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Design of a Data Logger for Biomedical Signals

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***Abstract*—Recording of physiological and psychological variables in real-life condition is useful in treatment of patients with health problem. In developing countries, delays in giving medical assistance to individuals (patients) usually occur due to the cumbersome process of getting patients' information to medical personnel. Due to advancement of low cost and portable electronic devices, this paper presents a non-invasive device that acquires and stores electrocardiogram (ECG) and temperature signals of patients. The analog signals from the signal conditioning circuit are sent to the microcontroller's analog to digital converter. The data is then logged in a SanDisk (SD) card for later transfer to a personal computer (PC). Playback of analog signals is also included using the microcontroller's CCP module to convert the stored data back to analog. A visual basic Graphical User Interface (GUI) is designed to view the graph of the data on PC. The circuit requires no external component for ADC and a simple low pass filter for DAC, resulting in reduced size of overall circuit and cost of the system.**

***Index Terms*—ECG, ADC, SD, GUI, SPI**

I. INTRODUCTION

A data logger is an electronic instrument that records digital, analogue, frequency of a signal within a specified period. Furthermore, data loggers are measuring equipment that has been effectively deployed in numerous applications. Some of the significant areas in which data loggers are extensively used include biomedical instrumentation, power quality measurement and automotive engineering. For effective operation of a data logger, it has to be portable, battery-operated and should be interfaced with computer or as a stand-alone instrument [1], [2]. The aim of signal processing in biomedical is to extract clinically, biochemically or pharmaceutically significant information so as to facilitate an improved medical diagnosis. Furthermore, signal processing in biomedical involves filtering the signal of interest out of the noisy background. All living organisms produce signals of biological origin. Such signals can be electric, mechanical, or chemical. All such signals can be of interest for diagnosis, for patient monitoring and biomedical research [3].

The human body contains systems such as skeletal system, nervous system, digestive system. These systems also entail subsystems which are involved in various physiological processes like the rhythmic pumping of blood handled by the cardiac system. These physiological processes manifest themselves as signals that reflect their behaviors and activities. Biological signals can be referred to as those signals recorded from a living system and convey information about the state and behavior of that system. Biological event such as the heart beat or a contracting muscle can be recorded [4], [5]. Furthermore, [6] described biomedical signals as signals used in biomedical fields mainly for extracting information on a biological system under investigation. The speed at which records of patients get to doctors or medical personnel determines the time patients can receive medical assistance. Since most hospitals especially in developed countries do not have the necessary biomedical signal acquisition devices, diagnosis of patients sometimes rely on the medical personnel's experience or what patient can remember about their family history and not on present or past interpretation of signals from the body. This could sometimes lead to improper diagnosis and wrong prescription. It is important for people in remote areas who do not have access to health care delivery especially in cases of emergencies to be able to access them when needed. In this paper, a low cost, battery operated, low power consumption and high memory capacity data logger unit for biomedical signals is designed.

II. RELATED WORK

A unit that converts acquired ECG signals to digital signals and stored them in 20MB memory cards was designed in [7]. Also, in [8] a device that stored the acquired signals (fetal and maternal heart beat signal) in a temporary SRAM for later transfer to a PC was designed. In [9] a unit that receives the skin response for autistic patients using RS232 and stores the data in a 16MB EEPROM was designed. A device that measures, records ECG and motion signals continuously in a SD (SanDisk) card for a moving subject and also notify the remote doctor of the situation by transmitting data on the emergent situation to a remote server was designed. Additionally, in [10] a long term portable recorder for ECG signals using SD cards for later transfer to a PC using RS232 interface was described. Furthermore, [11] described a microcontroller-based wearable heart rate monitor that acquires biomedical data and sends them to a nearby PC wirelessly using Bluetooth. This design does not include an internal storage memory. In [12], an advanced physiological data logger for medical imaging applications was designed. In the design, a 4MB SD card

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was used to store biomedical data. The data could then be transferred to a PC using an SD card reader, USB interface or wirelessly through Bluetooth.

Although EEPROMs have less complex firmware libraries, this research work stores biomedical data in a SD card which are less expensive and also have file system capability. The design also plays back the stored samples of the biomedical signal by converting them back to analog using the CCP module of the microcontroller, thereby eliminating the need for extra components of a Digital to Analog Converter.

III. MODULE DESIGN AND IMPLEMENTATION

The data logger is designed in two parts namely, signal conditioning and data storage. The signal conditioning circuits are simulated in Multisim while the storage circuit is simulated in Isis Proteus.

Signal Conditioning

For the ECG, coins are used as the electrodes to convert the ionic current in the body to voltage. An instrumentation amplifier, AD620, then amplifies the weak ECG signals and rejects common mode signals (noise). This instrumentation amplifier is accurate, cheap and requires only one external resistor to set gain. This is given in equation (1).

$$G = \frac{49.4k\Omega}{R_G} + 1 \tag{1}$$

The signal is then filtered with a band pass filter to remove the low and high frequency noise. The lower and upper cut off frequencies of the filter, calculated using equation 2 are 0.05Hz and 103Hz.

$$f = {}^{1}/_{2\pi RC}\ Hz \tag{2}$$

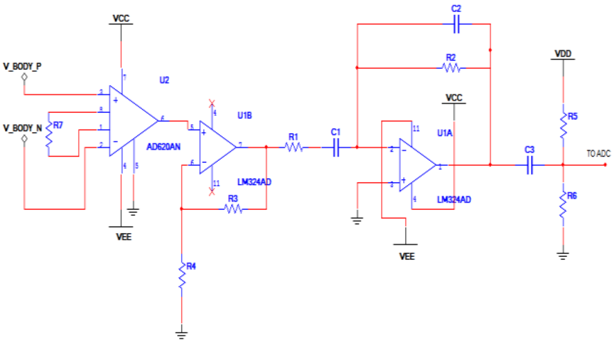


Figure 1. Overall ECG amplification circuit

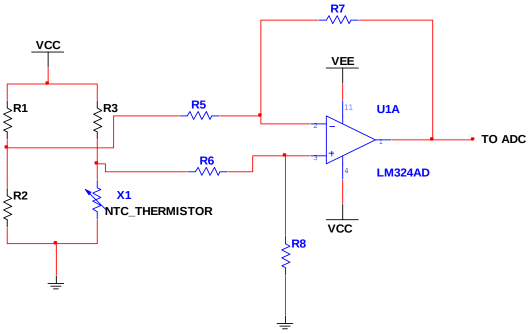


Figure 2. Overall temperature circuit

The signal is then level shifted so that the input to the ADC has only positive range of values. Fig. 1 shows the overall ECG amplification circuit.

A thermistor sensor whose resistance changes with change in temperature is used to sense the body temperature. This thermistor is placed in a Wheatstone bridge configuration as shown in Fig. 2.

Change in the voltage difference corresponds to change in thermistor resistance. The voltage difference of the Wheatstone bridge which corresponds to the thermistor resistance from equation (3) is then amplified with the difference amplifier since the voltage is in the mV range. The gain of the difference amplifier is calculated using equation (4).

$$V_{diff} = V_{in} \times \left(\frac{R_t}{R_t + R_2} - \frac{R_3}{R_3 + R_1}\right) \tag{3}$$

where R_t is the thermistor resistance and V_{diff} is the bridge voltage.

$$V_{out} = \frac{R_7}{R_5}\left(V_b - V_a\right) \tag{4}$$

The output of the difference amplifier then goes to the ADC of the microcontroller.

Data Storage

A signal generator was used as the analog input to the ADC. A saw tooth signal of 100Hz and 1V was selected to test the program function. The microcontroller source code was programmed in C language. The program included the ADC process where the sampling rate, analog pins and ADC clock were determined. Since the highest frequency component for the ECG signal is 100Hz, the sampling rate selected for the ADC was 500Hz which is above the Nyquist sampling frequency. The communication between the microcontroller and the memory card used the Serial Peripheral Interface (SPI) protocol. The microcontroller is powered at 5V and the memory card was powered at 3.2V. The typical logic 1 output voltage of a PIC microcontroller is 4.3 V which is too high when applied as an input to a memory card, where the maximum voltage should not exceed 3.6V. Table I shows SD Card Input-Output Voltage Levels.

TABLE I. SD CARD INPUT-OUTPUT VOLTAGE LEVELS

	Symbol	**Minimum**	**Maximum**
Logic 1 output voltage	VOH	$0.75 \times V_{dd}$	
Logic 0 output voltage	VOL		$0.125 \times V_{dd}$
Logic 1 input voltage	VIH	$0.625 \times V_{dd}$	$V_{dd}+0.3$
Logic 0 input voltage	VIL	$V_{ss}-0.3$	$0.25 \times V_{dd}$

Maximum logic 0 output voltage, VOL=0.4125V
Min. required logic 1 input voltage, VIH=2.0625V
Maximum logic 1 input voltage=3.6V
Maximum required logic 0 input voltage, VIL=0.825V

As a result, voltage dividers were placed between the microcontroller and the memory card to lower the SD card input voltage to approximately 3V. This is given by equation (5).

$$SD_{IV}\ Card\ input\ voltage$$

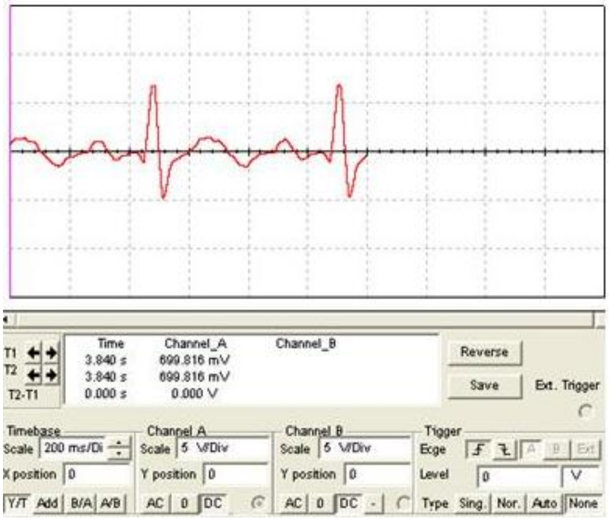
$$SD_{IV} = \frac{4.4\,V \times 2.2\,k}{2.2\,k + 1\,k} = 3.02\,V \tag{5}$$

The output voltage of the SD card is enough to drive the input of the microcontroller.

Five pushbuttons were used for user interaction with the system. Button 1 allows the user specify the file number, button 2 creates a new file when pressed, button 3 records the signal in the selected file number, button 4 plays back signal from a selected file number, button 5 cancels any ongoing activity when pressed. A simple low pass filter with cut off frequency of about 100Hz was designed to filter the high frequency components contained in the signal when it is played out as analog signal from the microcontroller's CCP2 module. The files in the memory card can be transferred to the hospital (or company as the case may be) database for further processing and/or storage. A visual basic GUI was developed for users to view and analyze the graphs of each patient on a PC.

IV. RESULTS AND DISCUSSION

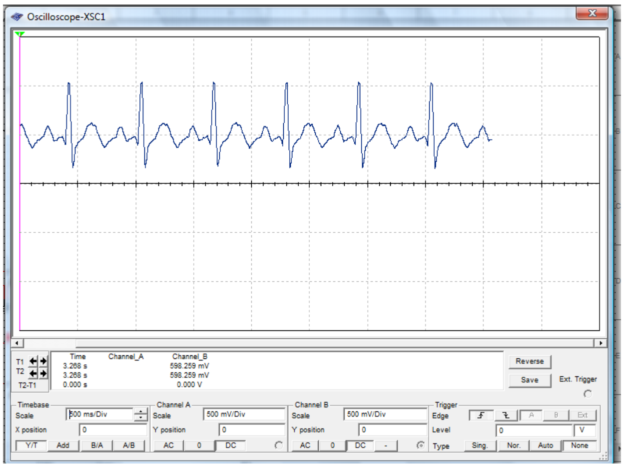
Fig. 3 shows the output of the circuit before level shifting the signal with dc offset circuit and Fig. 4 shows the output of the dc offset circuit.



	Time	Channel_A	Channel_B
T1	3.840 s	699.816 mV	
T2	3.840 s	699.816 mV	
T2-T1	0.000 s	0.000 V	

Timebase Scale 200 ms/Di; X position 0
Channel A Scale 5 V/Div; Y position 0
Channel B Scale 5 V/Div; Y position 0
Tigger Level 0 V

Figure 3. Output of amplifier



	Time	Channel_A	Channel_B
T1	3.268 s		598.259 mV
T2	3.268 s		598.259 mV
T2-T1	0.000 s		0.000 V

Timebase Scale 500 ms/Div; X position 0
Channel A Scale 500 mV/Div; Y position 0
Channel B Scale 500 mV/Div; Y position 0
Trigger Level 0 V

Figure 4. Output of DC offset

When a sine wave is selected in the signal generator as the analog input, the signal is converted to digital with the ADC and then stored in a file in the SD card. Fig. 5 shows the output of the PIC CCP2 on an oscilloscope. ECG samples are then placed in the microcontroller program to represent ADC samples. These are the samples that are then stored in a file inside the SD card. Fig. 6 shows the output of the PIC CCP2 on an oscilloscope.

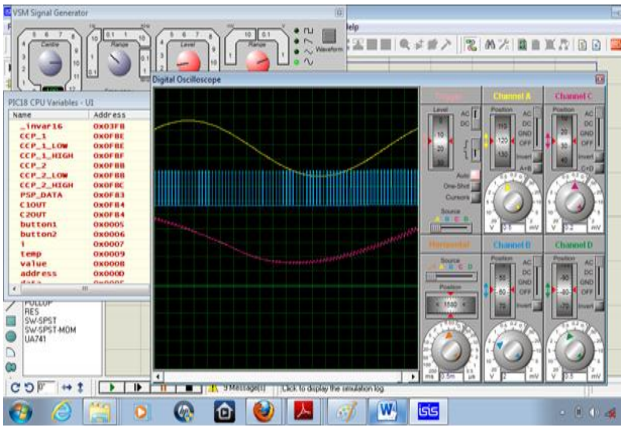


Figure 5. Oscilloscope showing output when sine wave signal samples are read from file

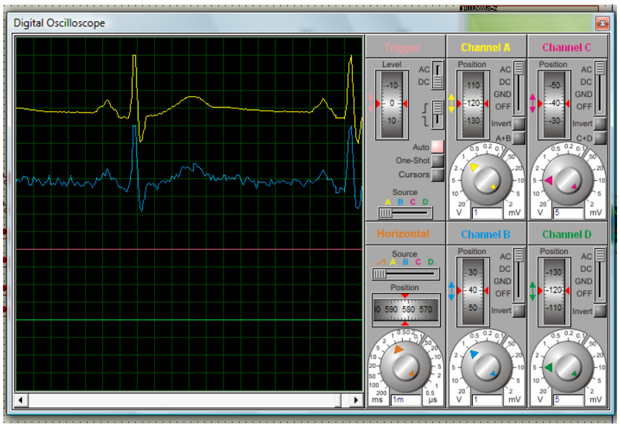


Figure 6. Oscilloscope showing output when ECG signal samples are read from file

The results show that acquired ECG signals are conditioned for analog to digital conversion and then sampled. They are stored in the SD card and can be played back using the CCP2 module of the PIC 18F4520 microcontroller. The PWM is a square wave cycle whose average DC value can be varied by varying the duty cycle. The pulse width, t, is the time during which the PWM cycle is ON and the duty cycle is the ratio of the ON time to the period. The samples read from the SD card are used to vary the duty cycle of the PWM signal. The original signal is then obtained by low pass filtering the PWM signal. The low pass filter consists of a single resistor and a capacitor. Fig. 5 shows the output of the circuit when the stored 100Hz sine wave samples are played back. The sine wave input is the waveform output from channel A of the oscilloscope, channel B output waveform is the PWM signal while channel C waveform is the output sine wave. The samples are used to vary the duty cycle of the PWM and then the original signal is filtered with the low pass filter having a cut off frequency of 106Hz.

V. CONCLUSION

In this work, the design of a data logger is presented. The signals from the signal conditioning circuit is converted to digital with the microcontroller ADC and then stored in an SD card. Users are given freedom to create and/or select file numbers in the SD card using an LCD screen for proper organization of patient records. Visual basic GUI is also designed to view graphs of signals stored in the SD card on PC. The CCP module of the microcontroller is used with a low pass filter to convert the stored data back to analog if the user decides to playback a selected stored signal. The proposed data logger provides the user with the desired accuracy, flexibility and cost-effectiveness rarely seen in commercially available devices. Performance evaluation of the data logger shows effective operation for biomedical signals.

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