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Development of an Analog ECG Simulator using Standalone Embedded System

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ABSTRACT: This paper describes the development of a microcontroller based hardware ECG simulator which generates real-time analog ECG signal in the range of 0-5 volt. The synthetic ECG signal generated by the simulator can be used for testing and calibration of medical instruments, biomedical experiments and research in laboratories. The PTB diagnostic database collected from Physionet has been used as the standard database to generate ECG signal. This database has a sampling rate of 1 kHz. The ECG database is amplified and quantized in 8-bit resolution. A MATLAB algorithm has been used to serially transmit the quantized ECG data using RS-232 protocol to an 8051 based stand alone embedded system where it gets converted into 8-bit parallel data and delivered to the digital to analog converter. At the DAC output we get the analog ECG signal in 0-5 volt range.

Index Terms— ECG, Embedded system, RS-232 protocol, Simulator.

I. INTRODUCTION

The bioelectrical signal generated by heart muscles is known as Electrocardiogram. This signal is the electrical signature of functioning of heart. The ECG signal is picked up from body using biopotential electrodes. In clinical practice there are 12 conventional leads, which may be divided into two groups depending upon their orientation to the heart- i)The frontal plane leads ii)The horizontal plane leads. ECG has a great clinical importance for diagnosis of diseases related to the heart. Traditionally ECG signal is recorded by an ECG machine on a graph with time along the X-axis and voltage along the Y-axis. A typical ECG beat tracing of the cardiac cycle (heart beat) consists of a P-wave, a QRS complex, a T-wave and an occasional U-wave.

For biomedical research works as well as calibration of biomedical instruments various types of normal and abnormal ECG signals are needed. It is really difficult to collect human patients with various cardiac abnormalities. Moreover, collecting ECG samples from human patients would require bio-safe amplifier with proper safety certification. These problems may be easily avoided using a hardware ECG simulator, which eliminates the necessity of human patients as well as an ECG machine. An ECG simulator is a PC-based system which generates synthetic ECG signal from standard database replicating the ECG signal from a human body. On the other hand it removes the difficulties of collecting real ECG signals with invasive and noninvasive methods. Real time ECG signal can be generated by maintaining the sampling rate same as the sampling rate of the standard database, so that the simulated signal replicates the original ECG database.

ECG waveforms having normal and user specified heart rate can be generated by probabilistic method using stored ECG waveforms [1]. Microcontroller based ECG simulators are available in the market which can be used for virtual reality application [2]. Application of embedded system and computer in biomedical instrumentation is of intense important now a days [3-8]. This paper illustrates a real time ECG simulator using a PC-based standalone embedded system. The simulator generates analog ECG signal in the range 0-5 volt using the standard ptb-db database collected from Physionet [9]. A MATLAB program is used for amplification and quantization of the ECG samples within (0-255) to be compatible with an 8-bit processor (Atmel 89C2051) system. Therefore these data are sent to the microcontroller based system by PC com port (serial com port) using RS-232 protocol. The microcontroller performs the job of serial to parallel conversion of the 8-bit ECG data. The simulator output is derived from the DAC output in the range 0-5 volt.

II. METHODOLOGY

The block representation of the system is shown in the Fig-1. The first block is the software block. A single lead ptb-db data array in *mat format is used as the input data to a software program. Next, the data array is amplified and quantized with 8-bit resolution. After that the quantized data array is transmitted at a constant baud rate by the serial port of the personal computer using RS-232 protocol. The next block is the standalone embedded system which consists of four components- (i) MAX232 level converter, (ii) Atmel 89C2051 Microcontroller unit (MCU), (iii) digital to analog converter

(DAC 0808) and (iv) current to voltage converter (using LM324). This standalone system converts the 8-bit serial data into 8-bit parallel data, then into an analog signal in the range of 0- 5 volt.

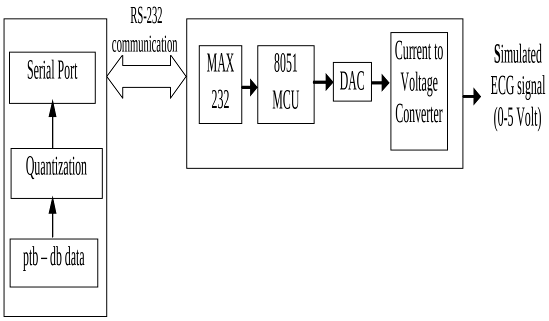


Fig 1: Block Diagram of the system.

A. Amplification and Quantization of ptb-db

The ptb-db database is a standard ECG database having a sampling rate of 1 kHz. Using a MATLAB program a single lead data samples are processed so that it generates an ECG signal from an ECG electrode system with certain amplification factor and a positive dc shifting. It is being observed that low amplitude ECG signal always ranges within ± 3-5 mV. The ptb-db database also contains data with amplitude with in ±5 mV. At first each sample array is amplified with a constant gain. Here the amplification factor is kept as 500 to get a value within ±2.5 volt. This process resembles an amplifier with a constant gain of 500. Now the derived value is dc shifted by a voltage 2.5 to generate an output of 0-5V, since most of the real life ADCs accepts unipolar analog signals. After that the signal is multiplied by 51 (which is equal to 255/5, or quantization factor of ADC) to quantize the database with 8-bit resolution, i.e., by the above processes milli volt samples are converted in 0-255 range. To summarize, three consecutive operations are performed to process the ptb-db for an 8bit system –

(i) A constant gain (500) is given to the data samples.
(ii) DC shifting of +2.5.
(iii) Multiplied by 51 for 8-bit quantization.

If X[i] is one ECG sample from ptb-db, then the quantized data is obtained as

$$Y[i] = \{X[i] \times 500 + 2.5\} \times 51 \qquad \dots (1)$$

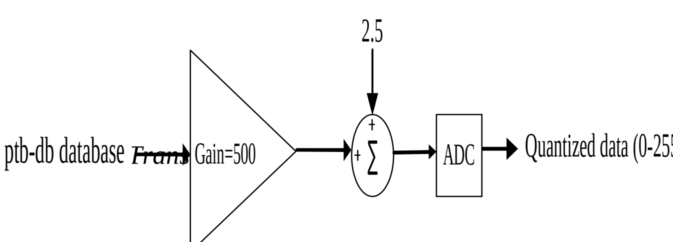


Fig. 2: Block representation of the amplifier with a dc shift.

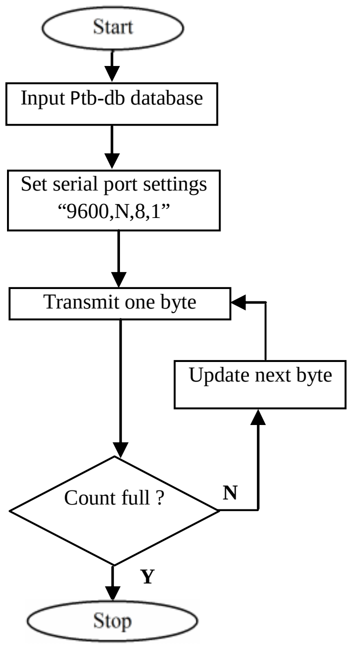
After 8-bit quantization of the data array, it is transmitted to the microcontroller using RS-232 serial communication protocol. To transmit the data serially an event driven programming is used where 10000 quantized samples are delivered trough the output port using an appropriate buffer length using a baud rate of 9600 and 'no parity'. At each occurrence of 'empty buffer' event, the sample is replenished with new data using a data counter. Two pins i) TxD and ii) GND of the DB9 connector are used to send the data serially to the microcontroller.

B. Serial to Parallel Conversion

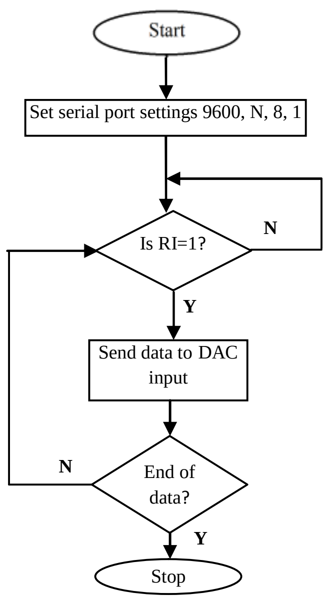
An 8-bit microcontroller (89C2051) is used to receive the 8-bit quantized data transmitted by the serial port of the PC through a level converter (MAX232), which converts the RS-232 logic level into the TTL/CMOS logic level. The main objective of the microcontroller is the serial to parallel conversion of the 8bit ECG data. The microcontroller serial data transmission mode is set as 8-bit variable baud rate universal asynchronous receiver transmitter (UART) mode. The serial communication Baud rate is also set at 9600. So that it properly synchronizes with the incoming data sampling rate. The 8-bit serial data is received at microcontroller serial receive (RxD) pin and hold by the SBUF register. After receiving a complete byte the microcontroller is interrupted by the Receive Interrupt (RI) flag. With this interruption the microcontroller sends the received data byte from the serial buffer register to the 8bit parallel port. This process is continued until the last data byte is received. The parallel port of the microcontroller is connected to an 8-bit digital to analog converter (DAC0808) input port. The 8-bit digital data is converted into an analog signal by the DAC. The reception of the serial data and its conversion to an analog signal is almost a simultaneous process and the ECG simulator can be called a real time ECG simulator. As the DAC output is a current signal, it is converted into a voltage signal in the range 0-5 volt using a current to voltage converter. For this purpose LM324 is used. The output of the current to voltage converter is the desired simulated ECG signal which is an analog signal of 0-5 volt.

III. RESULTS

The experimental hardware setup and the digital storage oscilloscope output of the simulated ECG signal is shown in Fig 5 (A) and Fig 5 (B) respectively. The PTB database is used to test the performance of the ECG simulator by calculating the ratio of important parameters of ECG waveform both for original ptb-db database and quantized database. By this process the capability of the simulator to replicate the original ptb-db at the simulator output can be determined. The percentage error between the ptb-db data and the 8-bit quantized data is calculated to examine the distoriton of the quantized ECG waveform due to amplification and 8-bit quantization.



(A)



(B)

Fig 3: (A) Flowchart for serial data transmission using MATLAB (B) Flowchart of serial to parallel data conversion at embedded system.

This error is calculated for different ECG leads (e.g. Lead I, aVL, aVR, V3 etc.) by determining the QRS complex height and T-wave height from the original ptb-db waveform and quantized ECG waveform by plotting the wave forms using MATLAB simulation program. The % error is calculated using the equation:

$$\%\ error = \frac{R_{ptb} - R_Q}{R_{ptb}} \times 100 \qquad \ldots (2)$$

Where, $R_{ptb} = QRS_{ht} / T_{ht}$ for ptb-db data,

$R_Q = QRS_{ht} / T_{ht}$ for quantized data,
QRS_{ht} = Height of the QRS complex of ECG waveform and T_{ht} = height of the T- wave of ECG waveform.
Here the % error is calculated using the ptb-db database for Lead I, aVL, V3, V4 for P1/s0014 and Lead I, V3, V6 for P2/s0016.

Table 1: The % error between the PTB data and the quantized data.

Lead Information		QRS_{ht}	T_{ht}	QRS_{ht}/T_{ht}	%error={(R_{ptb}-R_Q)/R_{ptb}}*100
P1/s0014 Lead I	ptb-db	2.207	0.506	4.36	-1.37
	Quantized data	56.82	12.85	4.42	
P1/s0014 aVL	ptb-db	2.565	0.57	4.5	3.68
	Quantized data	65.51	15.1	4.34	
P1/s0014 V3	ptb-db	5.452	0.504	10.8	-0.92
	Quantized data	138.98	12.72	10.9	
P1/s0014 V4	ptb-db	4.69	.245	19.14	-2.61
	Quantized data	119.86	6.1	19.64	
P2/s0016 Lead I	ptb-db	2.186	.514	4.25	.705
	Quantized data	55.3	13.1	4.22	
P2/s0016 V3	ptb-db	5.793	.318	18.2	0
	Quantized data	148.1	8.1	18.2	
P5/s0031 V6	ptb-db	1.938	.347	5.58	.537
	Quantized data	49.4	8.9	5.55	

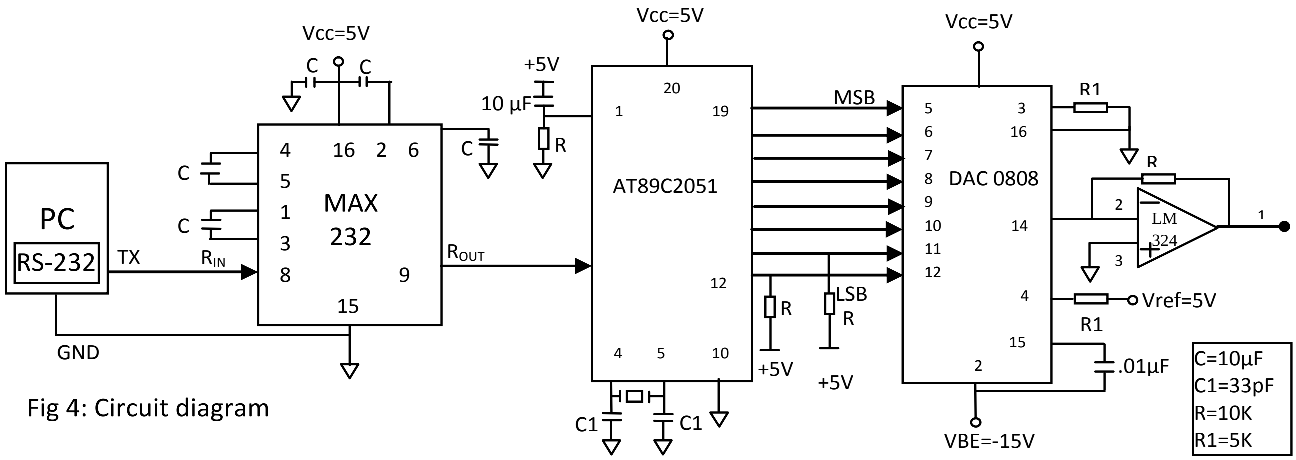
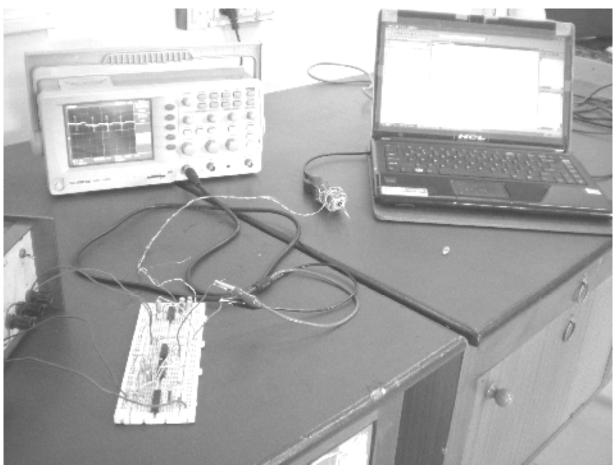
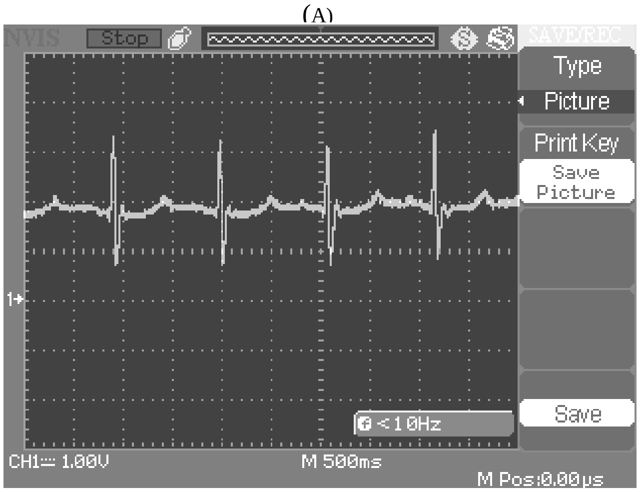


Fig 4: Circuit diagram

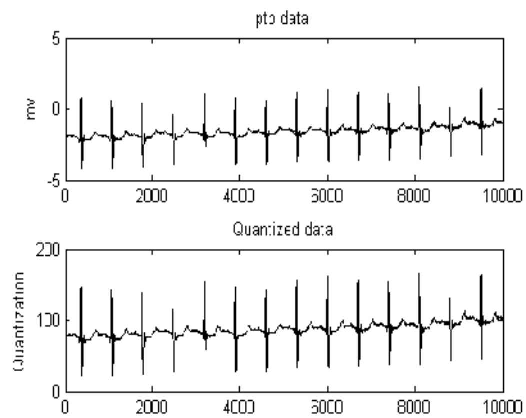


(A)

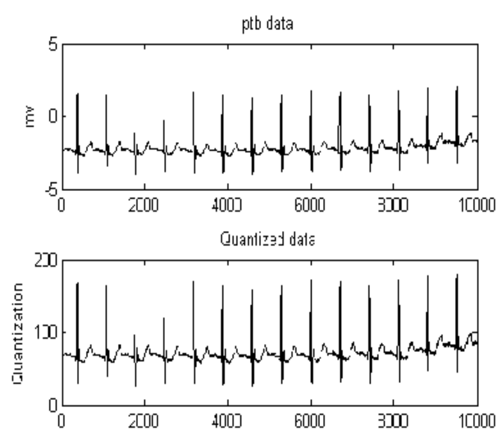


(B)

Fig 5: Experimental Results (A) Hardware setup for ECG simulator, (B) DSO output of Simulated ECG signal for p2/s0016_v3.



(A)



(B)

Fig 6: wave forms for ptb-db and quantized data for (A) p1/s0014 V3 & (B) p1/s0014 V4.

IV. CONCLUSION

8-bit resolution has been used for the quantized ECG database, 10-bit resolution can also be used. For 8 bit quantization all the databases are given a constant gain (500) and constant dc shift (+2.5). So, the wave form is not deformed and the clinical information is not affected by this manipulation. This is an 8051 based system so it is very much economical. Here 12 lead ECG signals are used to generated simulated ECG signal. Both normal and abnormal ECG signal can be generated by this simulator. The serial communication protocol (RS-232) is the simplest communication protocol and the connector (DB9) is available with almost all PCs. This system is also capable of generating other types of biomedical signals like EEG, EMG using proper amplification factor for the database. The noisy effect is not removed from the simulated ECG signal so whenever clean signal is required de-noising has to be done. Multi lead ECG signal for a 12 lead system can be generated by slightly modification of the developed software programming and hardware circuit. The ptb- db database for multi lead ECG signal can be send over the same serial communication line, in time multiplexed technique. In this case the serial communication baud rate or the data sampling rate (both for the RS-232 protocol and the microcontroller) has to be increased by multiplying with a number which is equal to the number of leads used. And also a multichannel DAC is required at the output.

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