J. Instrum. Soc. India **37**(4) 243-248

MICROCONTROLLER BASED ECG AND BLOOD PRESSURE SIMULATOR

Nivedita Daimiwal, Asmita Wakankar, Dipali Ramdasi and Mrunal Chandratreya

Cummins College of Engineering for Women, Pune – 411 052, Maharashtra

ABSTRACT

AN electrocardiogram (ECG) is a test that records the electrical activity of the heart. ECG is used to measure the rate and regularity of heartbeats as well as the size and position of the chambers, the presence of any damage to the heart and the effects of drugs or devices used to regulate the heart. The use of a simulator has many advantages in the simulation of ECG waveform. First one is saving of time and another one is removing the difficulties of taking real ECG signals with invasive and non invasive methods. This paper describes the design of a microcontroller based ECG simulator which outputs both normal and abnormal waveforms. Both heart rate and signal amplitude may be controlled. Applications include a test signal source for repair for maintenance of ECG monitoring equipment, and as a laboratory simulation device for student educational use. The system is designed to test any ECG equipment and invasive blood pressure monitor.

1. INTRODUCTION

The compact, easy, high precision Microcontroller Based ECG and Non-Invasive Blood Pressure (NIBP) Simulator is easy to use and have multiple features to fit many different applications. The simulator gives out a standard waveform that can be used for checking and calibration of an ECG recorder, heart rate meter, QRS detector etc. utilizing gated measurement for noise/artifact rejection. The normal sinus rhythm is simulated with a choice of selectable rates and amplitudes along with Blood Pressure Waveform. The latest microcontroller with a highly stable 12 MHz oscillator crystal and precision voltage reference provides the instrument's high accuracy. The inherent advantage of this system is the programming flexibility offered by microcontroller. A 9 volt alkaline battery powers the simulator. Applications include patient monitoring test signal generator for repair and maintenance of ECG monitoring equipment and a laboratory simulation device for student educational use.

Table 1 shows the relation between heart rate and blood pressure in normal as well as abnormal conditions.

Table 1: Relation between Heart Rate and Blood Pressure [3]

Patient Condition	Blood Pressure (mmHg)	Heart Rate (BPM)
Healthy Heart	120/80	75
Weak Pulse	110/80	95
Tachycardia	120/105	130
Bradycardia	120/60	45

2. ELECTROCARDIOGRAM

An electrocardiogram (ECG or EKG, abbreviated from the German *Elektrokardiogramm*) is a graphic produced by an electrocardiograph, which records the electrical voltage in the heart in the form of a continuous strip graph. It is the prime tool in cardiac electrophysiology, and has a prime function in screening and diagnosis of cardiovascular diseases. The electrocardiogram does not assess the contractility of the heart. The ECG has a wide array of uses:

- Determine whether the heart is performing normally or arrhythmically.
- It can indicate acute or previous damage to heart muscle (heart attacks) or ischaemia of heart muscle (angina).
- It can be used for detecting potassium, calcium, magnesium and other electrolyte disturbances.
- It is useful for the detection of conduction abnormalities. (heart blocks and in bundle branch blocks).
- It can be used for the monitoring of ischaemic heart disease during an stress test.
- It can provide information on the physical condition of the heart (eg: left ventricular hypertrophy and mitral stenosis).
- It is also useful in diagnosis of non-cardiac diseases like pulmonary embolism, hypothermia etc. [2]

An ECG is constructed by measuring electrical potential between various points of the body using a galvanometer. Leads I, II and III are measured over the limbs: I is from the right to the left arm, II is from the right arm to the left leg and III is from the left arm to the left leg. From this, the imaginary point V is constructed, which is located centrally in the chest above the heart. The other nine leads are derived from potential between this point and the three limb leads (aVR, aVL and aVF) and the six precordial leads ($V_{1\text{-}6}$). Therefore, there are twelve leads in total. [1]

3. BLOOD PRESSURE WAVEFORM

As one of the physiological variables that can be quite readily measured, blood pressure is considered a good indicator of status of cardiovascular system. When the left ventricle pumps blood into the aorta, the aortic pressure rises. The maximum aortic pressure following ejection of blood into the aorta is termed the systolic pressure ($P_{systolic}$). As the left ventricle relaxes and refills, the pressure in the aorta falls. The lowest pressure in the aorta, which occurs just before the ventricle pumps blood into the aorta, is termed the diastolic pressure ($P_{diastolic}$). When blood pressure is measured using a sphygmomanometer, which is indirect blood pressure measurement technique, the upper value is the systolic pressure and the lower value is the diastolic pressure. Normal systolic pressure is 120 mmHg or less, and normal diastolic pressure is 80 mmHg or less. The difference between the systolic and diastolic pressures is the aortic pulse pressure, which typically ranges between 40 and 50 mmHg. The mean aortic pressure (P_{mean}) is the average pressure (geometric mean) during the aortic pulse cycle.

As the aortic pressure pulse travels down the aorta and into distributing arteries, there are characteristic changes in the systolic and diastolic pressures, as well as in the mean pressure.

The systolic pressure rises and the diastolic pressure falls and there is a small decline in mean arterial pressure as the pressure pulse travels down distributing arteries due to the resistance of the arteries. When arterial pressure is measured using a sphygmomanometer (i.e. blood pressure cuff) on the upper arm, the systolic and diastolic pressures that are measured represent the pressure within the brachial artery, which is slightly different than the pressure found in the aorta or the pressure found in other distributing arteries. [6]

Thus, the pressure of blood against the walls of arteries is recorded as two numbers the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats).

The standard ECG along with Blood Pressure waveform is shown in the follwing figure.

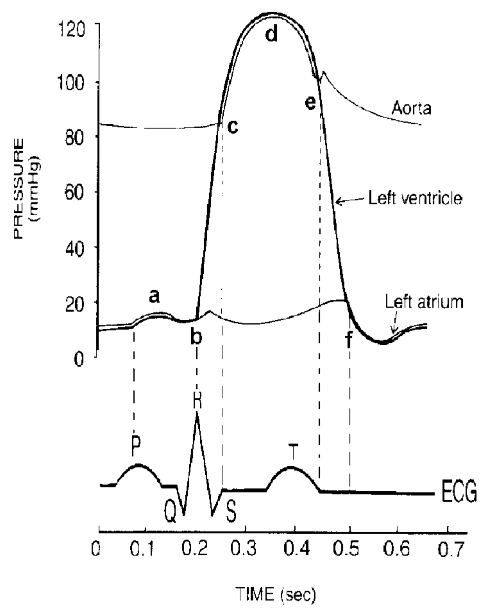

Fig. 1: The Standard ECG along with Blood Pressure Waveform [3]

From Figure 1 the relation between electrical activity of heart which is recorded by Electrocardiogram and the blood pressure can be visualized. Table 2 specifies the amplitude and time interval of ECG waveform.

Table 2: The Amplitudes and Timings of Segments of ECG Waveform. [1]

Segment	**Amplitude (mV)**	**Segment**	**Timing (sec)**
P wave	0.25	P wave	0.11
Q wave	25 % of R wave	P-R Interval	0.12 - 0.2
R wave	1.2-1.6	Q-T Interval	0.35 -0.44
T wave	0.1 – 0.5	S-T Segment	0.05 – 0.15
	— —	Q-R-S Interval	0.09

Atrial contraction 'a' begins the middle of the Pwave and continues throughout the PR interval. Note the atrial pressure increasing as the atria contract. As blood is pumped into the ventricles the ventricular pressure also rises. The PR interval corresponds to the delay necessary for the ventricles to fill after atrial contraction. Note that the atrial repolarization wave (electrical impulse) is usually hidden by the QRS complex and atrial muscle relaxation occurs after the QRS complex and is accompanied by a decrease in atrial pressure.

Ventricular contraction begins at point 'b' which corresponds to the peak of the QRS complex and continues during the ST segment and T-wave. At point 'b' the mitral (and bicuspid) valves close due to increase in ventricular pressure (as the ventricles contract). The closing mitral and bicuspid valves produce the first heart sound.

Between point 'b' and 'c', ventricular pressure increases sharply since the semilunar valves are still closed and there is no blood flow (ventricular pressure is still below aortic pressure) The semilunar valves open at point 'c' when the ventricular pressure equals the aortic pressure. The ventricular contraction forces blood into the aorta and an increase in both aortic and ventricular pressure is noted at 'd'. As blood is pumped from the ventricles and carried away in the aorta, ventricular pressure drops. When the pressure drops below aortic pressure, the semilunar valves slam shut 'e'.

Ventricular muscle repolarization begins at the end of the T-wave and causes further decrease in ventricular pressure. At 'f' the ventricular pressure falls below atrial pressure and the mitral and bicuspid valves open. [3]

4. BLOCK SCHEMATIC OF SYSTEM

Figure 2 shows basic block diagram of the system. 8-bit microcontroller 89C51 by Philips is used for ouputing the vaules sequentailly. It provides a variety of fast addressing modes for accessing the internal RAM to facilitate byte operations on small data structures. Microcontroller is used for storing the values of ECG and Blood Pressure waveforms. Two ports microcontroller is used for generating ECG and Blood Pressure waveform.

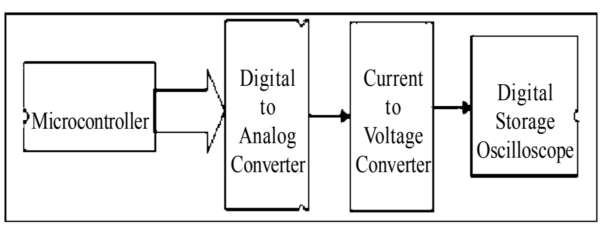

Fig. 2: Block Schematic of System

Digital to Analog Converter (DAC): The DAC used is 0808 having a resolution of 8 bits. The reference voltage used for DAC is 5V. The waveform generated is observed on DSO.

4.1 Features of the System

- Microcontroller based circuitry
- Normal Sinus rhythm: 30 - 240 bpm
- Variable amplitudes
- ECG and Blood Pressure waveform Generation

4.2 System Algorithm

An ECG waveforms for various heart rates are generated using simulator. Following steps are considered for generating ECG and Blood Pressure waveform.

1. Measure the R to R interval for a normal heart rate (72 beats/min).
2. Calculate the total number of samples for that perticular heart rate.
3. As per the standard amplitudes and timings calculate the samples for P wave as a sine wave, PQ segment as a straight line, R as triangular wave, ST segment is a straight line, T wave as sine wave.
4. Generate a look up table for storing these sample values.
5. Similarly calculate the samples values for normal blood pressure waveform.
6. Output the sample values after the particular time delay on the output ports of the microcontroller.
7. The digital data from the microcontroller is then passed to the digital to analog convereter which converts the digital values into corresponding analog values.
8. Repeate the same procedure for different heart rates as well as the amplitudes of ECG signal.

4.3 System Flowchart

The flowchart is one of the seven basic tools of quality control, which include the histogram, Pareto chart, check sheet, control chart, cause-and-effect diagram, flowchart, and scatter diagram. It is a schematic representation of a process. The logic used for programming the microcontroller can be explained with the help of sytem flowchart given in Figure 3.

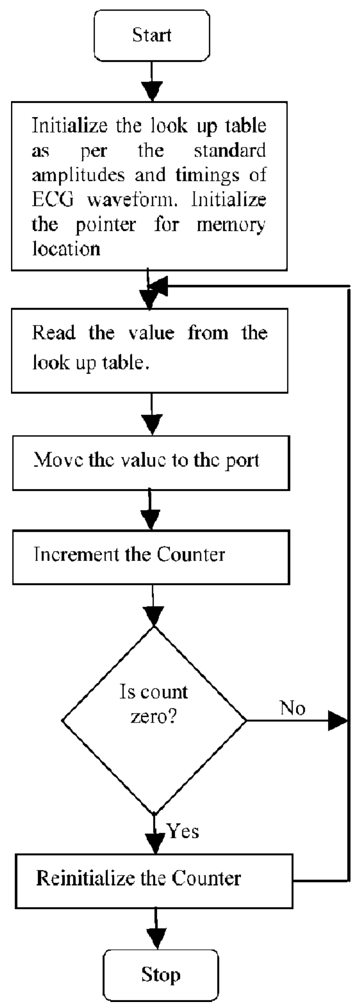

Fig. 3: System Flowchart

5. CONCLUSION

The aim of the study was to design and develops an ECG simulator intended for use in the testing, calibration, maintenance of ECG monitoring equipments and as a laboratory simulation device for student educational use. The output of this simulator is both normal and abnormal waveforms.

6. ACKNOWLEDGEMENTS

The authors are grateful to Prof Atul Joshi and Prof. A.D. Gaikwad for their motivation and help towards the completion of this paper, as well as for providing valuable advice.

We also like to thank our colleagues from instrumentation and control Dept. of Cummins College of Engineering for Women, for their feedback during discussions.

REFERENCES

1. Joseph J. Carr, John M. Brown, 'Introduction to Biomedical Equipment Technology' Fourth Edition, Pearson Education Asia (2001).
2. Leslie Cromwell, Fred J. Weibell, Erich A. Pfeiffer,' Biomedical Instrumentation and Measurements', Second Edition, Prentice hall of India, 1997.
3. R. S. Khandpur, 'Handbook of Biomedical Instrumentation', Second Edition, Tata McGraw-Hill, India, 2003.
4. Ajay V. Deshmukh, 'Microcontrollers Theory and Applications', First Edition, Tata McGraw-Hill, India, 2005.
5. Muhammad Ali Mazidi, Janice Gillispie Mazidi, 'The 8051 Microcontroller and Embedded Systems', Seventh Edition, Pearson Education Asia (2004).
6. Richard E. Klabunde, Cardiovascular Physiology Concepts, July 2006. http://www.cvphysiology.com