

LabVIEW Based Biomedical Signal Acquisition and Processing

MIHAELA LASCU, DAN LASCU
 Department of Measurements and Optical Electronics
 Faculty of Electronics and Telecommunications
 Bd. Vasile Pârvan no.2
 ROMANIA

<http://www.etc.upt.ro>

Abstract: - This paper describes a computer based signal acquisition, processing and analysis system using LabVIEW, a graphical programming language for engineering applications. Biomedical signal acquisition has greatly advanced over the years, using many different technologies. E series multifunction data acquisition cards are used for the acquisition of biomedical signals and the appropriate software NI-DAQ. With the increasing performance of the personal computer, computer based signal processing systems are becoming an efficient and cost-effective way of acquiring and analyzing these signals. The advanced analysis techniques available on the computer are becoming invaluable to the practicing physician. The diagnostic decision will be more accurate. Peak detection in electrocardiogram (ECG) is one of the solved problems using LabVIEW and filtering biomedical signals in different ways is a challenge that has to be solved.

Key-Words: - biomedical signal, electrocardiogram – ECG, acquisition, data acquisition card – DAQ device, device driver, LabVIEW – graphical programming language, signal processing, MAX – Measurement and Automation Explorer, filtering, analyzing, SCXI – Signal Conditioning Extended Instruments, VI – virtual instrument.

1. Introduction

Computers are becoming a necessity in the medical community. Physicians use computers for patient records and information. It is obvious that personal computers based signal acquisition and analysis is an efficient and cost effective method of patient biomedical signal acquisition and monitoring. A computer based system consists of a few external hardware components for isolation and amplification of the signals, a data acquisition card and a software analysis package as shown in Fig. 1.

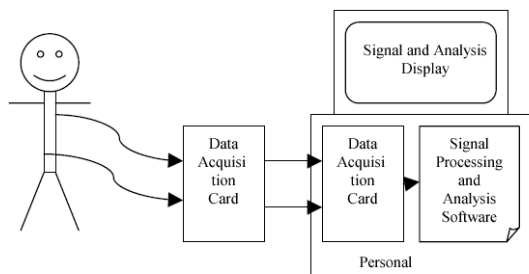


Fig. 1. Computer based biomedical signal acquisition and analysis system.

There are many software packages available for the acquisition and display of electrical signals in general. Of these packages LabVIEW, by National Instruments, is one of the most popular and powerful tools available [1], [4], [5]. General purpose DAQ devices are devices that connect to the computer allowing the user to retrieve digitized data values. These devices typically connect directly to the computer's internal bus through a plug-in slot. With DAQ devices the hardware only converts the incoming signal into a digital signal that is sent to the computer. The DAQ device does not compute the final measurement. That task is left to the software that resides in the computer. The same device can perform a multitude of measurements by simply changing the software application that is reading the data. So, in addition to controlling, measuring and displaying the data, the user application for a computer-based DAQ system also plays the role of the firmware, the built-in software required to process the data and calculate the result, that would exist inside a special instrument. While this flexibility allows the user to have one hardware device for many types of tests, the user must spend more time developing the different applications for the different types of tests. Fortunately, LabVIEW

comes with many acquisition and analysis functions to make this easy.

Acquisition of the signal can be handled through built-in procedures and LabVIEW's ability to easily create a user interface. The analysis of the received signal can be performed by ready made procedures which can be obtained from National Instruments.

2. Data Acquisition

A wide range of data acquisition cards is available from National Instruments. These cards provide for multiple channels of analog data input as well as output. In addition LabVIEW comes with ready-made libraries for interfacing with these DAQ cards. Using these libraries, programs for the data acquisition are quickly and easily made for allowing more time to be spent on the processing and analysis of the acquired signals [5].

We used National Instruments PCI-6023E board from the 6023E, 6024E and 6025E family. The 6025E features 16 channels (eight differential) of analog input, two channels of analog output, a 100-pin connector, and 32 lines of digital I/O. The 6024E features 16 channels of analog input, two channels of analog output, a 68-pin connector and eight lines of digital I/O. The 6023E is identical to the 6024E, except that it does not have analog output channels. The NI-DAQ driver software is included with all National Instruments DAQ hardware. NI-DAQ is not packaged with SCXI (Signal Conditioning Extended Instruments) or accessory products, except for the SCXI-1200. NI-DAQ has an extensive library of functions that you can call from your application programming environment. These functions include routines for analog input (A/D conversion), buffered data acquisition (high-speed A/D conversion), analog output (D/A conversion), waveform generation (timed D/A conversion), digital I/O, counter/timer operations, SCXI, self-calibration, messaging, and acquiring data to extended memory. NI-DAQ also internally addresses many of the complex issues between the computer and the DAQ hardware such as programming interrupts and DMA controllers. NI-DAQ maintains a consistent software interface among its different versions so that you can change platforms with minimal modifications to your code. Whether we are using conventional programming languages or National Instruments application software, our application uses the NI-DAQ driver software, as illustrated in Fig.2. After installing NI-DAQ device drivers we obtain on the desktop of the computer an icon named MAX – Measurement and

Automation Explorer. This program is necessary for identifying the presence of the DAQ-card and for settling the channels that will be used.

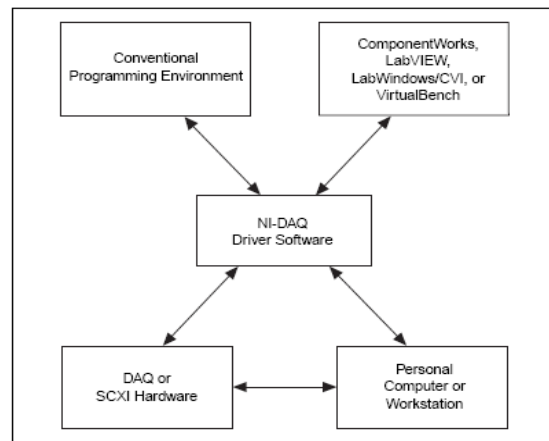


Fig.2. Relationship between the programming environment, NI-DAQ and DAQ-card.

Measurement and Automation Explorer (MAX) provides access to our PCI-6023E DAQ acquisition card. MAX can manage devices and interfaces, the installed National Instruments software, virtual channels or tasks for the used devices and as well it can create scales for the realised virtual instrument, can configure the IVI – Interchangeable Virtual Instrument drivers and import/export the device configuration file.

An overview of the hardware functions of PCI-6023E board is presented in Fig.3.

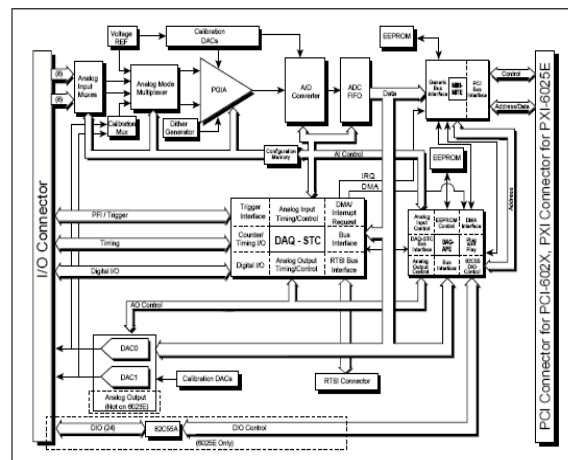


Fig.3. Typical block diagram of 6023E, 6024E, and 6025E acquisition cards.

The boards have three different input modes—nonreferenced single-ended (NRSE) input, referenced single-ended (RSE) input, and

differential (DIFF) input. The single-ended input configurations provide up to 16 channels. The DIFF input configuration provides up to eight channels. Input modes are programmed on a per channel basis for multimode scanning. It is possible to configure the circuitry to scan 12 channels - four differentially configured channels and eight single-ended channels. Table 1 describes the three input configurations.

Table 1

Configuration	Description
DIFF	A channel configured in DIFF mode uses two analog input lines. One line connects to the positive input of the board's programmable gain instrumentation amplifier (PGIA), and the other connects to the negative input of the PGIA.
RSE	A channel configured in RSE mode uses one analog input line, which connects to the positive input of the PGIA. The negative input of the PGIA is internally tied to analog input ground (AIGND).
NRSE	A channel configured in NRSE mode uses one analog input line, which connects to the positive input of the PGIA. The negative input of the PGIA connects to analog input sense (AISENSE).

In our application we use the RSE – reference single ended – configuration, for example between AICH1(PIN 33) and AIGND(PIN 32) for one channel. The boards have a bipolar input range that changes with the programmed gain. Each channel may be programmed with a unique gain of 0.5, 1.0, 10, or 100 to maximize the 12-bit analog-to-digital converter (ADC) resolution. With the proper gain setting, you can use the full resolution of the ADC to measure the input signal.

AICH6	34	03	AICH0
AICH1	33	07	AIGND
AIGND	32	00	AICH9
AICH10	31	05	AICH2
AICH3	30	04	AIGND
AIGND	29	03	AICH11
AICH4	28	02	AISENSE
AIGND	27	01	AICH12
AICH13	26	00	AICH5
AICH6	25	59	AIGND
AIGND	24	58	AICH14
AICH15	23	57	AICH7
DACDOUT1	22	56	AIGND
DAC1OUT1	21	55	AIGND
RESERVED	20	54	AIGND
DIO4	19	53	DIGND
DIGND	18	52	DIO0
DIO1	17	51	DIO6
DIO6	16	50	DIGND
DIGND	15	49	DIO2
+5V	14	48	DIO7
DIGND	13	47	DIO0
DIGND	12	46	SCANCLK
PF1WTRIG1	11	45	EXTSTROBE*
PF1WTRIG2	10	44	DIGND
DIGND	9	43	PF1CONVERT*
+5V	8	42	PF1WGPCTR1_SOURCE
DIGND	7	41	PF1WGPCTR1_GATE
PF1SUPDTE*	6	40	GPCTR1_OUT
PF1WTRIG	5	39	DIGND
DIGND	4	38	PF1STARTSCAN
PF1WGPCTR0_GATE	3	37	PF1WGPCTR0_SOURCE
GPCTR0_OUT	2	36	DIGND
FREQ_OUT	1	35	DIGND

* Not available on the 6023E

Fig.4. I/O Connector Pin Assignment for the 6023E.

Because it was not possible to make an acquisition of a biomedical signal in real time, we have studied at the beginning the possibility for an electrocardiograph realisation, that means the acquisition of a sinusoidal signal with an amplitude of 1 mV and frequency of 1-2Hz from a function generator. Then we have done the acquisition of an equivalent signal for a biomedical signal that is specific for the heart activity. Using the following block diagram from Fig.5. we have an acquisition and a visualisation of the real signal and the processed signal. Because there are a lot of imperfect connexions from an electronic point of view, and there are a lot of long linking wires in a polluted electromagnetic waves environment and the input impedance is high the acquired signal is noise disturbed. For filtering the disturbed signal it is necessary to cascade two filters: the first filter is a low-pass having a cut-off frequency of 40Hz and the second filter is an averaging Hanning filter [2].

When an ensemble of several realizations of an event is not available, synchronized averaging will not be possible. We are then forced to consider temporal averaging for noise removal, with the assumption that the processes involved are ergodic, that is temporal statistics may be used instead of ensemble statistics. As temporal statistics are computed using a few samples of the signal along the time axis and the temporal window of samples is moved to obtain the output at various points of time, such a filtering procedure is called a moving-window averaging filter and is implemented in LabVIEW by help of shift-registers. Such a filtering procedure is called a moving-window averaging filter in general; the term moving-average (MA) filter is commonly used.

The general form of an MA filter is:

$$y(n) = \sum_{k=0}^N b_k x(n-k), \quad (1)$$

where x and y are the input and output of the filter, respectively. The b_k values are the filter coefficients or tap weights, $k = 0, 1, 2, \dots, N$, where N is the order of the filter. The effect of division by the number of samples used ($N+1$) is included in the values of the filter coefficients. Applying the z -transform, we get the transfer function $H(z)$ of the filter as:

$$H(z) = \frac{Y(z)}{X(z)} = \sum_{k=0}^N b_k z^{-k} = b_0 + b_1 z^{-1} + \dots + b_N z^{-N}, \quad (2)$$

where $X(z)$ and $Y(z)$ are the z -transforms of $x(n)$ and $y(n)$, respectively. A simple MA filter for filtering noise is the von Hann or Hanning filter [2], given by

$$y(n) = \frac{1}{4} [x(n) + 2x(n-1) + x(n-2)]. \quad (3)$$

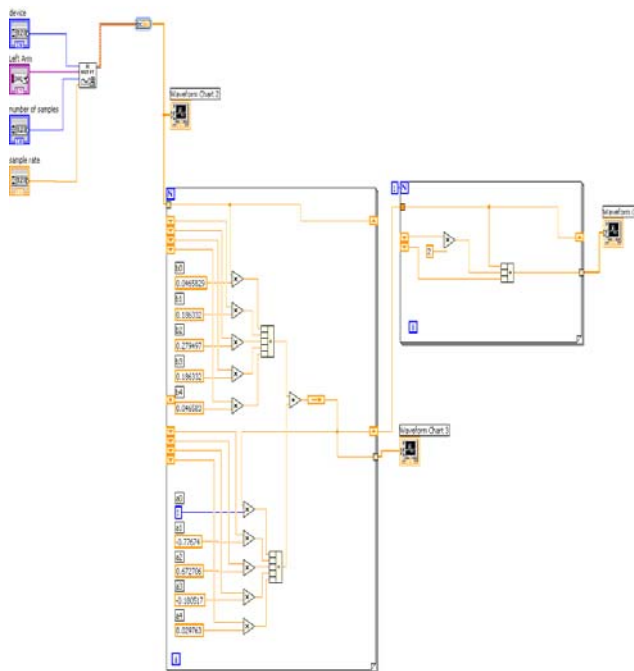


Fig.5. Electrocardiogram acquisition and processing.

The Analog Input Multipoint Block that was used in the above block diagram communicates with the data acquisition system and makes the acquisition of an external signal. We use an analog channel with following characteristics: the name of the channel *Ecg1*; the channel is programmed for signal input *Reference Single Ended* (unipolar signal); the input range is $[-5mV,+5mV]$; the number of samples inside one acquisition is 100; the sampling frequency is $200Hz$.

The first three characteristics are appointed by MAX, that is capable to communicate to any National Instruments data acquisition card. The last two properties are introduced with LabVIEW, that means the values and the name of the channel are selected from the controls belonging to the front panel; the terminal sources from the diagram block take these new values and channel name and actualize the acquisition.

After running the above program we can indicate the three graphs that meet the necessity to publish the input signal, the low-pass filtered signal and the averaging with the Hanning filter. The signals that have been acquisitioned and processed as in the above presented theory are visualised in following figures Fig.6. and Fig.7. Two acquisitions, for two different electrocardiograms are done with the PCI-6023E card. The easiest way to acquire a single waveform from a single channel is to use the AI Acquire Waveform virtual instrument [1].

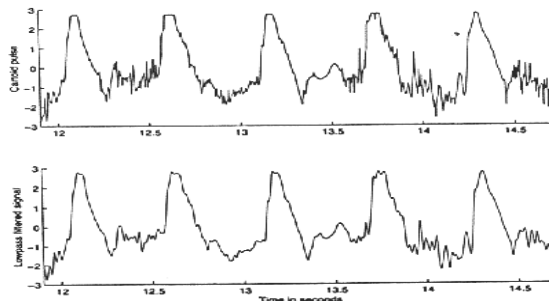


Fig.6. Electrocardiogram and low-pass electrocardiogram.

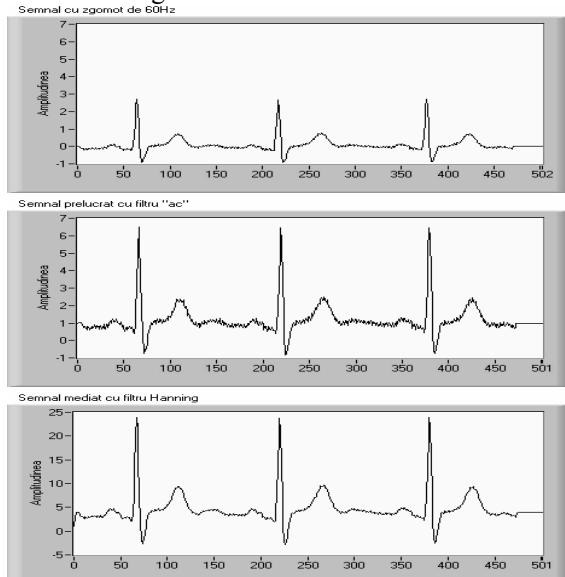


Fig.7. Electrocardiogram with 60Hz noise (first Graph), filtered electrocardiogram (second Graph) and averaged electrocardiogram with Hanning filter (third Graph).

Using this virtual instrument it is necessary to specify a device and/or channel, the number of samples to acquire from the channel and the sample rate measured in samples per second. It is also possible to set programmatically the gain by setting the high limit and the low limit. Using only the minimal set of inputs makes programming the virtual instrument easier, but the virtual instrument lacks more advanced capabilities, such as triggering. Also, it is possible to acquire more than one waveform at a time with another of the Easy Analog Input VIs, AI Acquire Waveforms. This virtual instrument has also a minimal set of inputs, but it allows inputs of more than one channel to read and return an array of waveforms from all channels it reads. To access or control an individual waveform, index the array of waveforms with the Index Array function or use input indexing on a For or While Loop. A two channel data acquisition system can be realized as in Fig.8.

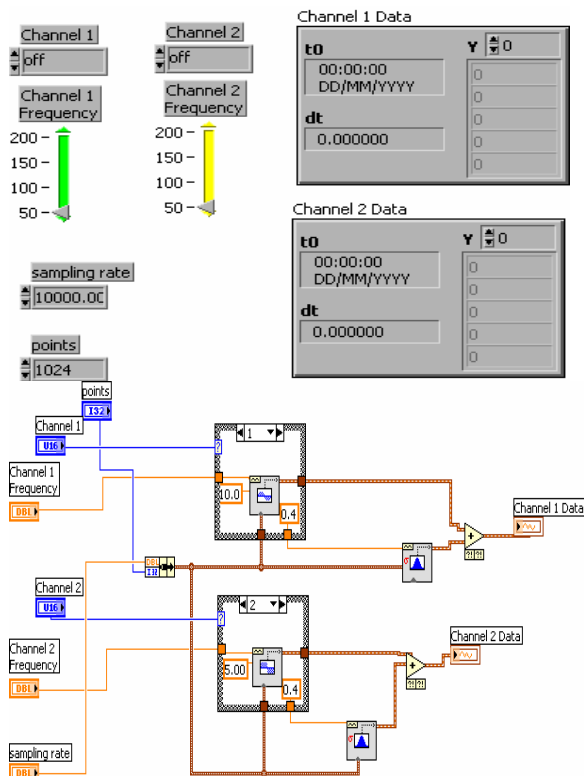


Fig.8. Two channel data acquisition system.

We have in this program the possibility to choose the channel, the frequency, the device and the sampling rate. To acquire multiple waveforms it is also possible using the Intermediate virtual instruments.

3. Signal Processing. Computer based analysis and display.

The biomedical signals acquired from the human body are frequently very small, often in the millivolt range, and each has its own processing needs. Electroencephalography signals are in the microvolt range and have many frequency components. Obviously these biomedical signals require processing before they can be analyzed. LabVIEW contains the tools, from fast Fourier transforms to digital filters to realize complex analysis. In order to do frequency analysis a complex signal must first be broken down into its frequency components. One of the most common way to do this is with an FFT. In order to facilitate this type of analysis, LabVIEW comes with built in FFTs that make the process of component separation quick and easy. In addition biomedical signals being very small are in danger to be overwhelmed by noise. To combat this it is

necessary to use a SCXI – card, that means to run the acquired signal through a set of filters and amplifiers [5]. However, after the signal reaches the computer, it can still contain noise. Another way to solve the noise problem is to use the digital filters provided with LabVIEW. LabVIEW offers the choice of Butterworth, Bessel, Chebyshev and digital filters. With a few adjustments these filters can be configured for almost any design that is needed.

A dual channel spectral measurement with filter is presented using the Express virtual instruments that have the possibilities to choose different kind of parameters from their internal implementation. The block diagram is represented in the following Fig. 9. Following steps are implemented: simulation of the biomedical signal using a generation of a DC signal with uniform white noise, the second step is filtering the signal with a bandpass filter; the third step consists of two parts: updating the Waveform Graph cursors to represent the current values of the upper and lower cut-off frequency models and checking to see if the upper or lower cut-off frequency values have changed since the last iteration, if so it is necessary to reset the Dual Spectral Measurement averaging; the fourth step performs a Dual Channel Spectral Measurement on the prefiltered signal and the filtered signal to determine the frequency response of the filter; the last step test determines the calculated filter frequency response against preset specifications and determine whether the filter meets the requirements or not. In the simulation we have used the uniform white noise because it represents the entire frequency range. In this way the Dual Channel Spectral Measurement Express virtual instrument easily determine what frequencies are being filtered out and by how much.

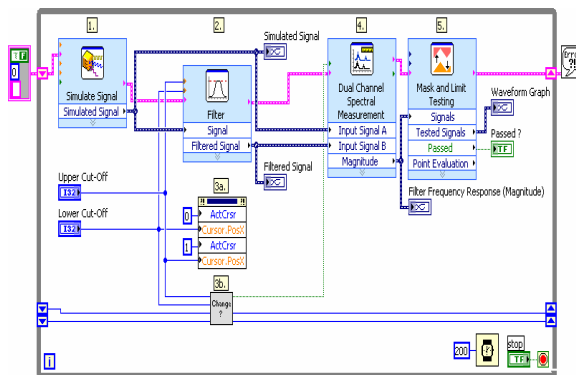


Fig.9. A dual channel spectral biomedical signal Measurement with filter using Express Vis.

For the signal display, several signals can be displayed on the same chart, or separate charts can

be configured for each signal. LabVIEW offers sweep, scope and strip charts; a sweep chart sends a vertical line along with the signal from left to right so that the new data is to the left of the line, while the old is on the right, with a scope chart the signal travels from left to right and when it reaches the right edge, the chart screen is refreshed. The most common chart type for biomedical signals, however, is the strip chart; strip charts bring the new data in on the right side of the screen, while the old travels off the left. One of the greatest benefits of this type of chart is the ability to view past data using a scrollbar attached to the chart.

Analysis of the biomedical signals can also be easily done in LabVIEW. The graphical nature of LabVIEW allows even the beginning programmer to easily write programs to analyze data without having to worry about the syntax problems associated with most programming languages. In Fig.10 is represented a peak detection in an electrocardiogram – Front Panel and Block Diagram. Using LabVIEW and the virtual instrument named Peak Detector we can obtain the desired diagnostic decision. These prebuilt modules are extremely useful in complicated applications.

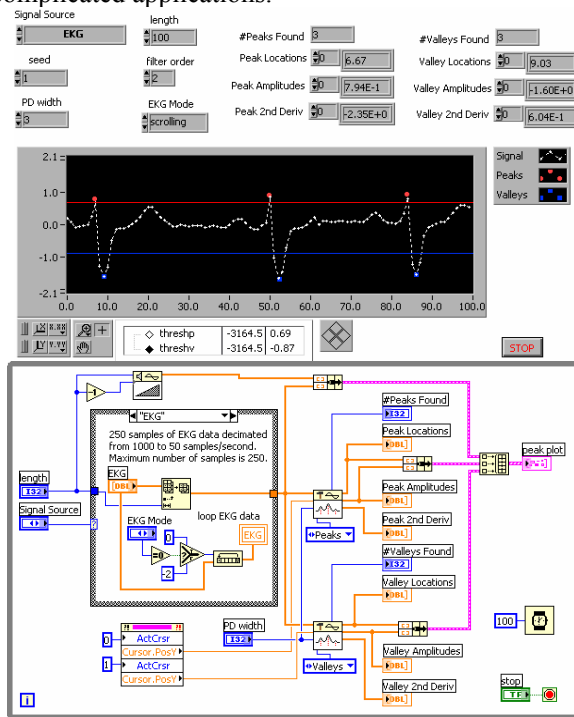


Fig. 10. Peak detection in an electrocardiogram.

We have established the peaks for different kinds of biomedical signals. Peak detection is the first step in event detection [2], [4], [5]. Finally, we can say that event detection is an important step that is acquired before attempting to analyze the corresponding

waves or wavelets. After a specific wave of interest has been detected, isolated and extracted, methods targeted to the expected characteristics of the event may be applied for directed analysis of the corresponding physiological or pathological event.

We can use this Peak Detection in an application like an ECG Rhythm analysis. The output of the final smoothing filter that passed the ECG signal could be subjected to a peak-searching algorithm to obtain a time marker for each QRS or ECG beat. The intervals between two such consecutive markers gives the RR interval, which could be averaged over a number of beats to obtain a good estimate of the inter-beat interval. The heart rate may be computed in *bpm* as 60 divided by the average RR interval in seconds. The heart rate may also be obtained by counting the number of beats detected over a certain period.

4. Conclusion

As the performance to cost ratios for computers continues to grow, there will be a great need for computer based acquisition-analysis systems. These systems can be an inexpensive replacement for the costly stand-alone, signal specific, systems currently in use. The components necessary for a LabVIEW based acquisition and analysis system are inexpensive and readily available. The experience necessary to program this type of system in LabVIEW is small and the numbers of libraries available from National Instruments is growing. These developments show that a computer based system using LabVIEW can be an efficient alternative to stand alone equipment and as the speed and reliability of the computer increases, there will be more and more of these systems available.

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