Abstract

With the advent of global information, researches of Smart Home system are in the ascendant, the ECG real-time detection, and wireless transmission of ECG become more useful. In order to achieve the purpose we developed a portable ECG monitor which achieves the purpose of cardiac disease remote monitoring, and will be used in the physical and psychological disease surveillance in smart home system, we developed this portable ECG Monitor, based on the analysis of existing ECG Monitor, using TMS320F2812 as the core controller, which complete the signal collection, storage, processing, waveform display and transmission.

Key words—ECG; DSP; ZigBee; Digital Home.

1. Introduction

ECG is mainly to monitor the cardiogram. The ECG, which has a hundred years’ Clinical application history, being closely integrated with clinical, is regarded highly by extensive medics. Because of its non-invasive detection methods, as well as the particularity of the signal, it is favored by the majority of scholars. People continued to study the theory and practice of the ECG and inject new activities to this ancient detection-method for promoting ECG monitoring technology continuous innovation and development.

Based on the subject objectives and analysis of existing ECG monitoring equipment, we use TMS320F2812 as the core controller to complete ECG acquisition, storage, processing, waveform display, and transmission functions. The system includes ECG acquisition module, liquid crystal display modules, RS-232 serial port modules and ZigBee module. The Liquid crystal is used as a human-computer interaction to display ECG waveform, and serial port connecting the computer to help transmit the date to the computer for being complex algorithms processed, and ZigBee module can be used to send ECG data by wireless and compose the wireless sensor network. Application client of the PC written with VC++ can be used to develop kinds of functions, such as detecting the ECG’s disease.
2. DSP Minimum System Design

Power, reset, clock, and decoupling circuit are the integral part of the DSP system. Power supply circuit supply the voltage for meeting different performance requirements to the system; Reset circuit initialize a definite state for the system, including the manual reset and power-on reset; Clock circuitry supply clock or the running real-time clock to the System and decoupling circuit mainly reduce the coupling noise and improve system performance.

![DSP power supply circuit](image)

In this article, DSP chip is TMS320F2812. The chip needs two different voltages: 3.3v for I/O port and 1.8V for the CPU core. To fit for this high require of the power supply, we use the exclusive power chip TPS767D318 to improve the reliability of the System. TPS767D3xx, which is designed for DSP applications, is a kind of dual power supply chips, and its input voltage is +5v and one of the output voltage is 3.3v, the other output voltage is different according to the different chip models, TPS767D318 output voltage is 1.8v[1]. Figure 1 shows the diagram for the power supply circuit of the system.

Crystal oscillator circuit provide the work clock for the system, here we use passive crystal. Phase-locked loop circuit is integrated in TMS320F2812, and users can use a lower external clock and then this lower external clock can be changed to the system-requiring CPU clock through phase-locked loop circuit, whose multiplier factor is configured by the register PLLCR. Using the external active crystal oscillator and phase locked loop to get the system clock, we can not only reduce the interference of the external signal to the clock signal, but also avoid interference of high-frequency clock to the circuit board and improve the electromagnetic compatibility ability for the DSP system[2].

3. ECG pre-processing circuit

According to the characteristics of ECG, in general, before the ECG collection process we get the signal of the ECG through sensors and then enlarge the signal secondly before it have been enlarged by preamp circuit, finally we’ll filter the amplified signal.

As the signals of the organisms are very weak (some is millivolt level and some is even micro-volt level), so it must be enlarge by pre-amplifier to make sure that it could be displayed in the oscilloscope or be recorded. Gain of pre-amplifier is contained within only a few times so as to avoid the interference
signal to be enlarged. Amplifiers use instrumentation amplifier which is low drift, low power, high common-mode rejection ratio, wide power supply range and small size, and it can also enlarge differential signal.

Band-pass filter is used to remove DC signals as well as the high-frequency interference signals from the natural environment and the body. Intermediate amplifier circuit is used to carry out re-amplification of ECG and the gain is 40 times. 50Hz interference signal is a major interference source to the ECG, so it is necessary to use a special circuit to remove it. The role of post-amplifier is enhancing the magnification and provides the potential voltage to match ADC port of the DSP.

ECG signal is required to be converted into digital signals after amplification, and then carried out the corresponding processing by DSP. In this system, the enlarged output signal is from -1.5v to +1.5v, while the input analog signal of AD converter must be 0 ~ 3.3v. Therefore, this paper designed an addition circuit, to couple the signal with 1.5v reference voltage and drive the signal up into 0 ~ 3v , before inputting the signal to the DSP for AD collection. The circuit is shown in figure 2[4].

4. Serial interface’s design

There is two serial communication interface modules (SCI) in the DSP, which use the asynchronous serial communication interface of two wire communications and its transceivers with 16 deep FIFO can reduce CPU overhead during the communication. SCI module can also check intermittent detection, parity, overtime and frame error to ensure data integrity. In practice, we need to configure the programmable general-purpose I/O (GPIO) pins of the TMS320F2812 to output SCITXD and get SCIRXD signals. The F-port’s 4 and 5 feet which correspond to the SCI module's internal SCITXD and SCIRXD pins is used in our circuit. In order to achieve the compatibility between GPIO output voltage levels with the RS-232 signal voltage level, we need a MAX232 chip to achieve the level conversion.

Connecting PC computers and LCD with DB9 plug, we can achieve data transmission and waveform display by controlling the serial port which simplifies the system design and reduces cost greatly [5].

5. ZigBee Module circuit’s design

In this paper, we use TI's ZigBee chip CC2420 RF transmitter module CC2420EM, the module interface circuit is shown in Figure 3, including a three-wire SPI interface, chip select and some other control lines.
Figure 3. CC2420 module DSP interface

FIFO pin and FIFOP pin allow DSP to know when to read the data. The connection of FIFOP pin & DSP GPIOE0 pin, can stimulate the DSP’s external interrupt to enable DSP read the CC2420's data in RXFIFO timely in order to avoid RXFIFO overflow [6]. Figure 3 is for the DSP and the CC2420 module interface circuit diagram.

6. software’s design

A. AD software

Since this is only one lead ECG monitor, so we set the converter channel number 1, which will set the first one signal input to conversion. EVA timer 1 is used to start AD conversion timing. We control the sampling frequency by changing the value of the timer. The following is part of the AD collection code:

```c
AdcRegs.ADCMAXCONV.all = 0x0000;  // one channel
AdcRegs.ADCSELSEQ1.bit.CONV00=0;  // first con.
AdcRegs.ADCTRL2.bit.EVA_SOC_SEQ1 = 1;  // Enable SOC
AdcRegs.ADCCTRL2.bit.INT_ENA_SEQ1 = 1;  // Enable int
EvaRegs.T1CMPR=0x80;  // Set up T1 compare value
EvaRegs.T1PR=0x8715;  // Set period register value
EvaRegs.GPTCONA.bit.T1TOADC = 2;  // Enable EVASOC T1
EvaRegs.T1CON.all = 0x1040;  // Set T1 mode
```

B. ZigBee software design

In order to control the CC2420 chip, with the DSP's SPI port, we access to CC2420's registers to achieve the function to send and receive and read the state of CC2420.

This paper presents the CC2420 driver software primarily consists of the following several parts:

1) Initialization

The initialization of the CC2420 include: the definition of the basic format of packet and DSP and CC2420 port, open the voltage regulator and reset CC2420, configuration register and select communication channels and so on. In the initialization process, the crystal oscillator should always be working.

2) Write data to FIFO register and start sending
CC2420 has two registers which is used to access the two transceiver FIFO buffer: one is used to access the send FIFO buffer, named TXFIFO register; the other used to access the receive FIFO buffer, named RXFIFO register. Through accessing to these two registers we can visit CC2420 transceiver FIFO buffer.

The module initialization and sending flow chart, is shown in Figure 4 and Figure 5.
C. showing ECG waveform in LCD

The LCD module has its own controller, and can provide stipple lines and graphics operations functions. Users can draw points and lines on the screen by using simple commands. Since ECG data is collected in integer, the curve should be displayed after the integer ECG data was changed into BCD code.

The LCD is 64 axis widths, while the maximum value of ECG is 4095, so each pixel is on behalf of 64, ECG data dividing 64 would be the vertical axis, the abscissa is 1,2,3,…,128. This only shows how to paint point, in order to show legible and visually curve, we need to connect points together. Assume that \( y(i) \) is for the vertical coordinate values corresponding to the LCD, if \( y(i+1) > y(i) \), We paint a line from \( y(i) \) just above until the half distance of \( y(i) \) and \( y(i+1) \), then from \( y(i+1) \) to paint to just below, until the half distance of \( y(i) \) and \( y(i+1) \). If \( y(i+1) < y(i) \), We paint from \( y(i) \) below until the half distance of \( y(i) \) and \( y(i+1) \), then to point from \( y(i+1) \) just above until half the distance of \( y(i) \) and \( y(i+1) \). With this method we can connect points into a curve.

D. Software design of serial

SCI clock is determined by the low-speed peripheral clock (LSPCLK) and baud rate register. In the case of the device’s clock frequency is determined; SCI’s baud rate could be set by a 16-bit register called SCI baud rate selection register. So 64K kinds of SCI can be used to communicate with different baud rate, different configurations of the baud rate selection register are shown in Table 1 [7, 8].

SCI’s baud rate could be calculated as follows:

\[
BAND - RATE = \frac{LSPCLK}{(BRR + 1) \times 8}
\]  

Serial communication data includes: a start bit, 1-8 data bits, parity bit and one or two stop bits. In serial communication, the first step is initialization and to stop the EVA timer 1. Then send the most recent 1000 ECG data individually to the serial port, when sending is finished, we restore the timer counts again to collecting ECG data.

| Standard Baud | LSPCLK CLOK (37.5MHz) | BRR   | Actual Baud | Error Ratio |
|---------------|------------------------|-------|-------------|-------------|
| 2400          | 1952 (7A0H)            | 2400  | 0           |
| 4800          | 976 (3D0H)             | 4798  | -0.04       |
| 9600          | 487 (1E7H)             | 9606  | -0.06       |
| 19200         | 243 (00F3H)            | 19211 | 0.06        |
| 38400         | 121 (00F9H)            | 38422 | 0.06        |

The initialization of the serial port includes: initializing SCIA pin for peripheral mode; setting the data format; enable sending and receiving bit; enable interrupt and set the baud rate and so on.

E. Applications on PC

We use visual C++6.0 to carry out Software development in PC. This application software we developed can be divided into serial communication program and ECG display program.

1) Serial communication program

We use the MSComm controls to develop serial communication program. MSComm control is a Microsoft ActiveX control, which is used to simplify the programming of serial communication under Windows. The control provides a range of standard communication commands interface, and serial connections can be established and be able to communicate through the serial port to connect to other devices (such as a modem). It can issue an order to exchange data and to monitor and respond to the serial connection when events and errors occur.
2) Program to display waveform

We insert Picture control in the dialog box client area, and then get the control’s ID and its device context, so that by calling the drawing function we can paint in the program. ECG waveform display is essentially to do the drawing operations in the dialog box. The dialog box support the basic drawing, lines, round and rectangular and other graphic methods or properties. We mainly use MoveTo, LineTo function. MoveTo function is used to set the pen position, LineTo function is used to draw a straight line from the current position of the pen to the specified location. Before drawing, we normalized the coordinate data to the text box pixel.

F. ECG segmentation algorithm

Detection of ECG’s QRS wave group is the primary problem in ECG waveform detection, and reliable detection of QRS wave group is the most important basis for diagnosis of cardiac arrhythmia. Only the QRS wave group is confirmed, will it be possible to further test and analysis the other details of the ECG information. In this article we propose an ECG segmentation Algorithm based on mathematical morphology.

While doing one-dimensional signal processing, we suppose: \( A = a(i)(i = 1,2,\ldots,N-1) \) as the signal sequence, \( B = b(i)(i = 0,1,\ldots,M-1) \) as structural elements, and then the erosion operation is defined as:

\[
A \ominus B(n) = \min_{m \in [i-1,i+1]} \{A(n+m) - B(m)\}
\]

During this formula \( m = 0,1,\ldots,N-M \). Dilation is defined as:

\[
A \oplus B(n) = \max_{m \in [i-1,i+1]} \{A(n+m) + B(m)\}
\]

During the \( m = M-1,M,\ldots,N-1 \). Corrosion expansion can also be composed of open, closed, hit, thinning, thick and so on. In this paper, expansion of operations, to eliminate the impact of peak signal detection, choice of 5 per unit length of the structural elements, and then do backward differential, differential results can be obtained response signal gradient information, namely, R-wave part of the differential results of larger, second-order differential can reflect the relative position of the peak. Finally, according to differential threshold to determine the specific location of QRS wave group, specific practices are as follows:

Take the threshold value \( \text{th}_1 \) giving a test to ECG signal \( y(n) \), if there are 5 continue points satisfied with \( y_1(n) > \text{th}_1 \), the wave R could be defined that it has already be detected, the maximal \( n_i \) of the five could be considered as the wave R’s crest.

After the wave R’s crest detection, the starting point and the ending point of the QRS should also be detected. Concrete method as follows:

Set the starting point threshold as \( \text{th}_s \) and the ending point threshold as \( \text{th}_e \), search the point before the wave R’s crest, when there are 5 point’s second differences continuing being smaller then \( \text{th}_s \), set the point \( n_1 \) which approach the wave R’s crest most in the 5 point as the QRS wave’s starting point. search the point behind the wave R’s crest, when there are 5 point’s second differences continuing being smaller then \( \text{th}_e \), set the point \( n_2 \) which approach the wave R’s crest most in the 5 point as the QRS wave’s ending point.

1) Search the minimal point \( n_p \) of \( y(n) \) during \([n_1,n_i]\), if there are 5 points near \( n_p \), and their first order difference equations are satisfied with:

\[-f_{\text{max}}/30 > f_1(n) > f_{\text{max}}/10\]  \hspace{1cm} (4)

The \( n_p \) can be see as the wave Q’s crest. In the formula, \( f_{\text{max}} \) indicates the maximum difference. If the minimum isn’t satisfied with this formula, the \( f_{\text{max}} \) should be adjusted range and re-searched.

2) Search the minimal point \( n_e \) of \( f(n) \) during \([n_e,n_2]\), if there are 5 points near \( n_e \), and their first order difference equations are satisfied with:

\[-f_{\text{max}}/10 > f_1(n) > f_{\text{max}}/30\]  \hspace{1cm} (5)
The ns can be see as the wave Q’s crest. If the minimum isn’t satisfied with this formula, it should be adjusted range and re-searched.

7. Experiment and conclusion

With the LCD we can give a simple customer interface to prompts the users’ operation, as shown in Figure 6. The users can select functions through the keyboard. The functions include: waveform real-time display, ECG data transmission through the serial port to the PC and wireless transmission of ECG data.

Figure 6. Instrument Prototype

After the welcome screen, LCD will show the menu to the users to prompt the users’ options. If the user press button one, and the instrument’s serial port is connected with the computer, the instrument will automatically transmit the ECG data collected to the PC through the serial port. If the user wanted to see their own ECG waveform, he can press button 2, while pressing button 3 can send data through ZigBee module.

When debugging serial communication, first we open the host computer software, and then press the keyboard one to observe whether the ECG data has been sent by the DSP. The results are shown in Figure 7. Software provided by the host computer also has saving the ECG data, waveform preview and some other functions.

Figure 7. Software interface diagram

ECG algorithm in section, at first, the signal should be processed by using morphological, and then, the QRS wave should be extracted by using the method of difference and threshold.
Figure 8. The ECG waves after morphological processing

Figure 9. The first-order differential wave of the ECG signal

Figure 10. The second-order differential wave of the ECG signal

Figure 8-11 show the morphology has played a significant role in filtering in the signal. The first-order differential near the wave R has a large amplitude and smaller at other place, so the wave R can be determined with the threshold method, and then, by using the detection algorithm described in 6.6, the test result of the QRS waveform feature point is shown in figure 11.
Our study’s starting point and core is to achieve the proposal to produce a small, intelligent and family-oriented ECG monitor. This paper describes the development of ECG monitoring and the basic theory of ECG first, and then proposed the instrument design.

This article achieved the basic hardware system design and debugging. Hardware system is divided into: data collection, liquid crystal display, the system power supply, and PC communications. Then we choose appropriate device and designed the hardware circuit, after revision and proofreading repeatedly, proposed the design of two-layers PCB.

According to components’ selection, we chose the dot-matrix graphic LCD Module, whose screen resolution is $128 \times 64$, which meets the requirements of dynamic display of ECG. We not only make full use of DSP’s peripherals resources to reduce system’s cost and difficulty of debugging, but also reduce the system size to meet the portability requirements.

We also completed the software design, with functional module debugging approach. We write low-level driver code for each hardware module, which can be directly invoked in the code integration of the system. Code including the AD driver, LCD driver, DSP initialization procedure and liquid crystal display procedures. Finally we discusses the ECG detection algorithm, using experimental data, we verify the effectiveness of the algorithm in PC.

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