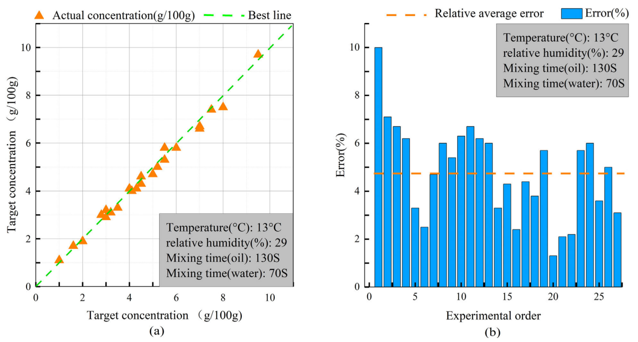


FIGURE 18. **Scatter plot of target and actual concentration with error histogram.**

error was 2.5%, and the average relative error was 5.9%. The remaining 15 groups of experiments were automatic emulsified oil addition experiments with the initial concentration less than the target concentration. The maximum error was 6%, the minimum error was 1.3%, and the average relative error was 3.9% at the end of the 15 groups of experiments. In comprehensive 27 groups of experiments, the minimum error is 1.3%, the maximum error is 10%, the average relative error is 4.8%, and the average relative error formula is shown in equation (7); the experimental data and errors are shown in Table 2; the target and actual concentration scatter plot is shown in Figure 18 (a), and the error histogram is shown in Figure 18 (b) [47], [48], [49].

$$Er = \frac{\sum_{i}^{n} \frac{C_{ini}^{i} - C_{tar}^{i}}{C_{tar}^{i}}}{n} \tag{7}$$

Er is the mean relative error, C_{ini} is the actual concentration, C_{tar} is the target concentration, i is the experimental sample order, and n is the total number of experimental samples.

VI. CONCLUSION

(1) MixIOT cloud platform control and on-site touch screen control to realize secondary control, the experimental effect is good, and the delay of remote real-time data display and real-time control is negligible to meet the monitoring needs. Compared with the traditional manual downhole liquid dispensing operation, it can effectively reduce the downhole staff and realize intelligent monitoring.

(2) This test uses high precision weight sensor as the input unit. It uses FIR digital filtering technology to filter out the influence of the emulsion pump, water pump, inherent vibration of the testing device, and external vibration to improve the measurement accuracy; after 27 times of dispensing tests, the average relative error is 4.8%, which meets the requirement of practical application. This proves that the weight sensor can be used as the signal input unit of a physical quantity in the automatic emulsion dispensing system, and the experimental accuracy meets the requirements.

(3) The critical parts of the built emulsion automatic dispensing system adopt electronic components with a high degree of automation, high controllability, and low failure rate for the dispensing task, and there are no redundant electronic components, so the degree of automation is high, the failure rate is low, and the operation is convenient.

VII. LIMITATIONS AND FUTURE RESEARCH REVERSE

In the preliminary construction of the model, after much searching, did not find suitable for the laboratory use of emulsion concentration real-time sensors, only to find suitable for coal production of large emulsion concentration real-time sensors because its size is too large and expensive not suitable for laboratory use, so this is a limitation of the place. If the emulsion concentration real-time sensor is added to the system, the degree of intelligence of the automatic emulsion dispensing and remote monitoring system can be significantly improved, and the use more efficient, so in the future, we can focus on the study of small emulsion concentration real-time sensor and add it to the system.

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