12-Channel USB Data Acquisition System For QT Dispersion Analysis

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Abstract

QT dispersion has been generally agreed that it is a marker for the sudden cardiac death. Therefore an automated QTd analysis system is crucial in detecting the symptoms. Various systems have been developed in this field to support various medical and sports practice. The 12-lead electrocardiogram system is one of them. PC-base electrocardiogram system with automated analysis has been in the market for years. However these systems adapt the conventional parallel port and serial port PC interface. Various products have been developed based on the popular USB communication because of its capability to plug multiple USB devices via a USB hub and its unique identification of the type of device plugged in. The purpose of this paper is to describe the development of a 12-channel USB data acquisition system for electrocardiogram as part of an automated QTd analysis system. This paper however focuses only on the development of the digital side of the system. The data acquisition is interfaced to the PC via a USB module base on the FTDI Chip hassle free USB interface module. The 12-bit resolution data acquisition system based on PIC16F84A-20 has been able to sample at 500 Hz per channel for 12 channels and plotting is done on a simultaneous real-time basis.

Keywords:

Electrocardiogram, QT Dispersion, Data Acquisition, USB

Introduction

QT dispersion has been shown to be a marker of those at risk of sudden cardiac death due to cardiac arrhythmias [1]. QT is among of the various parameters of electrocardiogram (ECG) that represents the heart abnormalities. QT interval is defined as the measurement between the Q onset and the T offset of the typical ECG wave. QT dispersion (QTd) is defined as the subtraction of the maximum QT interval and the minimum QT interval in any of the 12 ECG leads. Automatic QT interval measurement involves the accurate detection of the Q onset and T offset point in the ECG wave. The T offset computerized detection is the most challenging task. This is due to the different morphologies of the T wave [1]. Therefore it is critical to have in hand a database of ECG from various group of subjects from a variety of arrhythmias. Since the QTd has the potential in anticipating sudden cardiac death, it is important to have tool that acquires the ECG and produces the QTd index continuously and as instantaneous as possible. Moreover, the development of algorithm such as the T end point detection which utilizes digital signal processing is a endless study and improves with time. Hence a PC based data acquisition for 12 lead ECG is relevant to facilitate this never ending algorithm development and database growth.

A low-cost personal computer (PC) based virtual oscilloscope has been developed by [2]. It is an 8 channel, 8 bit resolution oscilloscope. The device interfaces with the PC via the inexpensive but bulky and uncommon parallel port nowadays. However, the system's ability to display all the 8 channels simultaneously on the PC graphical user interface (GUI) has inspired the author. The PC has seen the growth of the Universal Serial Bus (USB) as the standard for peripheral devices interconnection. It can be found on every desktop, laptop or PDA as with compared to the parallel port [3]. The Ethernet popularity goes along with the USB but it loses on the complexity and cost of implementation. [4] chooses USB over the RS232 serial interface due to its higher data transmission speed. This is because of the 48kHz sampling frequency required for their application for sound and vibration measurements. The internal expansion ISA and PCI slot has also been a common means of data transfer between a data acquisition unit and the PC. However, they are susceptible to obsolescence when the computer architecture evolves [5].

Various USB interface chip is available to be easily interfaced to a device. There are also microcontrollers with USB interface built in. However, [5] disregarded this due to avoid interaction with the internal buffers of a microcontroller which consumes clock cycles in firmware execution. [4] describes three transfer modes common to USB, namely the interrupt mode, bulk mode and isochronous mode, and ascertain that the bulk mode enables higher data transmission rate. [4] also proposed, in order not to lose time which is required for sending out data package, two FIFO buffers are essential. While one buffer is sending data out, the other is filled by data. USBN9602 and USBN9603 dedicated USB chip was implemented by [4] and [5] respectively and ISP1181 by [6]. These chips have yet requires the consumer to have deep knowledge in the USB protocol.

[7] describes the USB interface as a mean of isolation in designing medical devices. The system

described in this paper nevertheless assumes the isolation stage is to be implemented in the analog part of the 12-lead ECG circuit.

The system adapted in this paper is an easy-to-interface USB module with the PIC16F84A-20 microcontroller. The architecture of the data acquisition unit developed is detailed in the next section.

The Overall Architecture Of The System

The Main Components

MPC506 Analog Multiplexer

It is a sixteen channel single-ended analog multiplexer (MUX). It has a four channel selection pins, A0 through to A3 and features break-before-make switching, no channel interaction during over-voltage and 70Vp-p analog over-voltage protection. Input signals range from +15V to -15V and signal path of other channels would not be disturbed if analog input exceed power supply voltage.

One parameter of concern other than stated above is the settling time of the channel selected. Ignorance on this factor during firmware programming will affect the output voltage of the multiplexer. Such occurrence is a pair of neighboring analog to digital conversion from the same channel. The settling time for the MPC506 is at least 3.5µs. The MPC506 is configured to accept input voltage from -10V to +10V.

ADS7806 Analog To Digital Converter

The ADS7806 is a 12-bit analog to digital converter (ADC). It has a 25µs maximum conversion and acquisition time, parallel or serial selectable data output, and operates from a single 5V supply. It is a successive approximation ADC with built-in sample and hold circuit, clock, reference and interface with microprocessors. It provides input ranges of ±10V and 0V to +5V.

The ADS7806 configuration circuit is put to sample voltage ranges of ±10V with external offset and gain calibration. The ADC interfaces with the microcontroller via the parallel output and the conversion output is in the 2's complement format. The maximum conversion and acquisition time is 20µs and 5µs respectively and the convert pulse width must be at least 40ns.

DLP245BM USB Module

The proposed system utilizes the USB as a mean of data transfer and this is made realizable by USB interface chip manufactured by FTDI Chip. FT245BM, a parallel FIFO USB chip operates as a bidirectional data transfer. It interfaces with microcontroller with a 4 wire handshake control pins. The USB protocol is handled entirely on-chip and therefore there is no need for USB specific firmware programming required as in USBN9602, USBN9603 and ISP1181 USB dedicated chip. Provided also is the send immediate (SI) pin which helps in optimizing data throughput. The FT245BM only allows bulk and isochronous transfer mode. Transfer data rate is achievable at 1MByte per second when the D2XX driver, provided with no charge, is utilized. The DLP245BM USB module employs the FT245BM chip and incorporates a serial EEPROM to store the programmable Vendor ID (VID), Product ID (PID) and description string. Data to be sent or received can be access through the eight data pins.

PIC16F84A-20 Microcontroller

The PIC16F84A-20 operates on a 20MHz crystal making it fast enough to sample at 500Hz for 12 channels. With this crystal frequency, it executes instruction at 200ns per clock cycle. The microcontroller role is to control the overall data flow of the system.

The System

The Interconnection

Figure 1 shows the block diagram and the data flow of the developed system. Twelve analog signals enter the system via the analog multiplexer and digitized by the 12-bit ADC. The sampled data output is then interfaced directly to the data bus of the FTDI-based USB module. From the figure, it can be clearly seen that the microcontroller only controls the analog MUX, ADC and the USB module. Data output from the ADC is sent directly to the PC where data manipulation will be done.

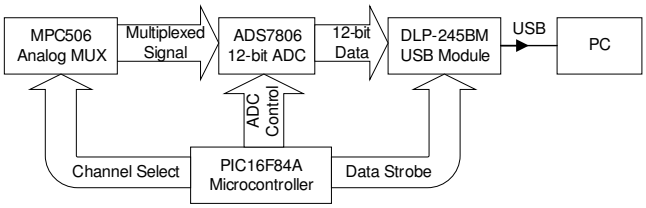

Figure 1: Data Acquisition System Interconnection

The microcontroller controls channel selection through the A3:A0 address pins of the analog MUX. The pins interfaced to the microcontroller from the ADC is the R/C* for starting analog to digital conversion and reading from the ADC output, BYTE for determining low or high byte selection at data output. The DLP245BM ports with the microcontroller via the TXE* pin that checks for empty transmit buffer, WR pin that strobes data on the bus into the transmit buffer and the SI pin that sends whatever data is in the buffer to the PC without waiting for the buffer to be full.

The Firmware Programming

The program flow for the firmware of the microcontroller is shown in Figure 2. On reset, the microcontroller initializes the analog MUX, the ADC and the USB module. It sets the MUX to the first channel selection, the ADC to the data output state and empties the transmit buffer. On completing initialization, the system sends a converts pulse of 200ns to the ADC to start digitizing the current selected channel. Conversion completes after 20µs and the high and low byte of the 12-bit conversion result is strobe into the USB module's buffer. Selection of the next channel follows so as to allow settling time for channel switching. This must be at least 3.5µs. The inter-channel delay routine completes the process for a total of 25µs. This delay is important to ensure

full convert and acquire process of the ADC and avoid erroneous conversion. The process will loop for the next eleven subsequent channels. After the total twelve channels data have been written to the USB module's buffer, the 24 byte of data will be sent to the PC. This 24 byte array is arranged in ascending channel order with the arrangement of high byte followed by low byte for every channel. With this, there is no need for appending channel identification since the location of the channel and byte is predetermined in the array. This way, the channel demultiplexing process at the PC side has been made simpler. The total time consumed is 324µs. The time required to achieve a sampling rate of 500Hz is 2000µs. Therefore, there should be delay of 1676µs before the next 12 channels is sampled and sent to the PC.

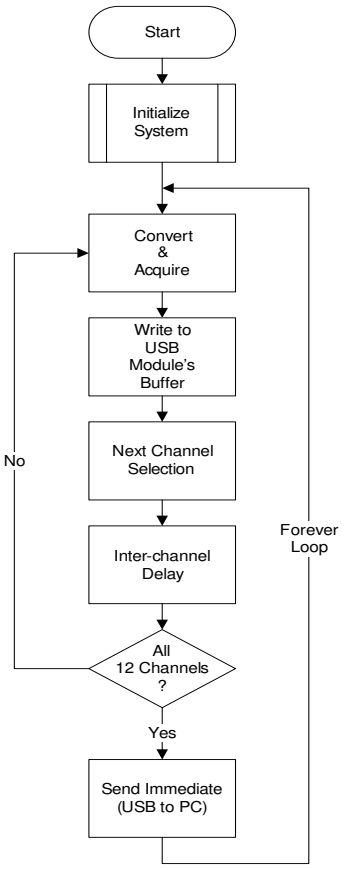

Figure 2: Firmware Program Flow Chart

The PC Software

The PC software is developed in Microsoft Visual C++ environment on a Windows XP platform. The software utilizes the single document interface (SDI) format. This enables the author to plot all the 12 channels on the document area of the interface. The main program resides in the USB data reception thread. The thread continuously monitors if there is data on the PC USB buffer. If there is data and the size of the buffer is 24, then the software will immediately sorts and append the appropriate data into 12 individual channel arrays. These data will then be plotted onto the document interface of the software simultaneously. This is depicted in Figure 3 as shown below. Figure 4 shows the GUI developed to display the signals in real-time and simultaneously. The software enables preview before the actual recording and save process.

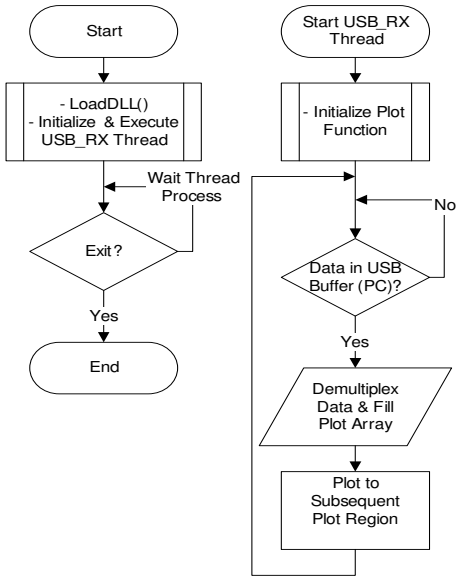

Figure 3: PC Software Program Flowchart

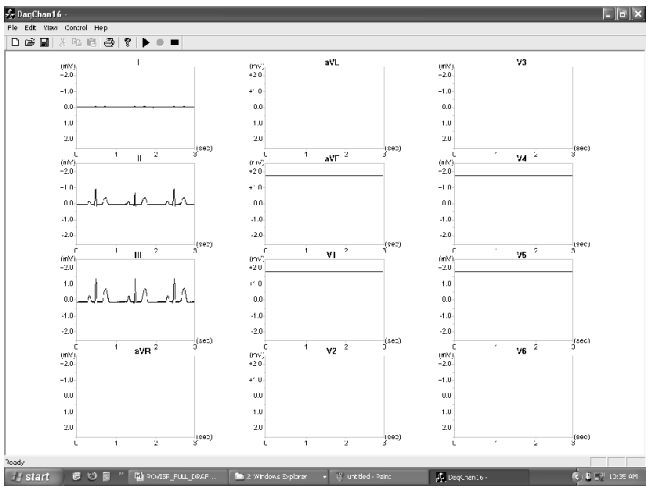

Figure 4: The PC Software Graphical User Interface

Results & Discussion

The system has been successfully been able to acquire twelve channel signals at a sampling rate of 500Hz each. The system has also been able to plot the signals in real-time simultaneously. Therefore it is ready to acquire 12-lead ECG signals and undergo digital signal processing for QT dispersion indexing in real-time too.

In realizing this system, several obstacles have been observed and overcame. Among them is in programming the multithreading process in the PC software. Initially, two separate threads are used. One thread is to acquire data from the PC USB buffer and the other is to plot. The maximum size of the PC USB buffer is 64kByte and it is observed that after approximately 60 seconds the data received from the buffer is erroneous and

the buffer count indicates that it is full. The condition should be that every data received are directly saved into an array and plotted. It seems that the data accumulates while it is being plot. The plotting thread of all twelve input signals simultaneously has created a noticeable delay. This is solved by combining both the acquire and plot threads into a thread. Experimenting with the PC USB buffer count, it is found that it takes approximately 120 seconds before the buffer gets full and the data become erroneous and this shows a good indication. The second obstacle is to get rid totally of the buffer accumulation. In the beginning, the plot width of every channel is defined for 5 seconds. Assuming that wide plot width for twelve channels consumes time, the plot width is reduced to 3 seconds for every plot. As expected, reception of data at the PC USB buffer empties at every PC USB buffer read instruction and eliminates accumulation and thus continuous real-time acquisition is achieved.

Conclusion

The problem of sudden cardiac death has prompted researchers to design a real-time QT dispersion indexing device. The research centre for biomedical engineering has come out with a 12-channel USB data acquisition for QT dispersion analysis. The device which is able to acquire data in real-time has been described. The device is able to acquire 12-lead ECG signals at 500Hz per channel. This device is part of an entire system for real-time QT dispersion analysis. The following task, would be to design the analog circuit to condition 12-lead ECG signal prior to data acquisition. This would then be followed by implementing digital signal processing for QT dispersion analysis.

References

[1] P Langley, JH Dark, A Murray. 2000. QT Dispersion Analysis of a Transplant Assessment Group. IEEE Trans. Computers In Cardiology, 27:167-170

[2] C. Bunia, S. Giri, S. Kar, S. Haldar, P. Purkait. May 2004. A Low-Cost PC-Based Virtual Oscilloscope. IEEE Trans. On Education Vol. 47

[3] A. Depari, P. Ferarri, A. Flammini, D. Marioli, E. Sisinoi, A. Taranoi. January 2004. IEEE1451 Smart Sensors Supporting USB Connectivity. IEEE Sensors for Industry Conference

[4] A. Podgorski, R. Nedwidek, M. Pochmara. September 2003. Implementation of the USB Interface In the Instrumentation for Sound and Vibration Measurement and Analysis. IEEE Int. Workshop On Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications

[5] B. Murovec, S. Kocijancic. 2003. Educational Data Acquisition System with USB Interface. IEEE EUROCON

[6] M. Popa, M. Marcu, A. S. Popa. 2004. A Microcontroller Base Data Acquisition System With USB Interface. IEEE

[7] S. Junnila, J. Ruoho, J. Niittylahti. 2002. Medical Isolation of Universal Serial Bus Data Signals. IEEE.