Design of a Low-cost Control System of Automatic Blood Component Fractionation Machine based-on MCU

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Abstract

Since there are many flaws in traditional blood fractionation method, such as a complicated operation, the results are not accurate, and non-standard information recording, etc. The low-cost blood fractionation machine has good research significance.

This paper proposes a low-cost control system of automatic blood fractionation machine to solve these problems. Up to more than one hundred of automatic blood fractionation machines can work together through CAN network connections, and all these machines can be centralized control by a PC. The control system of this machine is designed based on C8051F040 MCU, a kind of SOC with many AD interfaces, DA interfaces, digital IO interfaces, etc.

For the scalability and flexibility of the system, each sub-process of blood fractionation is realized by a sub-program, and the whole fractionation process can be flexibly programmed by users for special demand. The software of the control system uses a modular design method, propoes four states to realize workflow control.

In order to meet the requirements of blood bank blood fractionation requirements, the process of blood fractionation is accurate, precise, and standard, the records of every produced blood component bag is very detailed, and can be easily traceable.This system can produce the blood components meeting to the management standard of the Blood Bank, and has been shown adaptable in various blood bag systems.

Keywords: *Blood Components Fractionation, MCU, Control system*

1. Introduction

Human blood is formed of complex elements: erythrocytes, lymphocytes, granulocytes and platelets of plasma proteins, *etc.* [1]. After a low speed centrifugation, the whole blood(WB) can be mainly layered into three parts--the red cell concentrates (RCC), platelet-rich plasma (PRP) and buffy-coat (BC). And after a subsequent high-speed centrifugation, the PRP can be layered into two parts--platelet concentrates (PCs) and platelet poor plasma (PPP) [2]. The automatic blood component fractionation system can separates these components from the centrifuged whole blood (WB) automatically. Comparing with ordinary manual fractionation method, the automatic blood component fractionation system has a lot of advantages: the fractionation is precise and efficient, the products are standardized, the documentation of process data can come into being automatically [3,4].

Pasqualetti Evaluates a new blood components fractionation device, the result shows that this device is fast, easy to operate. The device can reliably generate corresponding blood components, and has been proved to be suitable to use a different blood bag system [5].

Hurtado analyzed the quality of blood components processed by a top & bottom system, test whether the components reached the recommended quality [6].

The process of the fractionation is shown in the Figure 1. After centrifugation at a low speed, the WB in a bag can be delaminated into three layers, then the top of the bag is the PRP, and the bottom of the bag is RCC, while a small quantity of BC is lying between them. The automatic blood component fractionation system uses the standard of quadruple bag systems, which are WB bag (also used as RCC bag), PRP bag, BC bag and the maintaining liquid bag.

At first, the delaminated WB bag is hung between an immovable board and two movable boards--the lower press board and the higher press board. The other bags are hung separately with tubes placed in the proper valve. There are five valves used in this process. The machine opens the valve 1, 4, 5 and closes the other valves, so the blood will be pressed into the PRP bag. The automatic blood component fractionation system presses the movable boards separately or both (chosen by user), and detecting the interface of PRP and BC simultaneously by one of the eight detectors (one placed in valve 5, seven placed in the movable boards).

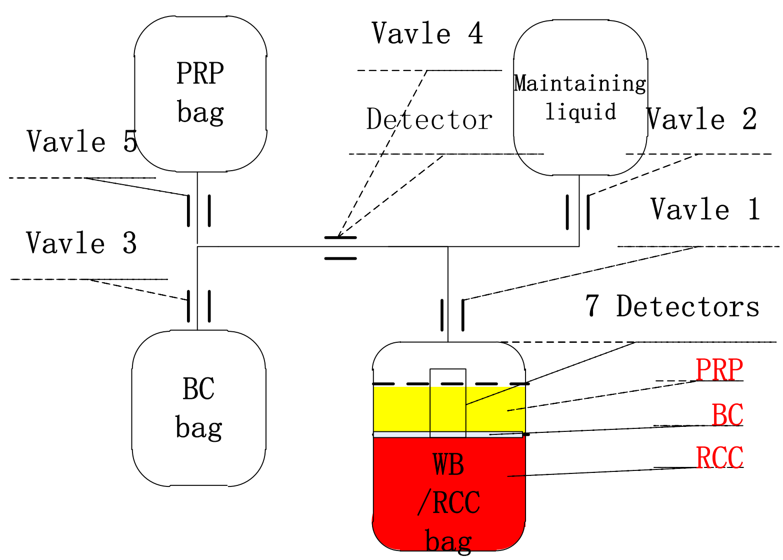

Figure 1. The process of fractionation

When the machine detects the interface come to the proper situation, which means all the PRP has been pressed into the PRP bag, the valve 5 will be closed while the valve 3 will be opened, then the blood will be pressed into the BC bag. When the interface of RCC is detected, the valve 3 will be closed. The maintaining liquid can be press into the RCC bag if needed. Then the valve 1, 3 and 5 will be sealed and these components are separated automatically.

2. Architecture of automatic blood component fractionation system

To meet with requirements of Blood Banks for blood component preparation, the fractionation should be precise and standard, the records of the process data must be saved into the detailed database. These data base makes management easy and can export the report forms flexibly. Figure 2 shows the architecture of the blood component fractionation system designed in the paper, approximately 100 fractionation machine can be connected through CAN bus [7, 8], A PC controller is connected to the CAN bus using a CAN to 232 converter. The CAN network provides high transmits rates and good reliability. These fractionation machines are managed by one PC, so the separation is highly unified and standardized.

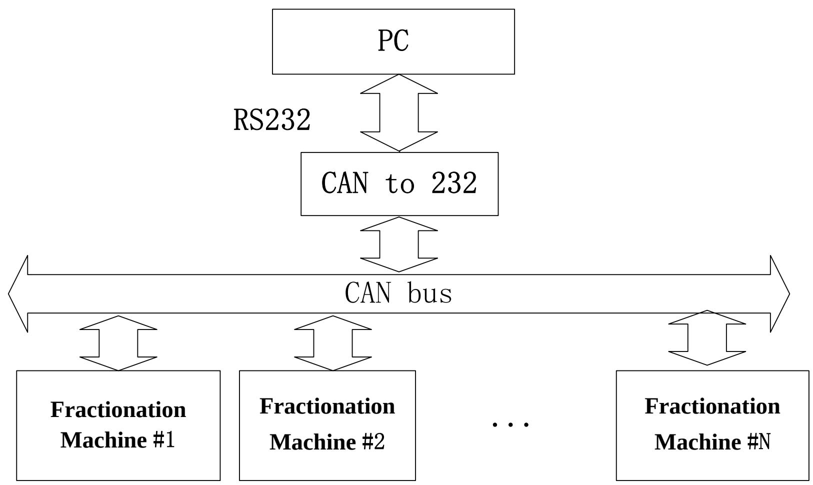

Figure 2. Architecture of automatic blood component fractionation system

The fractionation machines can do the fractional operation separately, or co-workers with the PC, this can be set by the user. The basic processes of fractionation are programmed on the PC, and then send to the proper machine or to all machines. The programmed methods make the fractionation very flexible.

To realize the cooperation of the PC and the fractionation machine, this paper using a lot of subprograms in the software designing on the fractionation machine, and the PC management software provides a platform of the program using the instructions according with these subprograms. When the user programmed an operation process using these instructions, and sends them to the fractionation machine, these programs will be translated into a process list; each step of the process is a subprogram. These subprograms are the basic operation of the process, such as open door, close door, upper press to xx mms, *etc*. Most of the subprograms have some parameters to control the operation, for example, if the machine received the instruction of “upper press to 20mms”, then the upper press advancing until reaching the position of 20mms, after that this machine will find the next instruction and continue working automatically until it received the end instruction. Table 1 shows some of these instructions provided by the PC management software.

The row of instruction shows the hexadecimal code of each instruction, each instruction occupies one byte space. The row of parameters shows relevant parameter of the instruction, takes one byte space too. The row of subprogram shows corresponding subprogram of the software, and the function row indicates the operation of the instruction.

Table 1. Some basic operating instructions

instruction	parameter	subprogram	function
0x01	none	popen_door(void)	Close door and start
0x05	x	pclose_head(x)	Close head x
0x06	x	popen_head(x)	Open head x
0x07	x	pseal_head(x)	Heal head x
0x08	x	Upperto(x)	Upper press to x mms
0x09	x	Upperwait(x)	Upper press out for x s
0x0c	x	Lowerto(x)	Lower press to x mms
0x0d	x	Lowerwait(x)	Lower press out for x s
0x0e	x	Lowerdet(x)	Lower press out until detectors cond
0x0f	x	Lowergram(x)	Lower press out until weight cond.
0x10	x	Bothto(x)	Both press out to x mms
0x11	x	Bothdet(x)	Both press out until detectors cond.
0x20	none	Endprog(void)	Operation end

Each machine can save up to 50 programs, and each program can contain up to 50 instructions. These programs will be saved into flash memory after receiving from CAN bus, and can be renewed by the PC command at any desired time.

3. The hardware design of the fractionation machine's control system

The fractionation machines have many devices such as press boards, press door, pressure valves, healing head, keyboards, electric balance, detectors, position sensors, scanner and so on. These devices can be divided into some parts of their interface—analog devices, serial interface device, DC motor, relay controlled devices. This paper designed the control system using C8051F040 as the main controller to be controlled, which is a kind of SOC(system on chip). C8051F040 has 2 A/D converter channels up to 12 inputs, 2 10-bitD/A outputs, 4 channels of PCA, supports serial ports, SPI bus, CAN bus[9,10]. The structure of the control system [11, 12] is shown in Figure 3.

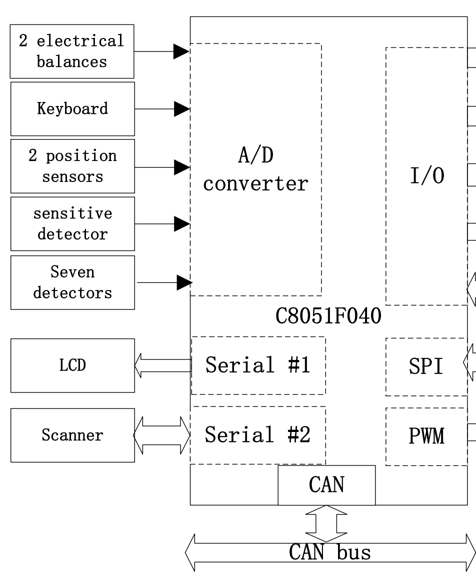

Figure 3. The structure of the control system of fractionation machine

This system used 8 detectors to control the proper time to stop the press process, which will direct impacts the precision of the fractionation. These detectors can be chosen by suggestions or through some experiments. The sensitive detector is placed on the tubes, so when most PRP is needed, this detector will be useful. The position sensor can detects press boards current position for displacement control [13]. The electrical balances can provide the weights of PRP and other components.

Valves control the blood flowing into the expected bag. After all components have flowed into the correct bag, the tube will be healed, and the quadruple bag will be separated into 4 bags. The upper press and the lower press provide a smooth extrusion lets the different components flows to the bags. Top press can be used for pressing the maintaining liquid into RCC bag or for air exclusion.

Flash memory saved the programs received from PC and some setting of the machine, such as the machine number, current program number and so on. The motor in the system can control the flow speed in the tube. The interface of flash memory of this system is SPI interface, this can decrease ports numbers for communications.

Figure 4 shows the Schematic diagram of the MCU part. Since C8051f040 integrates interfaces of many kinds, analog signals of sensors amplified through amplifiers can direct send to the MCU. This paper uses 12 A/D ports, CAN interface, 2 rs-232 interfaces, 1 SPI interface, and 2 PWM signals, and some digital input and output signals in this system.

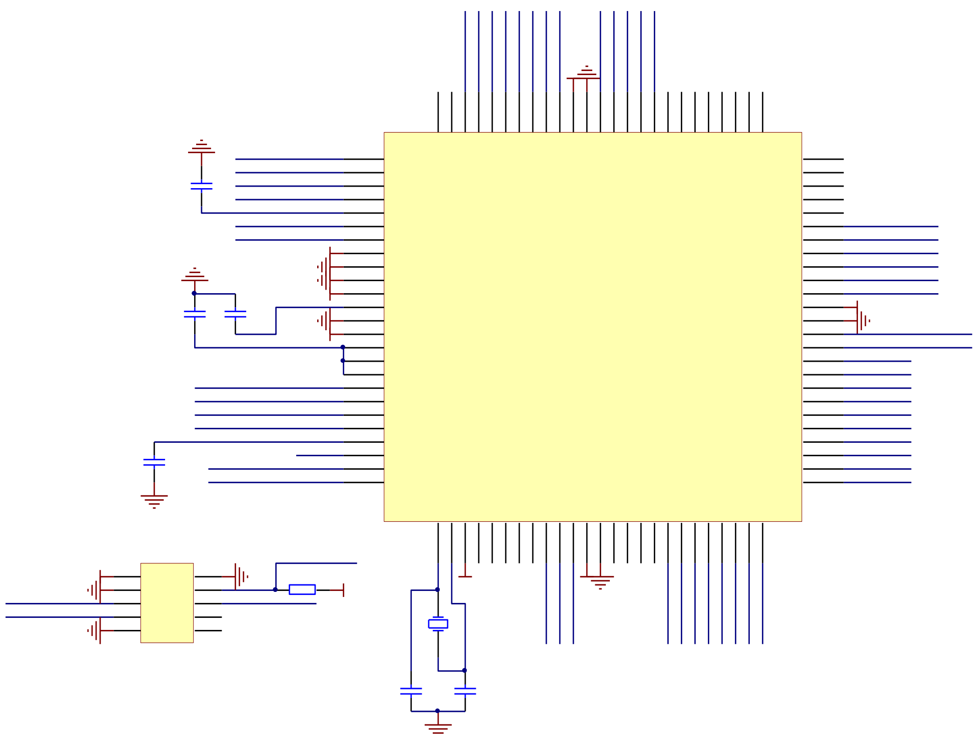

Figure 4. Schematic diagram of the MCU part

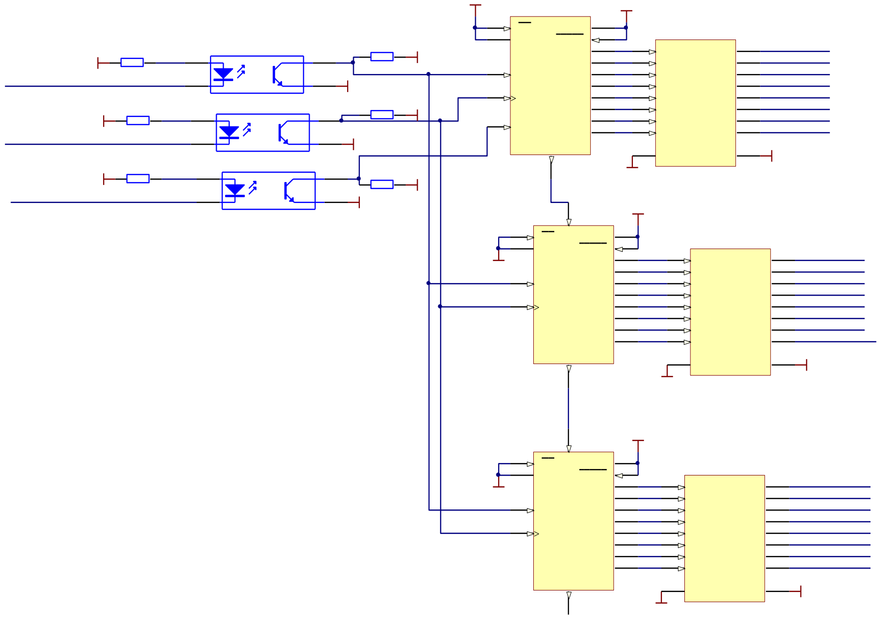

Figure 5. Schematic diagram of the out extends part

Since a lot of ports have been used for communication and the other use, the ports for digital input signals and output signals are very limit. To extend digital output signals, this paper uses 74HC595 extends 24 signals, each signal is driven by ULN2823 for increase the drive capability.

4. The software design of the fractionation machine's control system

The software of the fractionation is programmed using MCU C language, because there are many devices and some of them are complicated, the design of the software is a large project. This paper uses many sub modules to solve different functions, this modular and layered structure is easy to debug and design. The structure of the software is shown in Figure 6.

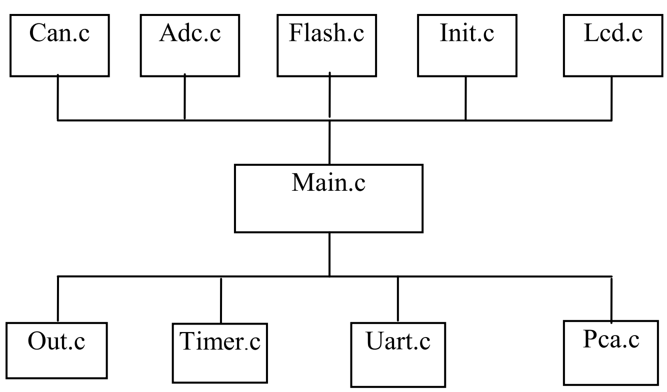

Figure 6. The structure of the control system of fractionation machine

The program's main module is “Main.c”, which maintains a task queue. This task queue is corresponding to the blood separation process, which can be programmed by the user. This module takes the first task in the queue, calls the corresponding subprogram, capturing the system sensor’s information during subprogram processing.

The module “Init.c” is an initialization subprogram, this module is used to presets all system parameters after system reset or power on.

The module “Can.c” is responsible for receiving operation instructions or system parameters from a PC, and sending the information and result during automatic operating. Receive subroutine of CAN message is processed in the interrupt service, when an operation instruction received, a subprogram call is added to the processing queue.

The module “Adc.c” captures the sensors status and computes the real values. This module is responsible for measuring the weight of blood component bags, detecting whether the user pressed any keys, analyzing which key is pressed if a key press operation is detected, computing position information of press boards, and *etc*.

The module “Out.c” is a very important module, which includes all subprograms of the basic processes. This module is in charge of all valves open or close, healing the pipes, upper press boards moving forwards or backwards, lower press boards moving forward or backwards, top press board lifting or lowering, and *etc*.

The module “Lcd.c” displays information about the system on a LCD, such as the sensor’s information, the system’s current status, the network status, the faults information, etc.

The module “Pca.c” is responsible for producing PWM signals, which are used to control motor’s speed and direction.

The module “Flash.c” is used for accessing Flash memory, which is used to read and write system parameters, subprograms, current system status, and *etc*. This system can save up to 50 self-defined separation programs, this programs saved in the flash memory. The structure of these programs is shown in Figure 7.

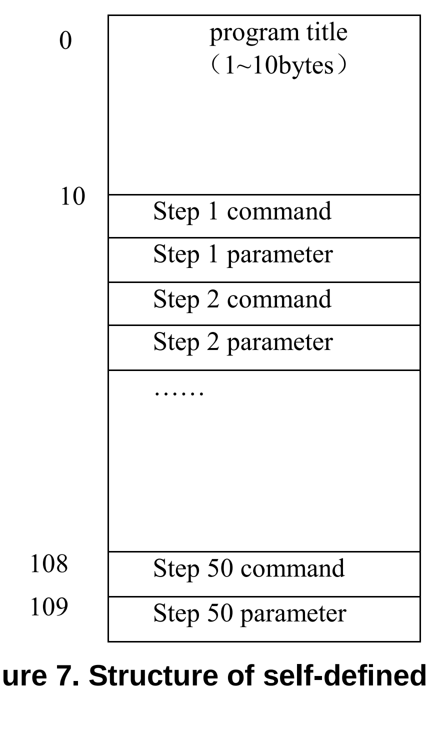

Figure 7. Structure of self-defined programs

Since there are 9 modules in this design, the dispatch method is very important for programming. The paper introduces the status machine into the MCU software designed. This system has 4 statuses: power off status, power on status, running status, pause status, showed in Figure 8.

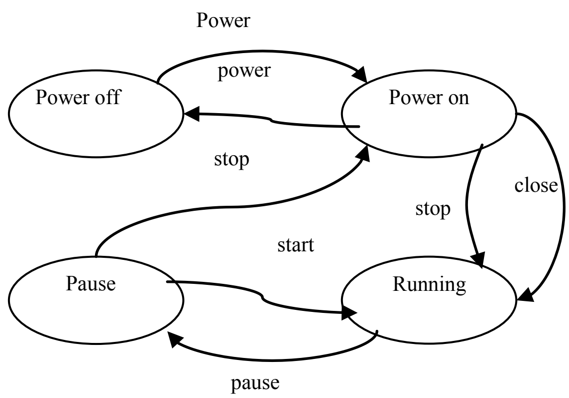

Figure 8. The status machine of the software

Power off status is the initial status after had given power to the system without press the power key. At the status, the machine reads settings in the flash memory, waiting for power key press action.

After power key pressed, the machine will turn to power on status, the system will firstly do self-test, check if have connected on to CAN bus, check if the PC is powered on, *etc*. Then open the door, wait for operators hang the bag and press the close key.

After system selft-test in power-on status, in case of the close key pressed by user, the system will close the door run the selected program.

When, in some case, the operator can press the pause key to pause, the current operation will be paused, waiting for keys to resume or stop. This is hard to solve on the MCU for the pause status doesn't mean just tap into an endless loop. Some pause operation must be done first before endless loop, such as if the current process is upper press to 20mms, the press is advancing until the position sensor showed the press have reached the correct position. This is a loop waiting for a special condition, but if when pause statue is just an endless loop, the press will not stop, and the blood will all go into a bag and all components mixed again. This design first stop the press moving, close all valves to avoid blood still flowing into the bag(the valve status should first be saved), then traps into an endless loop.

To realize this kind of status machine on the MCU, this paper sets number of traps in most of the loops, the flow chart of an ordinary subprogram is shown in figure 9. When the pause instruction is meet, or pause key is pressed, MCU first call pause subprogram, save the current valve status, then close all valves, stop all press moving and return. The program will trap into the pause loop until the status changed by another key pressed. The status value renews at the key interrupt programming, and is not needed to be considered in this subprogram.

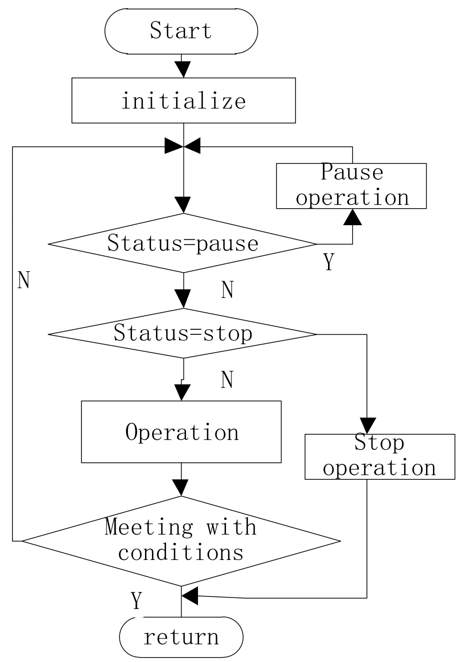

Figure 9. A flow chart using trap mechanism

5. Conclusions

This paper analyzes the weak points of traditional blood component fractionation methods, a scheme of automatic blood component fractionation machine is proposed. This paper mainly introduces the design of the control system of automatic blood component fractionation system, which is flexible, precise, easy to use, and meet with the Blood Bank standards. This system can be used in most of China blood systems, and have shown to be having a good market foreground.

Acknowledgements

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