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Simulation and Study of Asynchronous Pacemaker via MatLab

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Abstract

A pacemaker is an electronic device, which is used by heart patients when they suffer from arrhythmias. The sinoatrial node (SA node) of our heart generates electrical impulses which travel downs the atrioventricular (AV) node to the bundle of His and then to the Purkinje fibres, from where it distributes to the ventricular region. Importance of this impulse is that it makes the heart contract, which helps in maintaining blood circulation. In some cases, the SA node is unable to generate the electrical impulse or the impulse generated is so weak that it fails to reach other regions of heart for normal functioning. In such cases, doctors suggest the use of pacemakers. A pacemaker generates an impulse which is analogous to the impulse generated by the SA node and helps in heart contraction. The pacemaker either bypasses the use of SA node or works in collaboration with it depending upon the condition of SA node. Pacemakers are broadly classified into two types: the demand pacing or asynchronous pacemaker, which generates a fixed heartbeat, and the rate-responsive pacemaker, in which the heartbeat generated, depends on the physical activity being performed by the patient. Herein, we report the working of a demand-type pacemaker with the help of MatLab simulation, for its better understanding.

***Keywords:** Pacemaker, Demand pacing, MatLab, ECG*

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INTRODUCTION

The circulatory action of blood in most of the organisms is carried out by the heart. The heart is approximately the size of our fist and is located between our lungs towards the left side, protected by the rib cage. By pumping blood, it provides the body with oxygen and helps in removal of toxic waste. The heart is divided into four chambers: upper left and right atrium and lower left and right ventricles. The left atrium and left ventricle form the left side of the heart and the rest form the right side of the heart. It has valves which permit directional blood flow and prevents backflow [1]. Oxygenated blood enters the left atrium and flows to the left ventricle from where it is distributed to the body and deoxygenated blood enters from the right atrium and flows to the right ventricle, from where it is directed towards the lung for oxygenation [2].

Pumping of the blood from different chambers of the heart depends on heart’s contraction. This contraction is determined by the SA node, which is located in the right atrium walls. SA node, being the natural pacemaker of the heart, sends an electrical signal which travels to the atrioventricular (AV) node and then to the Purkinje fibres leading to ventricular contraction. The SA node generates an action potential, due to which membrane voltage fluctuates and the chambers contracts [3]. Cells of the heart do not have any resting phase, therefore, whenever one action potential (AP) ends, another electrical impulse is generated by the SA node and if the pacemaker potential crosses the threshold, AP is initiated which results in contraction. Cells, such as Purkinje fibres and AV node can also generate electrical impulses, but the potential generated by them is at a much slower rate as compared to the SA node and therefore, is overpowered by the SA node pulse [4].

A pacemaker is a device which is used by heart patients when the function of SA node is disturbed and they are suffering from a group condition called arrhythmias. In arrhythmias, the patient suffers from bradycardia in which the impulses generated by the SA node are slower as compared to normal or there could be a heart block in which the pulses generated are normal but the signal slows down or is disrupted when it progresses down the heart [5]. Another type arrhythmia is tachycardia in which the heart beats faster than normal. To overcome these problems, pacemakers are used.

Electrocardiogram (ECG) is used for the diagnosis of heart diseases. In a standard ECG waveform, PQRST wave is generated (Figure 1). P wave depicts atrial depolarization and it should be of a length of 0.3 mV or 3 mm. Enlargement or any change in P waveform depicts atrial problems such as atrial chamber enlargement. Multiple P waves are observed when there is a second or third-degree block [6]. Q wave is used for diagnosis of heart attack. After an attack, the Q wave is deep. Generally, it depicts septal depolarization– when the impulse travels down to the bundle of His, left ventricle is depolarized first and then the right ventricle, because of which depolarization travels from left to right releasing a small negative deflection—the Q wave [7]. R waveforms the peak of the ECG waveform and depicts early ventricular depolarization. Changes in R waveform depict hypertrophy and obesity as well. S wave represents late ventricular depolarization. T waveform represents ventricular repolarization. When T waveform is disturbed, possible causes are ventricular ectopic beats, myocardial ischaemia or bundle of His blockage [8].

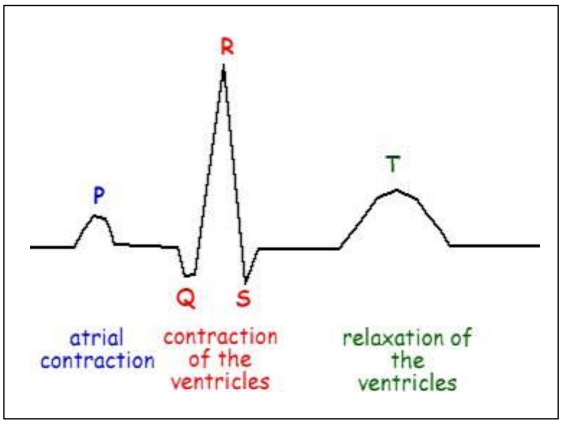

***Fig. 1:** PQRST Waveform [9].*

Pacemaker generates an electrical signal and acts as an artificial SA node. Pacemaker not only generates an impulse but remains in constant sync with the natural SA node for continuous and smooth pacing of the heart [10]. This activity of pacemaker is achieved by its components which are:

Pulse generator– it's a small lithium battery and an electric circuit which is enclosed in a titanium package. The generator generates an electrical impulse whenever the SA node fails to do so and also, it communicates with the node to maintain proper functioning.

Lead wires– one end of this wire is attached to the generator and the other is placed onto the atrium or onto the ventricles, depending on which part of the heart requires pacing.

Electrodes– electrodes are attached to the second end of the wire which is connected to the atrium/ventricles. Electrodes help in the transfer of signals from the lead to the heart for their contraction [11].

In arrhythmic cases, either atria or ventricles or both can require pacing. Depending on that there are three types of pacemakers:

- Single-chamber pacemaker—In this type of pacemaker, one end of the lead is attached to the generator and the other end to the right atrium or right ventricle, depending on patient's condition.
- Dual-chamber pacemaker—it consists of two lead wires, in both of them one end is attached to the generator and the other ends of both wires are attached to the right atrium and right ventricle, respectively. This pacemaker allows both the chamber to work together for a successful contraction [12].
- Bi-ventricular pacemaker—in this pacemaker, three leads are used, one is connected to either of the atria and the other two are connected to both the ventricles. Bi-ventricular pacemaker is used for patients with advanced heart failure. Pacemaker is programmed in such a way that both the ventricles contract together. This type of treatment for a heart disease is called cardiac resynchronisation therapy (CRT) [13].

Different pacemakers are used for different conditions experienced by the patients. In general, there are two kinds of pacemakers: demand pacing and rate-responsive pacemaker. In the rate-responsive pacemaker, the heartbeat is adjusted according to the activity performed by the patient [14]. For example, the electrical activity of the pacemaker is reduced to 60–65 bpm when the patient is sleeping and increased when the activity demands, such as climbing the hill. On the other hand, for demand or asynchronous pacemaker, the rate of pacing by the external device is kept constant, irrespective of the activity performed [15]. Herein, the working of a demand-type pacemaker is demonstrated.

MATERIALS AND METHODS

The ECG signals used in the development and testing of the biomedical signal processing studies are mainly from three sources:

1. Biomedical databases (e.g., MIT-BIH Arrhythmia Database) or other pre-recorded ECG data,
2. ECG simulator,
3. Real-time ECG data acquisition.

In this study, pre-recorded and simulated ECG signals are used [16]. Data analysis and preprocessing has been carried out in order to transform data into a useful form, this also removed the inconsistency and anomalies in the data. MatLab R2017a has been used for the entire signal processing and analysis, as well as, for the plotting of graphs.

Arrhythmic ECG data are taken and ECG waveform is plotted. The time difference between two R peaks can be considered to be the time for one beat so, we locate the R peaks in our given data and the time corresponding to the R peak values is also found [17]. The instantaneous heart rate or the instantaneous Beats Per Minute (BPM) is the reciprocal of the value of time elapsed in one beat. In a normally functioning heart, this value should be somewhat same for each passing beat and should average around 70–72 BPM. But in case of an arrhythmical heart, there can be variability in these values and which gives rise to the need of some kind of pacing to maintain a normal heart rate. We call this Heart Rate Variability or HRV [18]. The pacemaker essentially monitors the heart rate and whenever it falls below a certain value an impulse, depending on the settings of the pacemaker (typical values for pulse magnitude lie between 1V to 8V and pulse duration is programmable between 0.5ms to 2ms), is given to the AV node [19]. This ensures that the following beats will have a more regular pattern. In our study, where ever the heart rate falls below 60 BPM, the model sends an impulse to restore the heart rate to a normal value, i.e., 60–100 BPM. This is the most exact representation of a 'demand pacemaker' and provides a useful insight of the mechanism of demand pacing [20].

RESULTS AND DISCUSSION

The ECG waveform, prior to any corrections, is as shown in Figure 2(a) and the heart rate variability (HRV) of this segment of ECG signal in Figure 2(b).

The simulated pacemaker pulse, for the instances where the rate falls below 60 BPM in the given ECG signal snippet is depicted in Figure 3(a) and the heart rate correction can be depicted as shown in Figure 3(b).

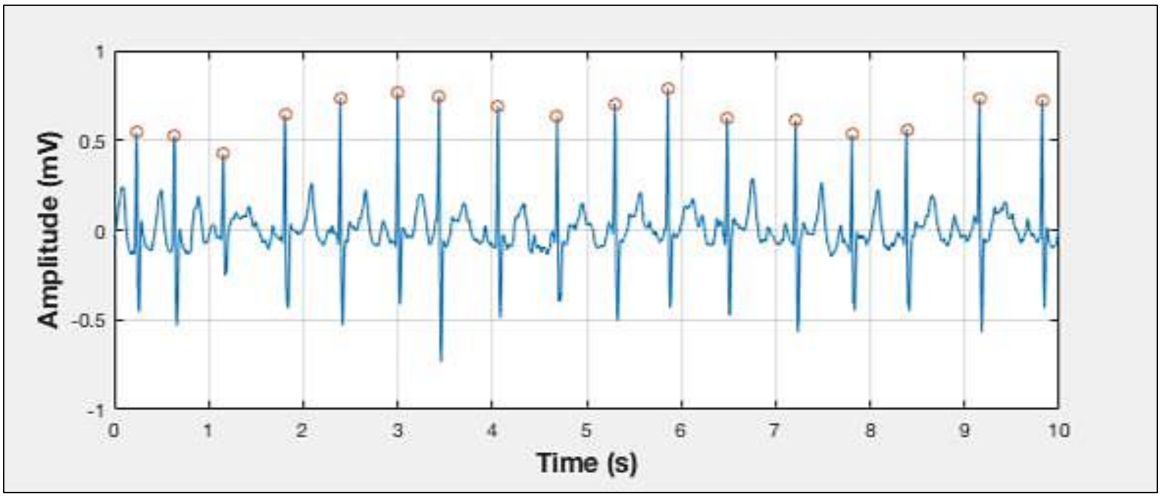

Fig. 2(a): *Input ECG Waveform.*

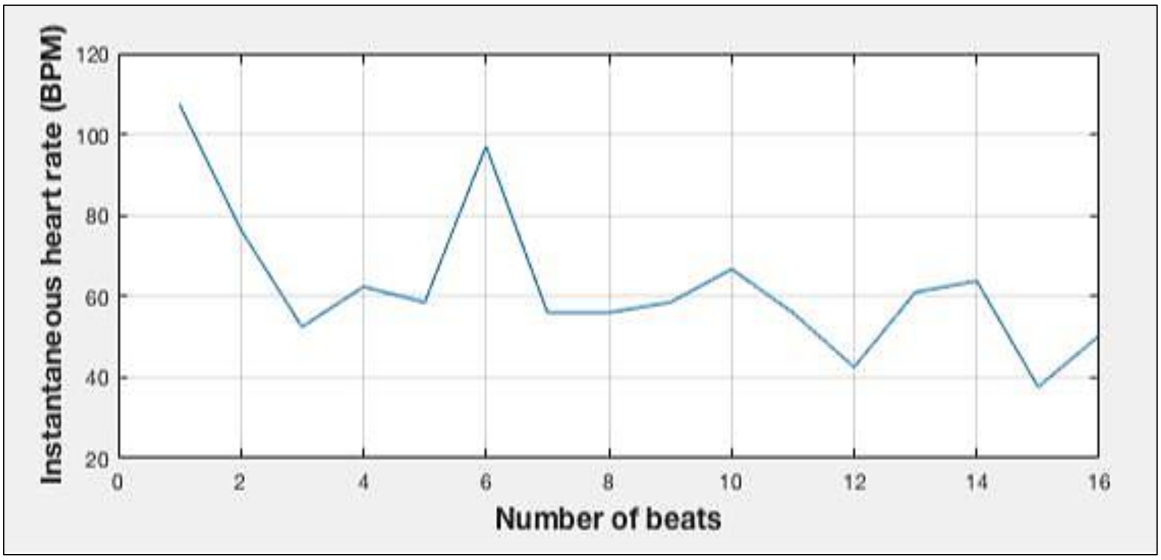

Fig. 2(b): *HRV of Input ECG Waveform.*

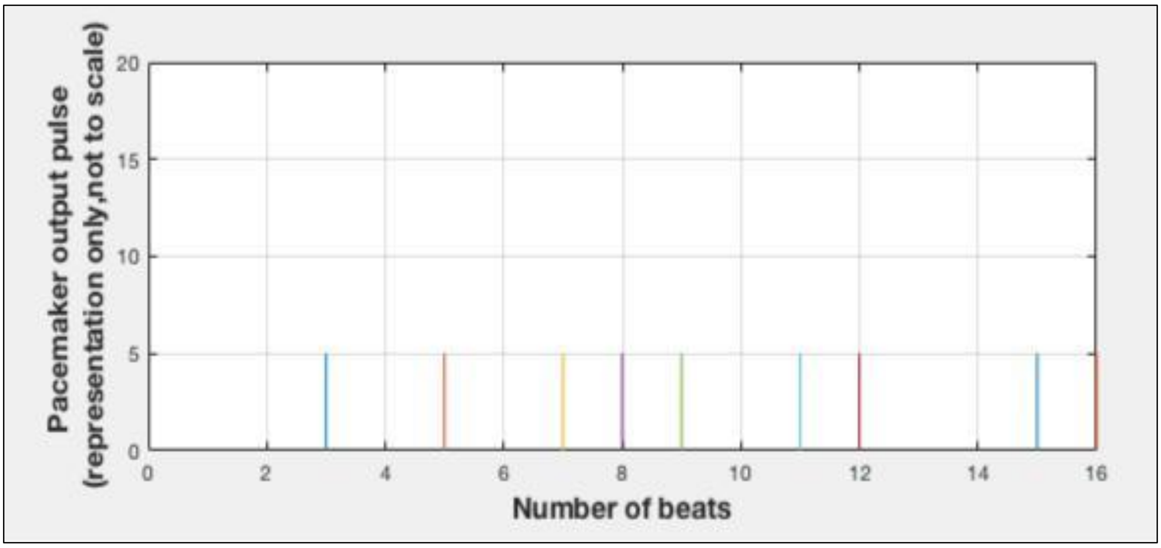

Fig. 3(a): *Simulated Pacemaker Pulse.*

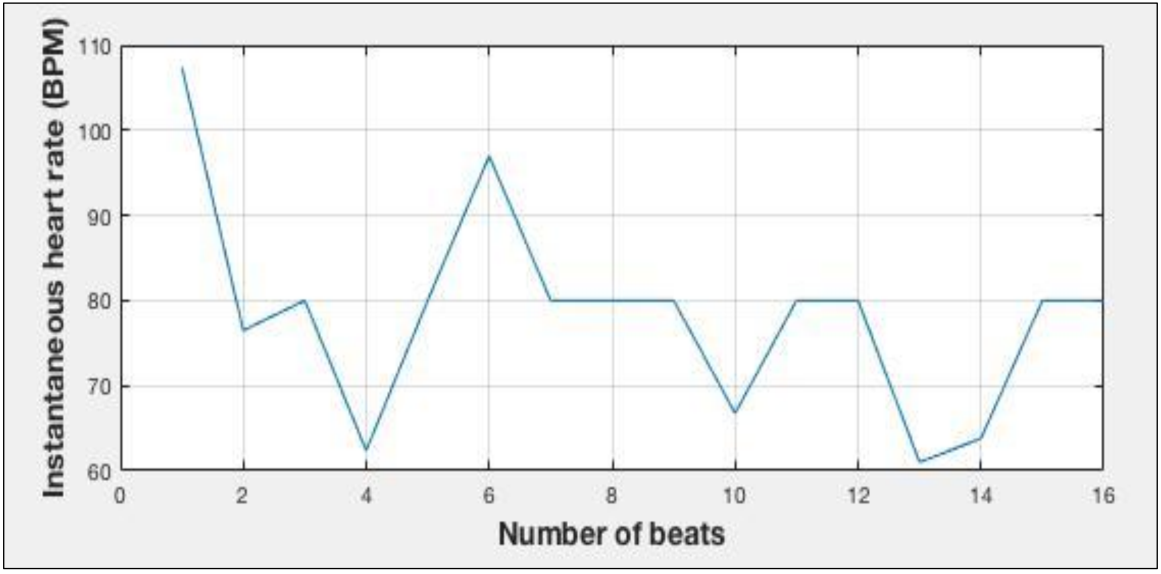

Fig 3(b): *Correction in HRV after the Application of Pacemaker Pulse.*

CONCLUSION

A successful simulation and study of the Demand pacing Pacemaker have been carried out in this study. Such studies improve the understanding of subjects like control system, signal processing and instrumentation, and their implementation in real life. The simulation of any model makes it easier to analyze and improve before implementing it in real time. Although we have taken only BPM into consideration and real-time data has not been taken, additional variables can be incorporated in this model to bring it closer to an actual representation of a real world, commercially available pacemaker. Nevertheless, the underlying notion is that this exercise will certainly go a long way in providing a critical academic value addition.

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