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Design of Real-time Detection System for Hemodialysis Machine Operating Parameters

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Abstract: Hemodialysis technology has been widely used, and more and more patients requiring hemodialysis have been treated, saving the lives of many patients. This paper studies the real-time detection and analysis techniques for key parameters of hemodialysis machines, focusing on several key parameters such as dialysate conductivity, pH, temperature, static (pulse) pulse pressure, flow rate, and line pressure in hemodialysis machines. . The detection system consists of two parts: hardware and software. The hardware part mainly includes data acquisition and computer interface. The software section mainly includes embedded data processing programs and displays. The hardware part mainly consists of a power module, a temperature module, a pH module, a conductivity module, a standard pressure module, a static (dynamic) pulse pressure module, a flow module, a wired communication module, and a wireless communication module. The main functions of the software are real-time acquisition and processing and display of relevant measurement parameters. The calibration data file is automatically generated based on the relevant parameters.

Keywords Hemodialysis machine; Operating parameters; Real-time detection; Hardware and software design

INTRODUCTION

In human physiological diseases, renal diseases are common diseases such as renal failure, renal insufficiency, pyelonephritis, and the like. Renal failure is a serious disease and one of the major life-threatening conditions [Holmer M et al., 2016]. It causes difficulty in the discharge of metabolic waste from the human body, electrolyte and acid-base imbalances, and uremia, coma, anemia, gastrointestinal bleeding, and edema.

For the treatment of renal failure, hemodialysis treatment is widely used in clinical medicine [Dahlke M et al., 2016]. With hemodialysis machines, metabolites in the blood, abnormal plasma components, and accumulations of drugs or poisons in the body are eliminated. It can correct electrolytes in the body and maintain acid-base balance. The basic principle of a hemodialysis machine is to draw blood out of blood vessels, introduce a dialysis filter with osmotic function, remove the waste in the blood by ion exchange, and then inject the blood back into the blood vessel.

The accurate and reliable measurement performance of hemodialysis machines is directly related to the patient's treatment effect and emergency control [Chen Y X et al., 2018]. Due to the extensive use of hemodialysis machines, its quality control issues have caused widespread concern among technical departments, medical institutions, and manufacturers. The development of the quality control system for hemodialysis machine operating parameters has become a hot research direction.

Therefore, this paper studied the parameters calibration of dialysate conductivity, dialysate temperature, static (pulse) pulse pressure, dialysate pressure, dialysate flow, and dialysate pH of hemodialysis machines. The research results can make up for the lack of a single parameter detection system for hemodialysis machines. The purpose is to improve the efficiency of testing and to ensure that the data provided by the hemodialysis machine for clinical treatment is scientific, objective, accurate, reliable and effective and meets relevant requirements.

REQUIREMENTS ANALYSIS OF OPERATIONAL PARAMETER DETECTION

The physical parameters of the normal operation of the hemodialysis machine are: conductivity, temperature, pH, dialysate pressure, dynamic (static) pulse pressure, and flow rate. According to the analysis of the working principle of the hemodialysis machine and the control of the physical parameters, the proposed detection of operating parameters is shown in Figure 1.

The physical parameters involved in dialysate detection can be partially integrated. Temperature sensors, flow sensors, and dialysate pressure sensors can be integrated and combined into one pipeline for simultaneous testing. Because the conductivity sensor

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and pH sensor are relatively large, they cannot be integrated into one pipe. The static/arterial pressure sensor and the prime pump injection flow sensor may not be integrated into one pipe and remain external.

For each signal collected by the sensor, a calibration function, a calibration function, and an interpolation function are separately prepared and used to process the signal processing collected by the sensor. At this stage, hemodialysis machines rely on single-parameter multiple detectors for calibration. Therefore, the parameter detection work is relatively cumbersome. For this reason, we have developed a multi-parameter real-time acquisition that sends the sensor's signal to the host computer at the same time. Due to the large amount of data collected, it is difficult to achieve data transmission.

DETECTION SYSTEM HARDWARE DESIGN

Overall Structure

The detection system can calibrate the six key parameters such as dialysate conductivity, dialysate temperature, dialysate pH, static pressure, dialysate pressure, and dialysate flow rate of the hemodialysis machine. Each parameter detection module in the hemodialysis machine detection system is independent of each other and can simultaneously measure the parameters. However, these parameters are linked and mutually corrected. For example, conductivity, pressure, and pH all require temperature parameters to correct them to ensure their accuracy. Hemodialysis machine detection system design block diagram shown in Figure 2.

The data acquisition part consists of six measurement modules, a microcontroller and a conversion circuit. High-precision, high-sensitivity sensors in the measurement system's measurement module detect the conductivity, temperature, pressure, flow, and pH of the dialysate. The output signals of these sensors are converted by the conversion circuit into digital signals that can be recognized by the microcontroller. After processing the signal by the SCM, it is transmitted by the RS232 to the embedded system. The multi-threaded mode of the embedded system LCD screen shows the value of each parameter. And, the measurement data adopts multi-channel parallel acquisition technology. This achieves mutual correction and calculation of data. The detection system can communicate with the computer via wireless or USB to facilitate computer data processing.

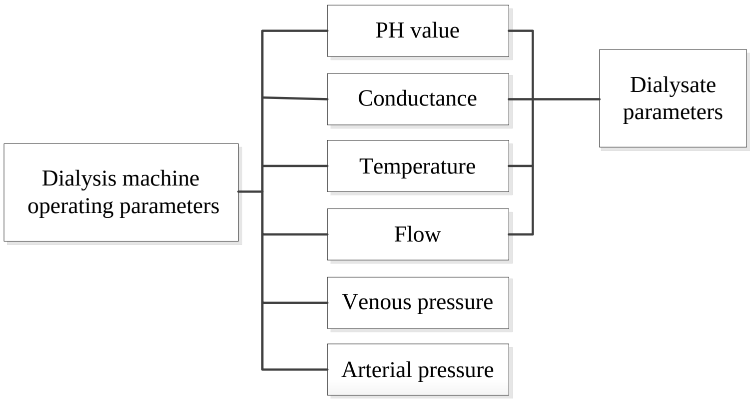

Figure 1 Dialysis machine operation detection parameters

Conductivity Measurement

In the field of applied physics and engineering technology, conductivity or conductivity is generally used to measure the conductivity of ionic conductors. The index of conductivity of the dialysate of the hemodialysis machine is used to control the electrolyte of the dialysate. The conductivity definition expression is

$$G = \frac{\sigma}{K} \tag{1}$$

where σ is the electrical conductivity in S/cm and is used to describe the conductivity of the conduction current, K is the cell constant.

The size of the conductivity is related to the type of ion, and also related to external factors that affect the ion, such as temperature, solvent, and Bot. Temperature is the most important external factor that affects the conductivity of the solution. As the temperature increases, the heat of ionization increases and the electrical conductivity increases. When the measured object is not changed, the conductivity of the solution at 25 ℃ is usually taken as the standard conductivity. When the water temperature is not 25 ℃, in order to unify the conductivity, it is necessary to carry out temperature compensation and convert the conductivity to the conductivity at 25 ℃.

Temperature Measurement

Temperature is a very important physical quantity, which reflects the degree of hot and cold matter . Also, in many parameter measurements, temperature can be corrected for other parameters. In production, all links are related to temperature. Therefore, people attach great importance to temperature measurement. Temperature measurement methods are classified into two types: contact temperature measurement and non-contact temperature measurement. This design uses a platinum resistance of a contact temperature sensor.

The relationship between the platinum wire resistance and the temperature is expressed as

$$R_t = R_0[1 + At + Bt^2 + C(t-100)t^3] \quad (2)$$

where, R_t and R_0 are the platinum resistance values when the temperature is t and 0 ℃, and A, B and C are constants.

PH Measurement

During measurement, a chemical battery is formed between the two electrodes, according to the principle of electrochemical analysis. The voltage difference between the electrodes follows the Nernst equation.

$$E = E_0 - \frac{2.30259RT}{F} \times pH \quad (3)$$

where, E is the electrode potential, E_0 is the standard electrode potential, R is the molar gas constant, T is the absolute temperature, F is the Faraday constant, and pH is the PH of the solution.

Static (Dynamic) Pulse Pressure and Pressure Measurement

Pressure sensors are the most commonly used sensors in the fields of industrial production, environmental monitoring, special pressure detection, and multi-functional test instruments. There are a wide variety of pressure sensors, including strain gauge pressure sensors and semiconductor strain gauge pressure sensors. Among them, piezoresistive pressure sensors are the most widely used, with low prices and good linearity.

Static (dynamic) pulse pressure and dialysate pressure measurement sensors are selected piezoresistive pressure sensors; the output mode is 4-20mA current output. The voltage line AD is used, so the current must be converted to voltage.

DETECTION SYSTEM SOFTWARE DESIGN

Overall Structure

Software systems include: menus, toolbars, view windows, status bars, and floating dialogs. The main problems solved by the software system are communication protocol, parameter initialization, data processing, data display, image display, data analysis, data storage and reading.

System Module and Function

According to the overall design of the hemodialysis machine quality control program and internal data processing, the system module has a total of seven parts. The system module structure is shown in Figure 3. According to the requirements of the quality control of the hemodialysis machine, the software system must have seven basic functions: communication protocol, data initialization, data processing, data display, image display, data analysis, data storage read and write functions.

The communication protocol module solves the data exchange function, realizes the control of the lower computer and collects data. The module uses the serial port for data communication, parameter configuration of the communication port, data structure for communication, and data exchange.

The parameter initialization setting function module can set the flow rate, pressure, temperature, conductance, pH collection cycle, and single data measurement interval.

The data processing function module builds a function module for data processing such as volume scale, interpolation calculation, data statistical analysis, data display conversion, and the like for the collection signals of flow rate, pressure, temperature, conductance, and pH.

The data display function module changes slowly due to temperature, conductivity, pH, and other data, and only displays numerical values. The image display function module displays the data of the dialysate flow and pressure for the visualization of the data. The data saving and reading function module measurement data has a data saving function and a data opening function. The data analysis function module can perform error calculations on the selected data.

Systematic Logic Design

The logical structure of the software test system is designed to meet the requirements of the physical parameters of the hemodialysis machine, environmental conditions, and data processing requirements. The system is divided into logical units according to the requirements of functional analysis and logical requirements, and each realizes its own function.

The function module is designed on the software interface, and directly controls the parameters, conditions, test functions, data display, etc. required for the test, and the user is directly and conveniently

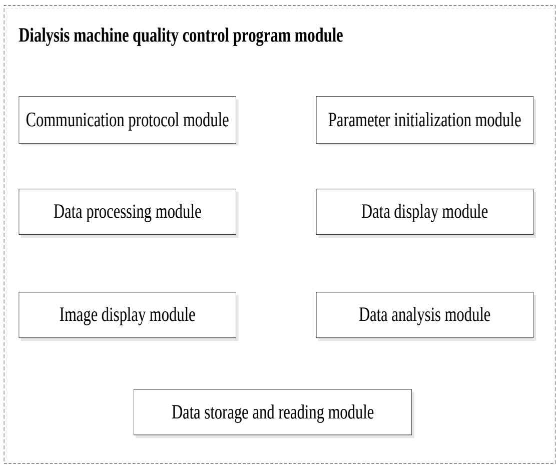

Figure 3 Hemodialysis machine

used. The choice of measurement method directly determines the data display and processing mode. The function of the floating dialog box solves the data recording, storage, and data analysis processing at the bottom. The view display will show the flow, stress test images. The status bar shows the selected flow and pressure test values for reading and displaying.

CONCLUSION

This article has carried on the thorough research to the hemodialysis machine key parameter detection analysis technology. First of all, introduce the measurement principles and test methods of several key parameters such as conductivity, pH value, temperature, static (pulse) pulse pressure, flow rate, and line pressure of hemodialysis machines. Then, the demand analysis of the quality control of the hemodialysis machine, hardware design of the detection system, software design, software implementation, and software testing were studied. The next research question is to choose a high-precision measurement sensor to improve the measurement accuracy.

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