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Design and development of bio-signal acquisition system based on lm3s1138

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ABSTRACT

This paper presents a bio-signal acquisition system design based on LM3S1138. The hardware system, the software design, and the implementation of key technologies are given in the paper. The designed program has advantages of simple structure, high reliability, excellent scalability, and good versatility.

KEYWORDS

Bio-signal acquisition; ARM LM3S1138; Preamplifier; AD7606; USB communication.

INTRODUCTION

Computer technology has been widely used in physiology experiments of life science. Its application has realized the intelligent processing of experimental data, and greatly improved the efficiency of experiment. The biological signal acquisition system mentioned in this paper are usually used for conditioning and amplification of the various biological signals (such as: ECG, EMG, EEG) and the non-electric biological signal (such as: blood pressure, tension, breathing), finishing the following A / D conversion, and then uploading the data to a computer for further analysis and processing. The paper puts forward a novel system based on ARM LM3S1138, by using its high-speed information processing capabilities. The system is very simple, versatility, and easy to maintain and extend. Its structure is also flexible.

FEATURES OF ARM LM3S1138[1]

LM3S1138 is Luminary Micro (now acquired by TI) introduced high-performance micro-controller, using the ARM Cortex ™-M3 MCU core, which is optimized ARM7 core, with the command execution speed of 1.25 DMIPS / MHz, also optimize the command structure, high computing power, most systems can meet the requirements of the microprocessor in order to achieve strong communication and management control of complex functions. Its main features are as follows:

(1) 32-bit microprocessor, 50 MHZ frequency, stable operation. With integrated Nested Vectored Interrupt Controller (NVIC), makes the more simple treatment interruption, 34 interrupts with eight priority levels.

(2) On-chip ADC, eight 10-bit input channels. 1,000,000 times / sec sampling rate, on-chip temperature sensor.

(3) Internal memory, 64KB single-cycle Flash; 16KB single-cycle SRAM.

(4) 4 General-Purpose Timer Module (GPTM), each providing two 16-bit timer. Each GPTM can be independently configured to operate: as a 32-bit timer, 32-bit timer as a clock (RTC) to capture the event for the Pulse Width Modulation (PWM), analog to digital conversion is triggered.

(5) Serial port: with two synchronous serial interface (SSI) modules, and three fully programmable asynchronous serial ports (UART), and two IIC modules

(6) GPIO counts to 9-46, the number is depending on configuration. The pin-bit TTL-level input can withstand 5V.

HARDWARE DESIGN

The hardware platform of the biological signal acquisition system is consisted of LM3S1138, AD7656, signal regulate circuit, real clock composition. The composition of hardware system is shown in Figure **1**.

Six-channel biological signal amplification conditioner

Mainly includes the amplifier circuit, filter circuit, the voltage follower and other components, as shown in Figure 2. Six-channel design according to the following parameters:

Channel 1, 2: minimum magnification of 50 times, the maximum frequency is 10 kHz. usually used to make nerve discharge type experiments, such as: depressor nerve, phrenic nerve discharge;

Channel 3, 4: minimum magnification of 50 times, the maximum frequency is 1 kHz. Action potential is usually used for class experiments, such as: neural stem to guide the action potential, AP conduction velocity determination, etc.;

Channel 5, 6: The minimum magnification is 5 times, the maximum frequency of 100 Hz. ECG is usually used for quasi-experimental;

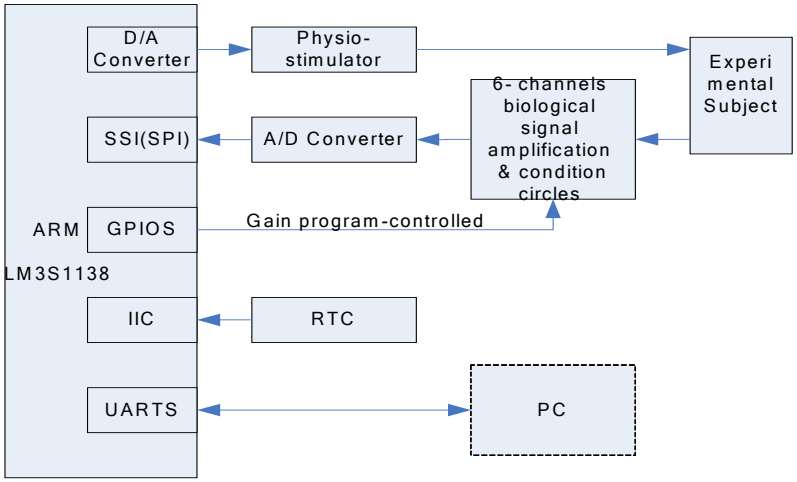

Figure 1 : System Hardware Diagram

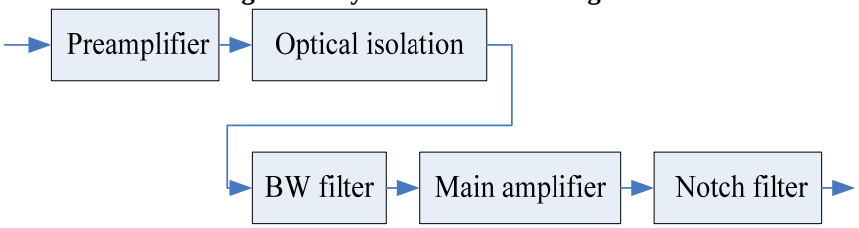

Figure 2 : Pre-processing circuit diagram

Preamplifier

Biological signals have the weak, strong noise and the low frequency range features. Usually require preamplifier with high input impedance, high common mode rejection ratio, low noise, low drift, such as performance, differential mode commonly used while design input. This design chooses instrument amplifier AD620 as preamplifier, as shown in Figure 3. In order to prevent the preamplifier works in the saturation region or the cut-off region, the gain can not be too large. The experiments showed that preamplifier about 10 times the effect is best. To provide accurate gain, the R33 in circuit used a resistance that precision of 0.1 ~ 1%, the temperature coefficient less than 10ppm /□.

For EMG signals, 5, 6 channel is also provided a pulse suppression circuit. Interference pulse diode D31, D32 transient conduction, it coupled to ground via a capacitor C31. The biological electrical signal by the U31 enlarged still far less than the diode conduction voltage of 0.7 V, So the ECG signals can pass U31 to the post-stage circuit.

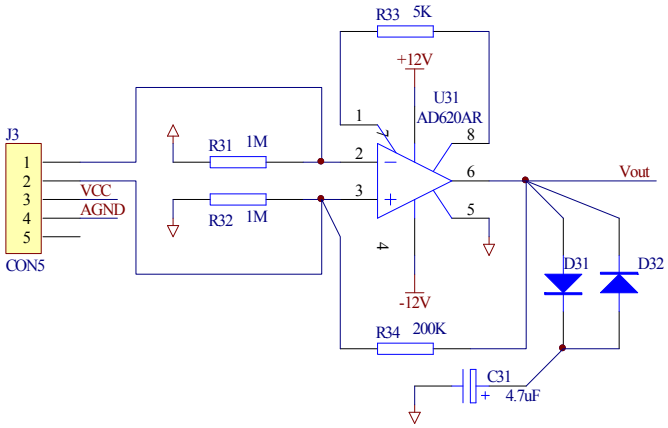

Figure 3: Preamplifier circuit diagram

Optical isolation circuit

Biological signal amplifier isolation technique must be adopted, that is the pre-amplification stage in contact with the organism used floating amplifier, so on the one hand, can improve the ability of anti-interference amplifier, it is more important to ensure the safety of the measurement. IS0130 chip is a kind of high isolation and high anti-jamming isolation operational amplifier, use very convenient, does not need any peripheral devices, analog signal isolation amplifier applications directly.

The band-pass filter and the main amplifier

After preamplifier into bandpass filter circuit filter out interference and noise, band-pass filter consists of two op-amp OP2177, as shown in Figure 4. OP2177 has some characters such as High precision, low offset, low power consumption, and it integrate two operational amplifiers inside which can compose any amplifier and filter circuits flexibly. Because biological's signals have wide band, we can use the OP2177's two operational amplifiers to design Voltage-controlled active second-order high-pass and low-pass filters and then combine to form a band-pass filter. In order not to lose the signal of the low-frequency components and high-frequency components, Bandwidth filter is applied. C34,C35,R40,R41 and U34A compose low-pass circuit. Its cutoff frequency is calculated according to the formula.

$$f_1 = 1/2\pi\sqrt{C34 \cdot C35 \cdot R40 \cdot R41} = 0.03Hz$$

And R42,R43,C36 and C37 compose high-pass filtering. Its cutoff frequency is calculated according to the formula.

$$f_2 = 1/2\pi\sqrt{C36 \cdot C37 \cdot R42 \cdot R43} \approx 100Hz$$

Different cutoff frequency varies according to the different channels.

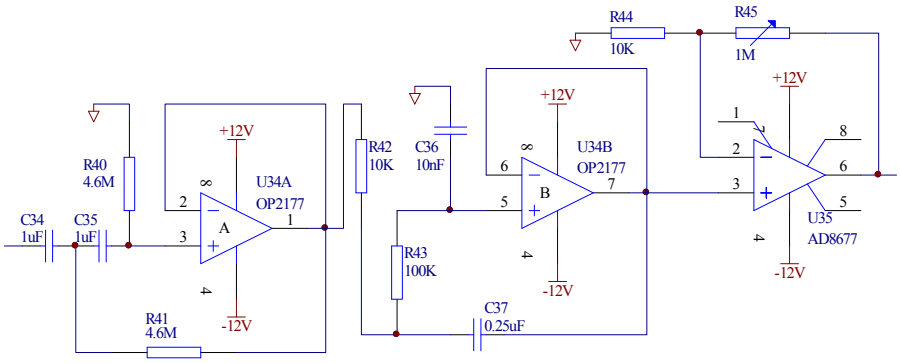

Figure 4 : Band-pass filter and main amplifier circuit diagram

A/D conversion of the input requirements for 0~5V. Considering the signal amplitude is about 0 ~ 5 mV, so the signal amplification required about 1000 times. if preamplifier compose 10 times, the main operational amplifiers should amplificate 100 times theoretically. The main operational amplifier uses AD8677, and access variable resistor R45, which can gain adjustable optimum output. The AD8677 is the next generation of precision, ultra-low offset amplifiers. Analog Devices' iPolar™ process enables the AD8677 to incorporate the high performance of OP07-type amplifiers.

Notch filter circuit

Frequency interference is the main interference of biological electrical signals[2]. Although preamplifier circuit for common mode interference has a strong inhibitory effect, there are still some frequency interference can get in the circuit by differential mode signal, and the frequency is in the band of biological electrical signals, coupled with electrodes and input loop instability and other factors, a notch filter is needed in pre-stage circuit to suppress the 50Hz interference. The conventional twin-T network requires high-precision components and strict symmetry, but it is difficult to tune. The 50Hz notch filter using the universal active filter chip (UAF42) eliminates above disadvantages.

The UAF42 is a monolithic, time-continuous, 2nd-order active filter building block for complex and simple filter designs. It uses the classical state-variable analog architecture with a summing amplifier plus two integrators. A notch filter is easily realized with the UAF42 and six external resistors. Figure 5 shows the UAF42 configured into a 50Hz notch filter. The auxiliary operational amplifier is used to sum both the high-pass and low-pass outputs to create a band reject (notch) filter.

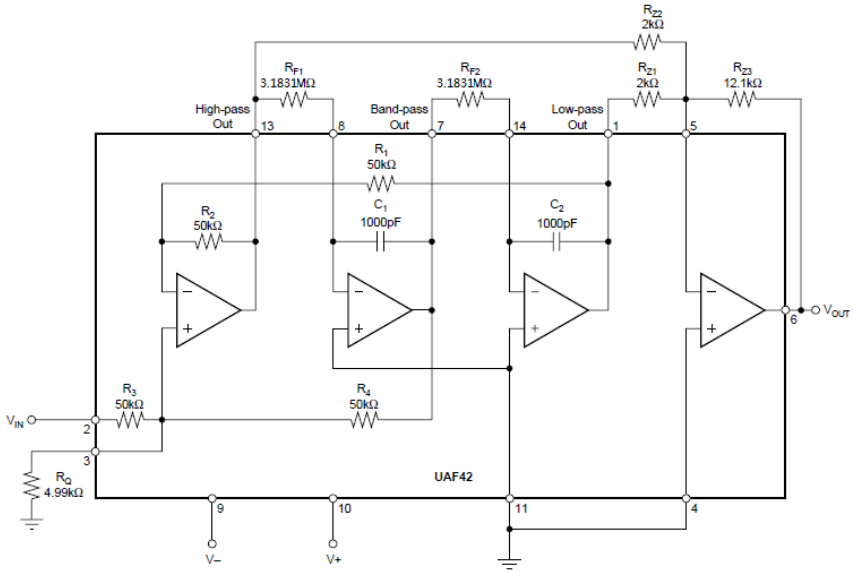

Figure 5 : UAF42 configured as a 50HZ notch fliter

f_{NOTCH} is given by, $f_{NOTCH} = f_0 = \frac{1}{R_F \cdot C \cdot 2\pi}$

Where, $R_F = R_{F1} = R_{F2}$ and $C = C_1 = C_2$. Refer to the UAF42 data sheet, $C = 1000pF$,then $R_F = 3.1831M\Omega$.

The circuit simulation shows the 50Hz notch filter using UAF42 meets the design requirements, the notch depth can rise up to 70dB, and $BW_{-3dB} = 8Hz$.

Physiological stimulator

In some physiological experiments, there must be a source of stimulation, such as in vitro experiments nerve discharge, needed to stimulate the nerve stimulator to generate excitement. Usually a certain drive power of the pulse output circuit firstly generate a pulse waveforms, then the pulse waveform with integrated power amplifier drive amplifier, amplifying circuit work in linear regions. This kind of amplifier circuit must have a static current to maintain the appropriate static working point, so the power consumption is high[3].

In order to reduce the power flow, the system of electrical stimulation is used way to generate stimulus pulse switch. LM3S1138 and its pulse generator circuit is given in Figure 6. JS is stimulating electrode terminals, PG4 pin outputs PWM signal when PWM mode of LM3S1138 is enabled. According the requirement of the experiment, the output strength can be adjusted. Using PWM output, RJ1 and CJ1 filter adjustment UJ1 positive phase of the input voltage. Op-amp UJ1 for positive phase amplification method, magnification is decided by the RJ2 and RJ3. Q2 for power amplifier transistor, increase the output driving ability. Q1 work on the switch state, is used to control the output pulse width and frequency. When 9 pin of LM3S1138 is high level, Q1 conduction and output stimulate pulse.

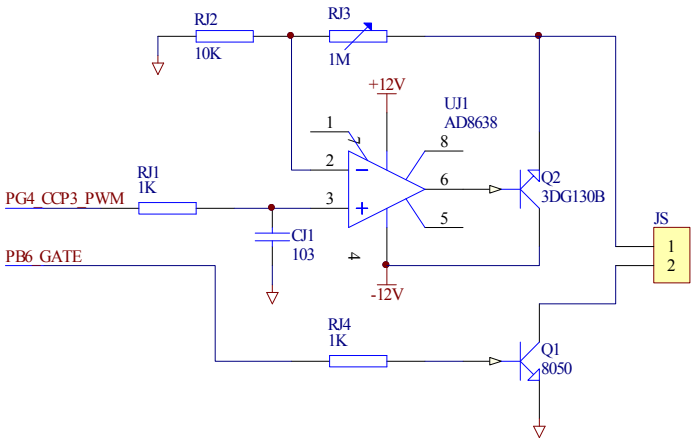

Figure 6: Stimulator pulse generator circuit

The ad and cpu interface circuit

Considering the acquisition signal precision and matching with the speed of the ARM, The AD7606 is selected. The AD7606 is 16 bit, simultaneous sampling, analog-to-digital data acquisition systems (DAS) with eight channels, respectively. The AD7606 operates from a single 5 V supply and can accommodate ±5 V true bipolar bioelectricity input signals while sampling at throughput rates up to 200 kSPS for all channels. The input clamp protection circuitry can tolerate voltages up to ±16.5V.

Since LM3S1138 does not have parallel interface, so through its built-in SSI interface connects AD7606 SPI interface. SSI of LM3S1138 is configured as a master, and SPI of AD7606 is onfigured as a slave. AD7606 working circuit as shown in figure 7. AVcc is analog supply voltage, +5V. This supply voltage is applied to the ADC core. VDRIVE is logic power input pin. This pin is at the same supply as the supply of LM3S1138 (3.3V). The RANGE pin is tied to a logic low, the analog input range is ±5V. PAR/SER/BYTE SEL pin is tied to a logic high, the serial interface is selected. In serial mode, the RD/SCLK pin functions as the serial clock input. The DB7/DOUTA pin and the DB8/DOUTB pin function as serial data outputs. When the serial interface is selected, the DB[15:9] and DB[6:0] pins be tied to ground. For simultaneous sampling of all input channels, CONVST A and CONVST B be shorted together.

The usb communication circuit

Because the RS232 serial interface cannot satisfy the high speed data transmission, data storage and high frequent data acquisition requirements. This design uses the USB interface chip CH374, realize the real-time collection of biological electrical signals and rapid communication of PC, and high reliability, easy to connect.

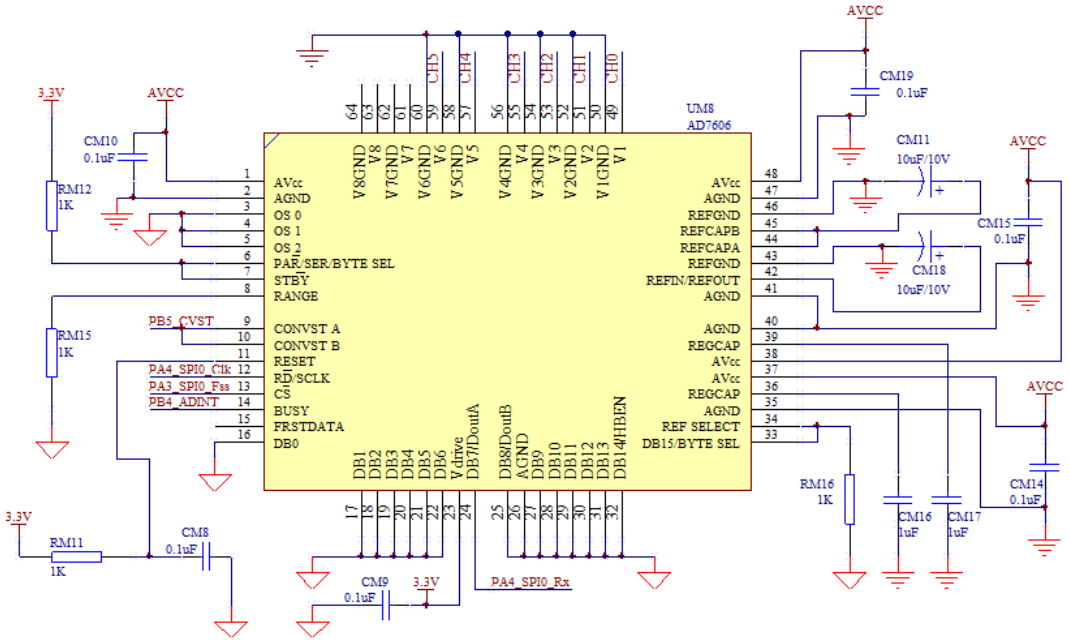

Figure 7: AD7606 interface circuit

Introduction of ch374 chip

CH374 supports USB-HOST and USB-SLAVE device, built-in 3 port HUB root HUB, supports low speed and full speed control transfer, bulk transfer, interrupt transfer, and synchronous transmission. CH374 has 8-bit data bus and a SPI serial interface. It can be easily hooked up to MCU/DSP/MCU/MPU controller. CH374 supporting software provides a simple and easy operation interface, reducing the development difficulty.

CH374 interface circuit

In order to save the MCU I/O pins, CH374 through the SPI serial interface and interrupt output connected to LM3S1138. /RD and /WD pins for low level (ground) and /CS pin for high level, In this way CH374 will work in the SPI serial interface mode. In the SPI serial interface mode, CH374 only need to connect with LM3S1138 five pins: /SCS, /SDI, SCK, SDO and /INT. Other pins can be suspended, as shown in Figure 8.

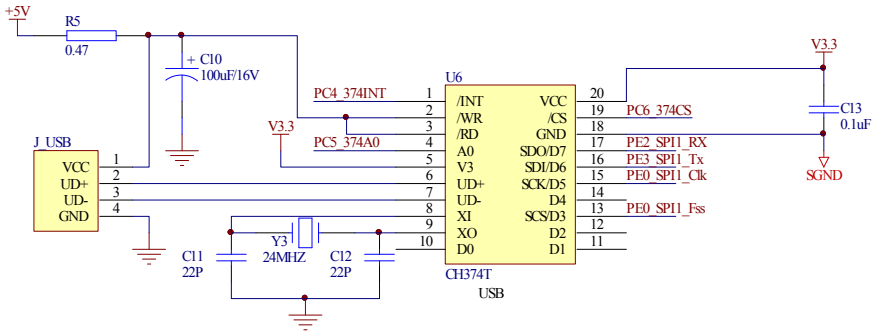

Figure 8: CH374 interface circuit

SOFTWARE DESIGN

LM3S1138 manufacturer Luminary Micro official provides free based on C language (accord with ANSI C) driver library package, and the source code is open. So users do not need to grasp the operation of bottom registers details, underlying hardware just call related library function, application development easy and convenient.

LM3S1138 operates data acquisition and data filtering. It also conducts the communication processing with the upper computers. The executive software within the system is written by C language on the development platform of ARM Embedded Workbench, and the software is designed based on the top-down ideas of making the programs modularity for the function partitioning, as shown in Figure 9.

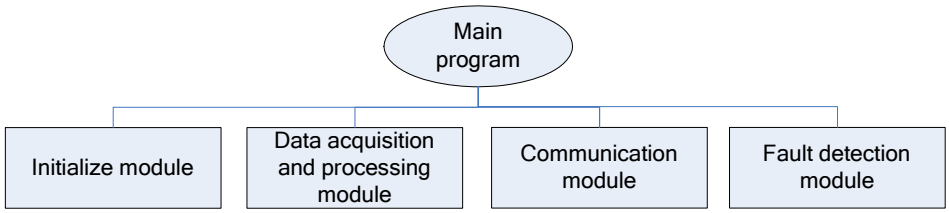

Figure 9: System software module chart

Initialize module mainly complete the configuration in ARM chip clock, GPIO port and slice of temperature sensor, serial communication (SSI, UART, IIC), and the way AD7606 Settings etc. Initialize end, the program get into the main loop, adopted quick inspection way, and continuously receives serial PC command, biological signal A / D sampling and processing, and in my leisure time self-check hardware. In order to improve the sampling of real-time and validity, data acquisition and sending all in an interrupt service routine operation.

Data collection

Obviously, the core part of the software is data collecting and processing module. It samples 5 times every time of the every six analog channels and reduce the noise by the median filtering. Flowchart of data collecting and processing module is shown in Figure 10.

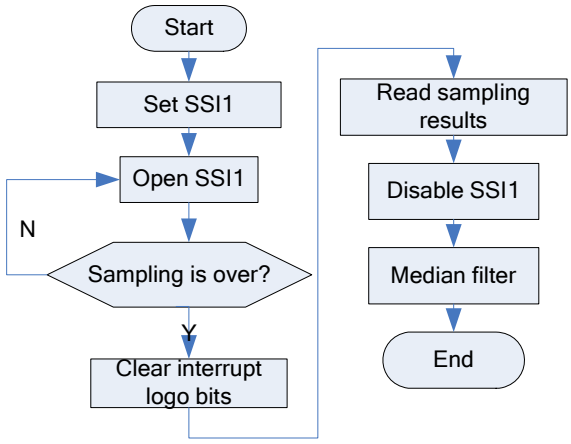

Figure 10: Flow chart of data acquisition of SSI interrupt service program

USB communication program

USB communication program mainly includes the firmware, application and driver programs.

Design of firmware program

LM3S1138 programs are very simple for the built-in underlying protocol of the USB communications in CH374. In the external firmware mode, after initializing of CH374, the LM3S1138 deal with all kinds requests of USB according to the need, thus completing the bus connection process of USB. Initialization of CH374 is mainly to complete enumeration of the USB device, and the initializer of CH374 is listed as follows:

```
void CH374_PORT_INIT () /*Initialize*/
{ unsigned char i;
PORTB |=0x03; // Forbid the SPI chip select, set the CS default to high level
DDRB |=0x07; // Set the CS#, SCK, SDI to the output
DDRB&=0x08; // SDO input
SPCR=0x5C; // Set the SPI to the module 3
CH374_DAT_PORT=1; //Set to using the external firmware of USB device
}
```

Design of application program

The design of the application program can be appropriately adjusted according to the needs of users for the application layer interface of CH374 on computers. The application layer interface is the function application oriented API provided by the dynamic link library DLL of CH374, including the API of the equipment management, data transfer and interrupt handling. Therefore, the communication between the application program to the lower computer can be realized depending on the operation API function by a few simple files. and the data downlink is just to send data as well as the interruption of CH375 to receive it.

Device management of API mainly includes: 1) open and close device; 2) get USB device, configure descriptor; 3) reset USB device. Data transfer of API mainly includes: 1) read data block; 2) write data block. Interrupt handling of API mainly includes: 1) read the interrupt data; 2) set the interrupt service program.

Using the functions of API, it is easily to develop the application software matching to hardware circuit. The overall program flow chart of the connection the CH374 to the upper computer is shown in Figure 11.

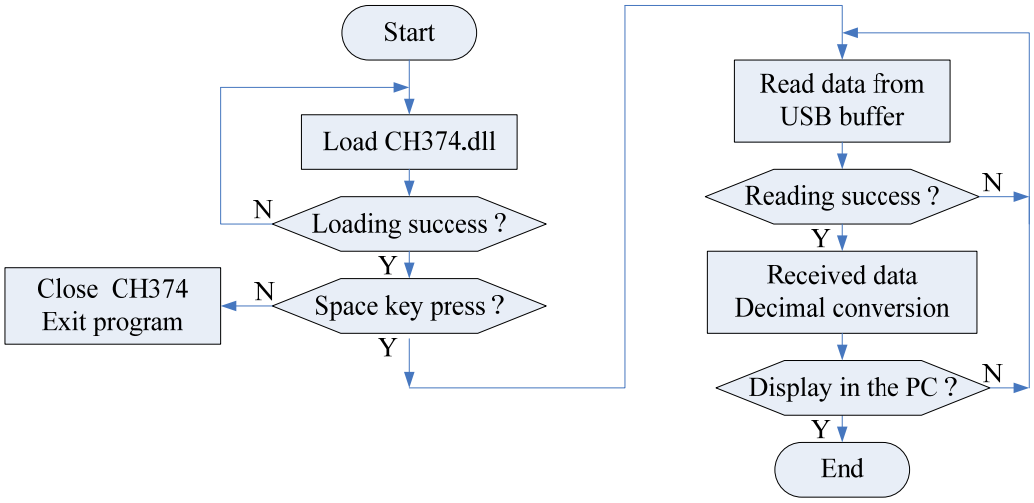

Figure 11: Upper PC program flowchart

Design of USB driver

USB Driver can be designed by using the WDM (Windows Driver Mode) module. WDM driver adopts the flexible layered drive method, where it exist several different driver levels between the users and the physical devices, and different priorities in each layer of the WDM driver. With good flexibility and adjustment according to the needs of users, the drivers are designed depending on WDM. However, there is large workload to know the principle of operating system and the related details of hardware. The manufacturer of CH374 provides the universal driver for the USB driver design, and it can be directly installed after downloading, which grealy reduces the difficulty of development.

CONCLUTION

LM3S1138 has the advantages of high integration, fast operation and low power. The bio-signal acquisition system based on LM3S1138 is stable and reliable, and has good versatility. It has been applied to the actual products, and meets the technical requirements.

REFERENCES

[1] Luminary Micro Company; LM3S1138 microcontroller data sheet, **(2007)**.
[2] Chen Xu; A medical pre-amplifier design (in Chinese), Shandong Journal of Biomedical Engineering, **(Mar. 1997)**.
[3] Liu Yanfei, Ye Datian, Yue Xicai,et al; The realization of biomedical signal high-speed sampling based on windows environment, Beijing Biomedical Engineering, **21**, 183-186, **(Mar. 2002)**.