Implementation of Signal Detection and Control of Bioartificial Liver Support System

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ABSTRACT

Liver failure is an extremely dangerous disease whose mortality rate is 73.9% and the rate of acute liver failure is as high as 87.8%. As the only effective way to treat liver failure, liver transportation is facing a serious shortage of donor. As an extracorporeal circulation device, artificial liver support system could effectively replace the patient's liver in a short period of time so as to improve the survival rate of patients greatly. At present, the control core of the artificial liver control system is PLC. However, with the increasing complexity of functions and demands, the control system based on PLC will gradually show some disadvantages in cost, safety, reliability, stability, real-time Performance and other aspects which will restrict the development of artificial liver. Aiming at the deficiencies in the existing control system, a bio-artificial embedded control system based on ARM and CPLD was designed and implemented in this study, completes the hardware design, PCB design and control program writing, and designs the safety control loop to improve the control system Reliability. The experimental results show that performance of the control system has been improved to a certain extent in terms of safety, reliability, stability and real-time performance. Meanwhile, the cost of control system is lower, which is conducive to the market promotion of artificial liver.

CCS CONCEPTS

• Applied computing; • Life and medical sciences;

KEYWORDS

Bioartificial liver, Signal detection, Embedded Control, ARM, CPLD

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1 INTRODUCTION

As one of the most important organs of human body, the liver has functions of synthesis, detoxification, metabolism, secretion, biological transformation and immune defense. However, when the liver is severely damaged by a variety of factors, (such as virus, alcohol, drugs, etc.), it will cause massive necrosis of liver cell, lead to serious liver dysfunction, and then develop into liver failure. The mortality rate of liver failure is as high as 73.9%, among which the mortality rate of acute liver failure is as high as 87.8% [1]. At present, the only effective way to treat liver failure is liver transplantation. However, the primary problem of liver transplantation is lack of donor, which severely restricts the clinical application of liver transplantation [2]. More than 300,000 people in our country desperately need liver transplants every year to save lives. However, only a few thousands of people have received the transplant successfully, 50% of the remaining receptors died within a year [3]. This contradiction between supply and demand makes liver transplantation difficult to become the main therapeutic approach for liver failure in the short term.

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Figure 1: Topology of Control System.

The artificial liver support system uses extracorporeal circulation to draw blood that should normally flow into the human liver to the artificial liver, and when the blood flows through the artificial liver, it is returned to the body. Thus, the purpose of using artificial liver to replace the patient's liver for a short time is achieved. Nowadays, artificial liver treatment has been widely used in the treatment of liver failure [4, 5]. At present, different types of artificial liver have entered the phase I to III clinical [6], mainly including HepatAssist 2000 [7], ELAD [8], BLSS AMC-BAL [9], Hybrid LSS-MELS systems, etc [10]. The core controller of the artificial liver control system is mostly PLC(programmable logic controller). The control system with PLC control core has the characteristics of simple programming, strong adaptability, and easy to build a platform [11]. However, with the increasing complexity of the artificial liver function, the increasing demand in control requirement, the PLC system with modular control will gradually show some disadvantages in terms of cost, safety, reliability, stability, real-time Performance and volume of control unit, which limits the development of artificial liver. For this reason, a new artificial liver system control scheme is proposed in this paper, the function of artificial liver is realized based on ARM and CPLD, and the performance optimization is carried out for the deficiency of existing control system.

2 CONSTRUCTION OF HARDWARE PLATFORM

Artificial liver control system mainly includes controller, human-machine interface, peristaltic pump, heparin pump, valve, fastener, protocol communication type sensor, level sensor, heating plate, alarm indicator, solenoid valve, safety circuit, etc. The topology structure of the control system is shown in Figure 1. Among them, the main processor adopts ARM9 kernel S3C2440, the main task of which is to control the scheduling of the system, detect and calculation processing System sensor data, issue peripheral control module control instruction, control alarm system signal; the secondary treatment adopts EPM1270, the main task of which is to control peristaltic pump, heparin pump, pinch valve, fastener,

heating plate and other devices; AD7606 is a 16-bit bipolar AD acquisition chip, which mainly used for the detection of heparin pump position and data collection of PT100 temperature sensor.

The peristaltic pump actuator adopts YZ-ACSD608, the motor of it is 24V to three-phase AC motors, and pulse + direction control mode is adopted; the clamp valve and lock driver adopt DKC-230A, its motor is stepping motor, and it adopts point control mode; heparin pump drive adopts SMD-202M, the motor is stepping motor, and pulse + direction control mode is adopted; heating plate adopts heater band with 24V and 100W, its sensor adopts PT100 that precision is 0.1°C.

2.1 Communication Between Modules

In the design of the control system, we first treat the EPM1270 and AD7606 as storage with high bandwidth external storage interfaces, and then extend EPM1270 and AD7606 to Bank2 and Bank3 respectively in S3C2440, the starting address is set to 0x10,000,000 and 0x18,000,000. In the end, extend 16-bit system bus through hardware, in order to achieve the communication between S3C2440, EPM1270 and AD7606. The connection mode is shown in Figure 2

Main controller connects with touch screen and protocol type sensor by RS-232 and RS-485, The agreement voltage conversion chip is used for MAX3232 and MAX485 respectively. The communication between the main controller and the touch screen is designed with the identification code and the CRC test code. MODBUS protocol communication is used between master control and protocol type sensor.

2.2 Acquisition Circuit of Heating Plate Temperature

The heating plate temperature sensor used in artificial liver is PT100 platinum resistance temperature sensor, precision of which is 0.1°C. It is mainly used to feed the heating plate temperature to achieve the purpose of providing stable temperature environment for circulating plasma and biological reaction tank. The heating plate temperature acquisition circuit first collects the voltage value of PT100, In turn, after amplifying the voltage signal, the signal is

Figure 2: Block Diagram of System Bus Connection.

Figure 3: Schematic Diagram of Preamplifier Circuit.

converted with AD, the data is converted to temperature, and the temperature data is read in the main controller. The preamplifier circuit is shown in Figure 3. The amplification circuit adopts single - power supply for LM358. In order to improve the linearity of amplifying circuit, a two-stage amplification circuit is adopted, The first level amplifies the small signal collected, and the magnification is 11, magnification of the second stage is 3, a total of 33. After amplification, the signal is converted by AD7606 channel 4. By adjusting the adjustable resistor of 200 Ω , amplifying circuit for zero point correction, improving the accuracy of amplifying circuit.

2.3 Design of Safety Circuit

In the control system, the main controller can monitor bubbles, liquid level and blood supply shortage sensors through external interruption, When the state of the sensor is alarm, it enters the safety protection program to perform the operation of the peristaltic pump to ensure the patient's safety. However, when the controller fails to respond to the alarm interrupt signal in time, the peristaltic pump cannot be suspended in time to bring danger to the patient. Therefore, a separate hardware safety circuit is set to avoid the above situation. The safety circuit is shown in Figure 4 .

The enable end of the peristaltic pump operation is formed by the combination of the main controller and the sensor level series signal through the AND gate.. When the sensor sends an alarm signal, in order to provide the main controller with the appropriate time to respond to the interrupt, the hardware signal after the serial connection will act on the peristaltic pump enable terminal after a delay of about 1.1s. In this way, it avoids the system reliability due to too sensitive safety circuit.

The delay circuit is shown in Figure 5. With the 555 timer, the output control signal is changed as the capacitor C1 voltage increases and the resistance R21 voltage changes to about 1.66 V. Resistance R21 voltage varies with time as in formula (1), when $C1=100\mu\text{f}$, $R21=10\text{k}\Omega$, delay time is about $T \approx 1.1 \times \tau = 1.1 \times RC = 1.1\text{s}$.

$$U_r = U_{alarm}(1 - e^{-t/RC}) \quad (1)$$

3 SOFTWARE PROGRAMMING

The design of artificial liver software includes the design of the upper computer monitor screen and the control program of the lower computer. The upper computer adopts LABVIEW to design

Figure 4: Schematic Diagram of Safety Circuit.

Figure 5: Schematic Diagram of Alarm Signal Delay Circuit.

the monitoring interface, and implement the command, data transmission and data reading. The lower computer realizes control and detection of peristaltic pump, clamp valve, heparin pump, sensor, heating plate and so on.

3.1 Control Algorithm of Peristaltic Pump and Heparin Pump

The peristaltic pump in the artificial liver adopts a pulse + direction control method. The main controller S3C2440 achieves the purpose of controlling the different frequency pulse of EPM1270 by adjusting the frequency count comparison of the secondary controller

EPM1270 memory, then the control of the rotational speed is realized. The memory bandwidth is 16 bits and the highest position is the direction control, 1 indicates that the peristaltic pump rotates in the forward direction, and 0 indicates that the peristaltic pump rotate in the reverse direction; the lower 15 bits represent the size of the divider. Among them, the calculation formula of frequency counting is shown in formula (2) :

$$C = \frac{50000000}{2K_a} \times \frac{1}{2 \times P_a \times Q} \quad (2)$$

50,000,000 represents the EPM1270 clock frequency; K_a represents the division frequency coefficient of EPM127; P_a Indicates the pulse frequency required when the peristaltic pump flow is set to 1ml/min;

Q represents the amount of traffic to be set. The control parameters of the creep pump are set as follows: $K_a=3$, $P_a=60$; the control parameters of heparin pump are as follows: $K_a=60$, $P_a=3.19$. The value of the divider is 15 bits, so the range of data is 0~32,737, according to the formula (2), the minimum flow rate of the peristaltic pump can be approximately 2.2ml/min; the minimum flow of heparin pump can be approximately 1ml/h, all can satisfy the system requirement.

3.2 Rotation Pump Control Algorithm

The artificial liver rotary pump also adopts pulse + direction control. However, the data that needs to be set during operation is the rotation period, which controls 180° periodic operation of the rotary pump. The calculation of the numerical value of the rotary pump divider is as the formula (3) :

$$C = \frac{50000000}{2K_a} \times \frac{1}{2 \times f} \quad (3)$$

$K_a=3$; f Indicates the frequency of the pulse that needs to be set. The directional switching limit signal of rotary pump is provided by three photoelectric switches. When the rotation is in place, the photoelectric switch provides the signal and the rotation direction is switched in EPM1270. The rotation period and pulse frequency are not linear due to the delay of the switching instantaneous. The calculation formula of the pulse control frequency and the rotation cycle of the rotary pump are obtained through the measurement and the segmentation of the data, as shown in formula (4):

$$f = \begin{cases} -34.24 \times T + 1712.2 & (20 < T \leq 30) \\ -102.73 \times T + 3082 & (10 < T \leq 20) \\ -408.26 \times T + 6137.3 & (5 < T \leq 10) \\ -4095.95 \times T + 24590.75 & (1 < T \leq 5) \end{cases} \quad (4)$$

3.3 Program of Sensor Data Reading

When the artificial liver system is in operation, it is necessary to constantly collect the data of the sensor to monitor the normal operation of the instrument. The detection process is shown in Figure 6

The system adopts MODBUS protocol, which reads the data of pressure, weighing, PH, DO, blood leakage and other sensors in the form of polling. The process of reading instruction send and state judgment are implemented in the timer interrupt, the process of reading instruction send and state judgment is implemented in the timer interrupt. When a sensor does not respond to a system's read command for three consecutive times, it is determined that the sensor is running abnormally, and the ALARM_REMIND status is sent to the monitor screen and the yellow alarm indicator light is lit.

3.4 Interrupt Priority Setting

There are 12 external interrupts and 2 timer interrupts in artificial liver control. The safety, real time, and reliability of the system operation can be guaranteed only by the proper allocation of interrupted priorities. According to the speed and importance of corresponding function to each interrupt in the artificial liver, the priority of the configuration system interrupt is shown in Table 1 from high to low:

By configuring the register PRIORITY of S3C2440, the PRIORITY of each interrupt signal in ARB_SEL6 is setting as 0-2-3-1-5, and the priority rotation enable of ARBBITER6 is turned off to realize the configuration as shown in the table.

4 EXPERIMENTAL RESULTS AND ANALYSIS

Debug the control panel installed on the design. Experiments mainly aimed at the peristaltic pump flow, heparin pump flow, rotary pump cycle, the heating plate temperature control, electromagnetic valve on-off, clip pipe valve switch, protocol sensor communication, level sensor alarm, blood pump and rotary pump speed control, safety circuit etc.

During the experiment, when peristaltic pump flow was set to 5ml/min, 50ml/min, 100ml/min, 200ml/min and 250ml/min, the error remains within the range of -4.7%~+ 4.71%, which meets the requirements of the system -5% ~+ 10%; when the flow of heparin pump was set at 1ml/h, 10ml/h and 20ml/h respectively, the error remains at -4.6%~+ 0.2%, which satisfies the requirements of the system -5% ~+5%; when the rotary pump cycle was set to 18s, 20s, 22s, 24s, 26s, 28s and 30s respectively, the error remains at -0.25%~+ 5.11%, which meets the requirements of the system -10%~+10%; when the flow of blood pump is 50 ml/min, the heating plate temperature was setting to 35 °C, 36 °C and 37 °C respectively, heated liquid temperature fluctuations in value plus or minus 0.1 °C scope, meet the system requirements; The safety circuit is tested by turning off the sensor in S3C2440, When the sensor alarms, the peristaltic pump stops rotating about 1s later The function of the safety circuit meets the design requirements; Under the condition of normal operation of the artificial liver components, the fatigue test was carried out for 4 consecutive days. During the experiment, the system was operating stably without failure.

5 CONCLUSION

Based on the deficiencies of existing artificial liver control system in terms of cost, safety, reliability, stability, real time, scalability etc., this paper proposes a brand-new biological artificial liver embedded control system based on ARM and CPLD. The main control circuit and peripheral module circuit are designed and implemented, and corresponding control methods and algorithms are designed for each module, and finally installed for testing. After testing, its safety, reliability, stability real-time, and other aspects are correspondingly improved compared with the existing artificial liver system, and the control accuracy meets the system requirements. The control system based on ARM and CPLD greatly reduces the cost of control unit, which brings benefits to the promotion and industrialization of artificial liver systems. At the same time, the control unit is smaller in size, which is more conducive to optimizing the mechanical structure of artificial liver, and brings convenience to the overall appearance of the artificial liver system and system writing.

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Figure 6: Block Diagram of Sensor Detection.

Table 1: The Table of Interrupt Priority Configuration.

Interrupt group	Interrupt	System function
ARBBITER0	EINT_0	Insufficient blood supply sensor alarm
	EINT_1	Bubble sensor alarm
	EINT_2	Liquid level sensor alarm
ARBBITER2	uart2 reception	The main control chip receives the touch screen command
ARBBITER3	DMA	The main control chip sends data to the touch screen
ARBBITER4	uart1 reception	Modbus protocol sensor receive data
ARBBITER1	EINT_4	Increase blood pump flow
	EINT_5	Reduce blood pump flow
	EINT_6	Increase cycle pump cycle
	EINT_7	Reduce cycle pump cycle
	EINT_9	The AD7606 transform is completed
	EINT_18	Send sensor reading instructions through uart1

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