# Analysis of Pacemaker Performance and Design of a Holistic Pacemaker Monitoring Tele-communication System

LAVANYA JAGANNATHAN, SANTHOSH GANESH, SASIKALA T, MAHESH VEEZHINATHAN
Department of Biomedical Engineering
SSN College of Engineering
Rajiv Gandhi Salai, OMR Road, SSN Nagar, Kalavakkam, Tamil Nadu 603110
INDIA
Lavan.92@gmail.com, santhosh.unowho@gmail.com, sasi.92t@gmail.com, maheshv@ssn.edu.in.

*Abstract:* - The role of artificial pacemakers in the rehabilitation of patients with cardiac abnormalities is indispensible. Even after over 75 years of existence, the pacemakers still face a range of issues and faults, thereby causing problems, which are sometimes fatal. An analysis of the reasons for pacemaker failure and its solutions is essential to avoid similar problems in the future. These problems occur due to the parameters going unmonitored, which results in faults being undetected. A system to detect the essential parameters such as the pacing algorithm synchronization, current delivery and battery lifetime will help in the drastic reduction of the problems faced in a pacemaker. This system, along with a GSM telecommunication module can further enhance the performance and quality of the pacemakers over the existing models with short range telemetry and magneto-storage systems. This system is also to be extended into the realm of controlling the pacemaker from outside the body by the same communication system.

*Key-Words:* - GSM, LabVIEW, Pacemaker alarm, Synchronous pacing.

## 1 Introduction

Since the introduction of the modern artificial pacemakers in 1950 by John Hopps, there has been more than 75% improvement in the life expectancy of patients with chronic cardiac abnormalities. There have been 2.9 million patients with permanent cardiac pacemaker implants in the USA between 1993 and 2009. The use of dual-chamber pacemakers alone has increased from 62% to 82% in 2009 while single chamber ventricular pacemaker fell to 14% (Fig. 1). This indicates the importance of dual chamber pacemakers in prolonging the life of cardiac patients [1,2,3].

The internal pacemaker uses Li ion batteries which are expected to last 8-10 years depending on the physiological activity of the human cardiovascular system and its effects on the pacing system. The battery powers the sensing, pace timing and pulse production functions of the pacemakers. The discharge levels depend on a lot of factors; pulse width, rate and physiological parameters. The discharge levels of the batteries adversely affect the functions of pacemaker and can ultimately lead to its failure. The failure of pacemakers is a major problem and 26% of pacemakers fail well before the expected lifespan of the system [4,5,6].

Cardiac pacemakers are categorized into synchronous and asynchronous pacemakers. An asynchronous pacemaker constantly produces pulses, even when the heart is functioning normally. This leads to a lot of power wastage. Thus, the synchronous pacemaker was developed. In synchronous pacemakers, pulses are produced only when the system does not detect a P wave or a QRS complex. The disadvantages of asynchronous pacemakers are partially overcome by the synchronous pacemakers.An ideal pacing pulse (Fig.2) has a fast rising edge. Once the maximum amplitude is reached, a capacitive droop follows and then a trailing edge occurs [7]. The polarity of the pulse is then changed for the recharge portion. This is required so that the heart tissue is left with a net charge of zero.

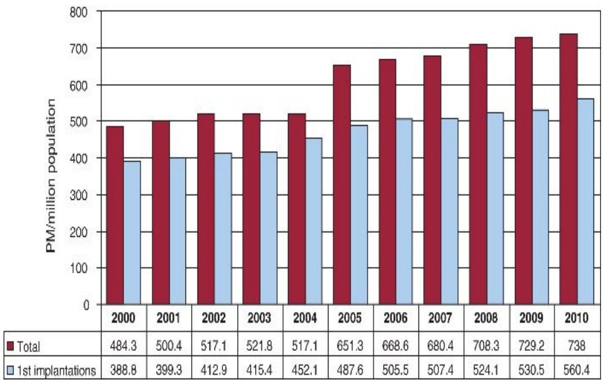


Fig.1 Increased use of Pacemakers

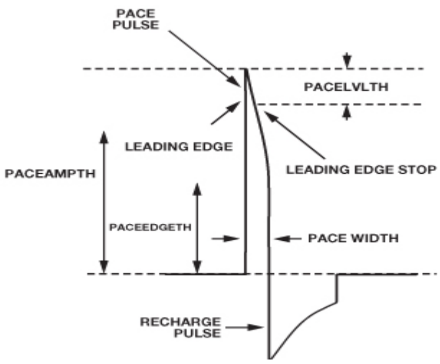


Fig.2 An Ideal Pacing Artifact

The pacemaker encounters various errors during its operation which can cause problems with the natural pacing causing disorders like pacemaker syndrome. Pacemaker syndrome consists of the cardiovascular signs and symptoms of heart failure and hypotension induced by right ventricular pacing. The reported incidence of pacemaker syndrome likely approaches 26% in rate modulated ventricular-based pacing [8, 9, 10].

This problem has to be addressed and is mainly caused due to the problems associated with the electronic malfunction of the pacemakers. This side of the pacemaker has been overlooked and has seeped as a major problem in the use of pacemakers. The problem can only be solved by building in a continuous monitoring of pacemaker functions and a communication protocol to alert the user and associated physician regarding the problem. Also, an on-demand communication of signals is necessary for the monitoring of the instrument.

Another important problem is the battery induced errors in the functioning of a pacemaker [11, 12]. This makes the monitoring of battery levels and current delivered by pacemaker also a very integral part in the maintenance of the pacemaker's health. This necessitates a system to estimate power of the battery in a non-loading way and communicating the level at periodically. GSM is a universal protocol of mobile communication and can be used to communicate the error messages and the waveform on demand. Death rates due to ignorance of patients can be reduced to a large extent, with the introduction of such systems [13].

## 2 Methodology

The work was split into 2 separate modules of which one was for simulation and the other was for real-time experimentation. The simulation module is to be done in LabVIEW for modeling the errors and determining the algorithms for their monitoring. The real-time module was for testing the existing pacemaker and deducing the errors induced in them. It will also be used for interfacing the GSM module for communication.

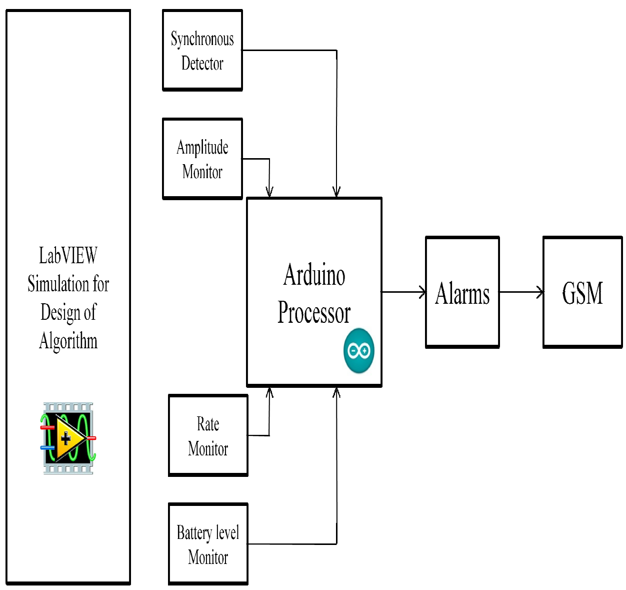


Fig.3 Work Flow

## 2.1 LabVIEW Simulation

The initial requirement of a pacemaker was needed for the testing and evaluation of the system and algorithms. The use of a real pacemaker was replaced by a simulated one so as to increase the testing range of the algorithm. A simple algorithm was used to simulate the pacemaker and the input was given through the synthesized ECG. This code for ECG synthesis was retrieved from the AAMI database which is used as standard test for pacing devices.

### *2.1.1* Fault Detection and Monitoring

Fig.4 illustrates the different parameters which are monitored in a pacemaker system and how the thresholds are set for the different values. The pacemaker simulator gets the input ECG which is processed and the output pulse is delivered if the pace is below the set threshold. The generated pacing pulse is usually a square pulse waveform with low duty cycle. The pulse usually encounters 3 types of errors [14]. The amplitude threshold and pace rate detector use simple comparator logic. The synchronous detector merges the input and output waveforms with time equalization and thus helps in eliminating the synchronous collision of the signals which may result in arrhythmic excitation and pacemaker syndrome.

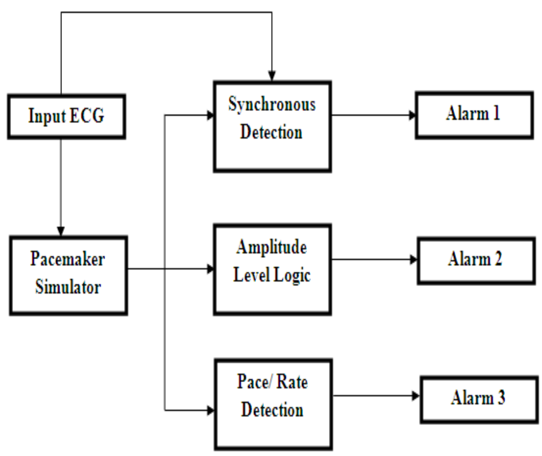


Fig.4 Pacemaker monitors using LabVIEW

### *2.1.2* Battery Level Monitor

The battery monitor consisted of two parts – the hardware interface and the comparator. A circuit which measures the amount of voltage delivered by the Lithium ion battery through the measurement of the voltage which is divided in the load circuit was built. The battery is connected to a load circuit and then a DAQ to interface it with LabVIEW. This is then compared with a threshold and converted into a percentage. The battery monitor was set to generate messages at every 10% interval and was set to alarm at a discharge level of 25%, as it is the level at which most pacemakers fail.

### *2.1.3* Communication Module

The communication protocol used is a GSM system to transmit alarm messages and signals on demand. The monitoring system is integrated with a GSM modulation tool which is prompted on the activation of any alarm. The GSM module communicates to the server, the string message generated [15, 16]. The string is then sent to the destination address. Systems to show error on disconnect or network non-availability problem is also built.

Fig. 5 indicates the input and output of the GSM modem. The input is from the system which gives information on the detection of errors. This activates the modem to modulate and send the alarms to the destination

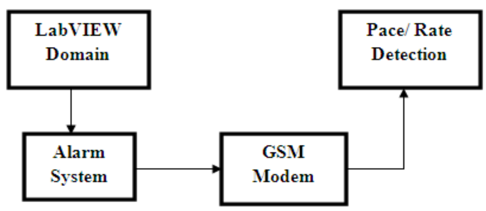


Fig.5 Alarm communication system

## 2.2 Arduino Processing

A simple algorithm for detecting and extracting the QRS peak from the ECG and convereting it into a square pulse was coded. This pulse is compared with the preset amplitude and rate thresholds of the pacing pulse. When the measured value goes less than the threshold corresponding alarm system is triggered [17]. Fig. 6 illustrates the overall algorithm.

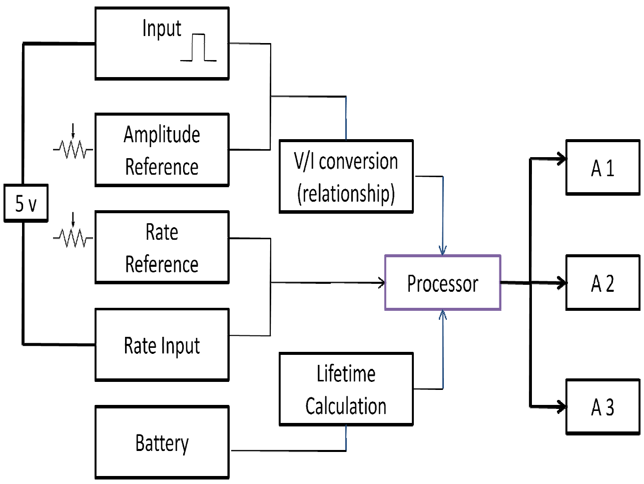


Fig.6 Alarm system- Arduino

### 2.2.1 Battery Life Estimation

The battery life time is estimated by using the formula

$$Cell\ life\ time = \frac{Total\ energy\ stored}{Energy\ delivered\ per\ pulse(E_p)} \quad (1)$$

where,

$$Stored\ energy\ of\ cell$$
$$Amp\ second\ rating\ x\ Terminal\ Voltage \quad (2)$$

$$E_p = \frac{(V_p{}^2 * T_p)}{R_h + V_p * I_p * T} \quad (3)$$

where,
$V_p$ is Pulse Voltage, $T_d$ is Pulse width, $I_d$ is Delivered current, $R_h$ is electrode resistance and T is Heartbeat period

## 3 Results

The system which was simulated was tested by using multiple rate ECG signals synthesized from the AAMI database. The tolerance of the rate detection algorithm is considered an important parameter as it is the one which characterizes the performance and the accuracy of the detection algorithm. The measurement of tolerance involved was done by a monitoring of the rate detected and the occurrence of alarms for incorrect rates was also noted. A factor was derived from the range of minimum detection and the synchronization at the R-T interval. This factor was mapped to the tolerance and it was repeated for all values of rate. This was then plotted (fig 7) and maximum tolerance of up to 0.5% were observed. There was also a positive linear relationship between the pace and tolerance which can be observed from the figure. This is due to the fact that at lower rates, the occurrence of features is easier to identify due to the higher number of samples which can be identified. The tolerance can be enhanced and the performance can be improved by increasing the sampling rate of data acquisition.

### 3.1 LabVIEW Results

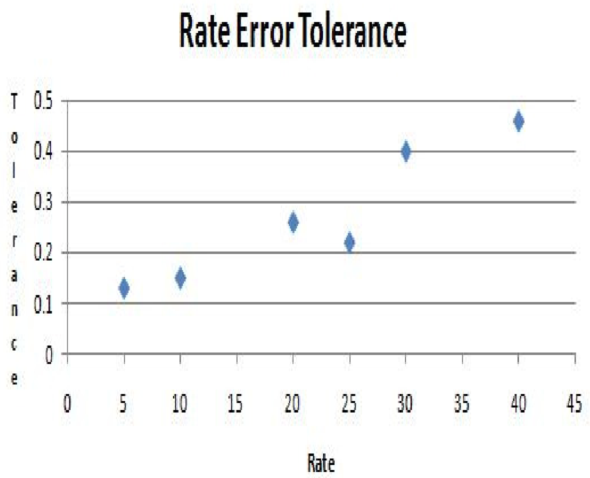


Fig.7 Rate Error Tolerance

delivered from the simulated pacemaker. The three knobs on the left are used to set threshold values which are to be compared with the set values The


Fig.8 LabVIEW front panel

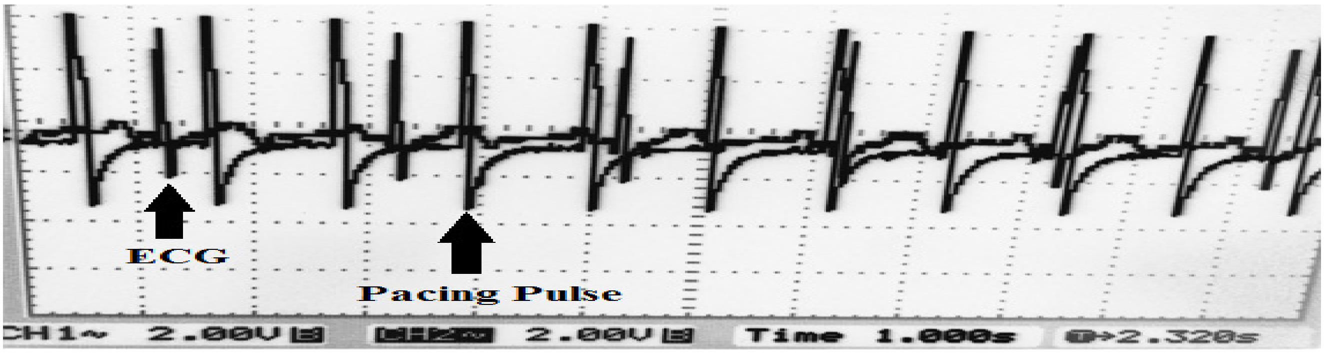


Fig.9 Asynchronous Pacing Pulse

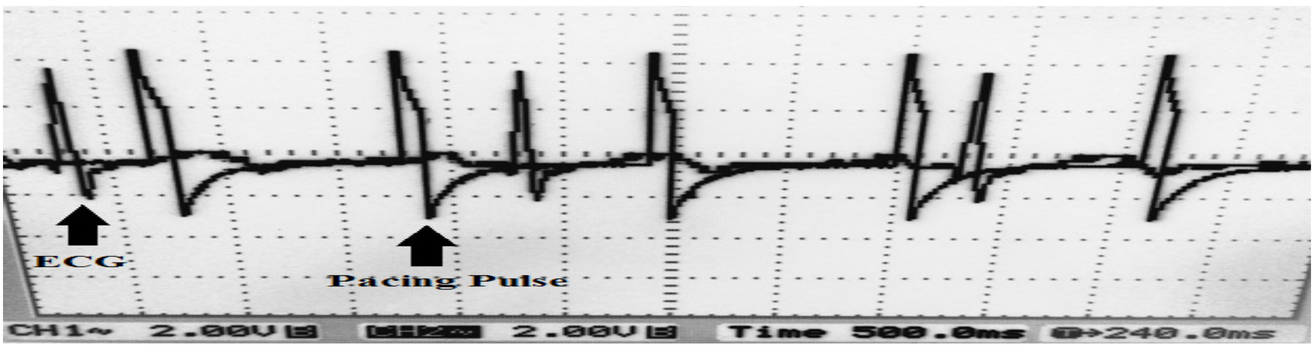


Fig.10 Synchronous Pacing Pulse

results obtained from the LabVIEW module are as shown in Figure 8. The figure is a screen shot of the front panel of the VI developed. The two knobs on the right are the pacemaker knobs used to set the rate and amplitude of pulses in the pacemaker. The first graph displayed is the ECG which was obtained from the AAMI database. The second graph displays the pulses that are delivered by the pacemaker.

On detection of any fault, an alarm is triggered by the system which eventually lights an LED. The figure shows two alarms (Pacing, Synch) that were triggered on detection of pacing and synchronization errors.

Two indicators to display the original rate (from ECG) and Pacing rate. The Pacing rate displayed is the difference between the set threshold and original rate. An indicator to display the battery levels has also been included. It displays the percentage of battery remaining in the device. Apart from that, a separate alarm will be triggered if the battery level goes below 20%.

### 3.2 Pacemaker Design

An algorithm to generate pacing pulses in two different modes (Asynchronous and Synchronous) was implemented using an Arduino Processor.

## 3.3 Arduino

The system developed in the Arduino platform reflects the algorithm which was formulated in the LabVIEW simulation. The algorithm was tested using both self generated and external artificial pacemaker.

The system used a tolerance range of 0.2mA for the current monitoring while normality ranges of 5 pulses per minute was used for the rate monitoring. These ranges centered at the thresholds set manually. The hardware system gave a better accuracy than the simulated system.

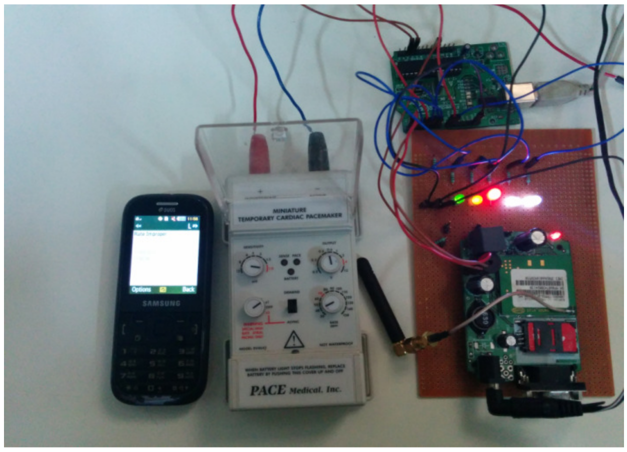


Fig.11 Monitoring System

Fig. 11 shows the monitoring system where battery, amplitude and rate alarms are triggered on, as a result of a fault and a message was sent to the destination address by the GSM modem.

## 4 Conclusion

Failure of a Pacemaker can lead to serious complications. It is thus important to integrate alarm systems into the device which would notify the doctors in case of any fault with the device. Also, this system enables the patients to self evaluate the condition of the device. A telecommunication system such as GSM provides the sophistication of sending the alarms as messages to any universal device.

The system designed using LabVIEW was tested for simulated error conditions i.e. Pacing, Synchronization and Current delivered errors. It proved to have high tolerance to errors and also has high efficiency. Further, plans to test the system with real time ECG signals and faulty temporary pacemakers and analyze the efficiency are considered.

To implement this system into a real time pacemaker, a hardware module was developed. The hardware system consisted of a set of algorithms designed to detect the pacing, amplitude and synchronization errors. A circuit to measure the battery level to monitor the rate of discharge of the battery should also be included. An Arduino processor was used to integrate the circuit with the GSM modem. The GSM Modem was programmed with a unique SIM card according to the requirements of the physician. The system was tested using a live pacemaker and also, a pacemaker with both synchronous and asynchronous modes was developed using the Arduino itself.

The system and its concept can be extended to programming the pacemaker from an external source and also can be used for the monitoring of other such implantable devices in the future.

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