GSM Based Artificial Pacemaker Monitoring System

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Abstract—The incidence of cardiac abnormalities has seen an unprecedented increase and the pacemaker has been instrumental in expanding the life span of patients. The internally implanted pacemakers are guaranteed 8-10 years of life but get dysfunctional within 4 years due to a variety of problems. The pacemakers which survive this encounter problems with the pace timing leading to a serious problem, pacemaker syndrome. A system to continuously monitor the parameters and battery levels is required. The existing technology uses short range telemetry and scanning transmission method. But these methods have a limited range. The integration of the monitoring system with a GSM communication module can be a feasible solution to this problem. A system has been developed with alarms for amplitude delivery, pacing rate and synchronization errors. Also, a battery level indicator with messages for every 10% discharge and an on-demand delivery of pacemaker parameters and pacing pulse is included. All these are communicated to the user and physician via GSM operated cell phones and uses LabVIEW platform for monitoring and programming. This can be extended to programming the pacemaker and other medical devices as well.

Keywords—GSM, LabVIEW, Pacemaker alarm, Synchronous pacing.

I. INTRODUCTION

Since the introduction of the modern artificial pacemakers in 1972 by Greatbatch [1], 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% [2]. This indicates the importance of dual chamber pacemakers in prolonging the life of cardiac patients. 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 of the batteries adversely affect the functions of pacemaker and 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 [3].

Cardiac pacemakers can be of two types: synchronous and asynchronous. An asynchronous pacemaker constantly produces pulses, even when the heart is functioning normally. A lot of power is wasted. Thus, the synchronous pacemaker was developed. In synchronous pacemakers, pulses are produced only when the system does not detect a QRS complex. The disadvantages of asynchronous pacemakers are partially overcome by the synchronous pacemakers.

An ideal pacing pulse (Figure 1) has a fast rising edge. Once the maximum amplitude is reached, a capacitive droop follows and then a trailing edge occurs. The polarity of the pulse is then changed for the recharge portion [4]. This is required so that the heart tissue is left with a net charge of zero.

Fig 1: Ideal pace 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. Over the last three decades the understanding of pacemaker syndrome has evolved [5]-[7].

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. This makes the monitoring of battery levels 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 periodic signals. The monitoring protocol can bring about a change in the way people perceive the safety of pacemakers and their utility. GSM is a universal protocol of mobile communication and can be used to communicate the error messages and the waveform on demand.

The pacemaker, as a part of its function records the ECG for use in feedback purposes. This can be extracted and used to monitor the patient from time-to-time. This wave can indicate all data of the circulatory function such as the heart rate and the various pathological conditions associated with it. This can also be incorporated into a system where the waveforms are delivered via the GSM system whenever the physician requires monitoring the patient.

In this work, the use of LabVIEW platform to monitor the pacemaker properties and identify the errors has been proposed. The identified errors prompt the GSM server to send the messages and also the waveforms when user requests to send the data. The system is used to integrate the alarm software algorithm and the hardware including the pacemaker, battery circuit and the GSM modem.

II. SYSTEM REPRESENTATION

A. LabVIEW Block

Figure 2 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 [8]-[9]. 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.

B. LabVIEW Block

Figure 3 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.

![Alarm communication system](image)

Figure 4 shows the double way on-demand data communication from one domain to another. The user can send the request to the GSM modem, which in turn acquires the data from the pacemaker and delivers it as a data file to the user.

![On-demand data communication](image)

III. MATERIALS

This section describes the software and hardware resources used in the fault detection and notification systems.

A. NI LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Work-bench) is a platform and development environment for a visual programming language. It can be used as a platform to integrate signal acquisition, processing and transmission of the
processed signal. It is a graphical programming environment. LabVIEW simplifies the most complex coding problems. The Software also includes a wide variety of blocks for mathematical functions, filters (IIR, FIR) and other blocks like SMTP which can be used to export data from LabVIEW. The software allows the user to create stand alone executables which can be distributed to a number of systems and be reused unlimited.

The GSM interface module available in the software has already been used in several medical telemetry applications [10].

B. GSM Modem

GSM (Global System for Mobile Communications) is a standard developed by the European Telecommunications Standard Institute. It was developed to describe a set of protocols for the second generation (2G) digital cellular networks. GSM Technology can be used to deliver data or signals from an instrument or device to the doctors. The device needs to be integrated with a SIM (Subscriber Identity Module) and is programmed with a telephone number. On trigger, the SIM establishes connection with the network and broadcasts the data to the destination as specified by the programmer. The dimension of a SIM card does not exceed 25mmX15mm.

GSM Modems are used to integrate the technology with LabVIEW. An example of a MODEM used is RTD GSM 35. It is a GSM/GPRS enabled Modem that is capable of sending and receiving data. It works on frequencies 900MHz and 1800MHz. It is compact in size [11].

IV. METHODS

This section describes the process, protocols and methodologies used in the fault detection and notification systems.

A. Pacemaker 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. The pacemaker simulators amplitude and pace were controlled manually and there was a provision to introduce synchronizing error as well.

The battery level was also simulated using a DC power supply integrated into the device through a DAQ device.

B. Fault detection and monitoring

The monitoring system incorporates three parameters of the pacemaker

- Amplitude
- Pacing rate
- Pacing synchronisation.

Each of these parameters were extracted from the pacing pulse and compared with a threshold continuously. The comparator, in case of the first two and a synchronous detector for the third parameter were built in LabVIEW and tested using the built-in simulator.

A straightforward amplitude comparator was used for the amplitude monitoring while a timed counter was used for the pacing rate monitor. The LED alarms were used in the case of the simulation and a GSM prompt was given to the GSM modem interfaced with the device.

C. Battery level monitor

The battery monitor consisted of two parts – the hardware interface and the comparator. 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 [12].

The levels of indication, when executed through the circuit, were not very accurate and also resulted in the loading of the power source. Considering this, a simple algorithm was devised in the Arduino platform, to measure the battery level and provide indications for each 10% reduction in its power as well as an alarm when it goes below 25%.

D. 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. The string is then sent to the destination address. Systems to show error on disconnect or network non-availability problem is also built.

The second system involves an on-demand delivery of pacemaker parameters and pacing waveforms. This involves the user/physician dialing into the pacemaker by sending in a request to send the information. The GSM tool, on receiving the message connects with the pacemaker monitor and acquires the data from the system. The data is encoded as a MMS and sent to the destination address.

E. ECG storage

The ECG is continuously recorded as a part of the pacemaker system and an additional program of retrieving the recorded ECG from the pacemaker is done so as to deliver the patient ECG to the device whenever a request is made. This is done by the program which converts the ECG data into a 3-4KB data packet and then sends it to the encoder and GSM modem to be transmitted to the device.

V. RESULTS

The pacemaker monitoring system has been designed and tested using the synthesized ECG at different rates. The error tolerance rates for different pacing rates are given in Table 1.
<table>
<thead>
<tr>
<th>S.No</th>
<th>Pacing Rate</th>
<th>Tolerance (%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0.13</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>0.15</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
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<td>30</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table 1: Pacing error tolerance rates

The pacing alarm tolerance exhibits a low value which states the efficiency of the system. This in addition with the average tolerance of the amplitude error, which was found to be 0.1% also, retains the performance of the system. The performance of the GSM system was also evaluated and a VI was developed for the simulation of the pacemaker and its monitor. The VI was used for transmitting the messages regarding the pacemaker parameters and warnings as well.

The communication module to supply parameters and waveform was also produced. The VI was generated for this communication also. The data was transmitted using the 900 and 1500 Hz modulation frequencies also. The network response errors were not received and the system worked perfectly well in distances over 35-40 kilometer tested.

VI. DISCUSSIONS

The pacemaker alarm system using GSM (shown in Figure 4) is a very different one in comparison with existing technology such as the scanning memory transmission and other telemetry units used. The battery level indicating messages and the on-demand will improve the performance and the efficiency of the pacemaker by enabling continuous monitoring. The GSM also enables the communication over long distances as it is a universal satellite controlled system. The interferences provided by the body also are very less for this system due to optimal frequencies used.

The method can also be developed for further changing pacing modes and giving further instructions which are currently done manually and by using the scanning transmission method.

VII. CONCLUSIONS

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 [13].

The system designed using LabVIEW was tested for simulated error conditions i.e. Pacing, Synchronization and Amplitude 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 needs to be developed. The hardware system will consist of a set of circuits 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. A PIC or an Arduino processor can be used to integrate the circuits with the GSM modem. The GSM Modem has to be programmed with a unique SIM card according to the requirements of the physician.

REFERENCES


