DEVELOPMENT OF A VIRTUAL INSTRUMENT FOR DATA ACQUISITION AND ANALYSIS OF THE PHONOCARDIOGRAM

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ABSTRACT

A medical virtual instrument has been developed to acquire and analyze the phonocardiogram (PCG), the heart sound and murmur signal. This instrument consists of a Pentium 200 computer running Windows95, equipped with LabVIEW software and a plug-in data acquisition board, and a two-channel custom designed bio-signal preamplifier. The bio-signal preamplifier allows the data acquisition board to acquire both the PCG and the electrocardiogram (ECG). LabVIEW software modules have been developed to create virtual instrument's front panels for the following functions: to manage patient information and data files, to capture and display current ECG and heart sound signals while saving or analyzing previous acquired signals, to perform the spectral and time-frequency analysis of the heart sounds and murmurs, and to review the previous recordings. This instrument can be used to display the PCG and to analyze the individual heart sound and murmur for the detection of heart valve diseases. It can also be used to analyze the carotid bruit for the diagnosis of carotid artery stenosis. This study demonstrated that a LabVIEW-based medical virtual instrument provides a low-cost, reliable, and flexible solution for data acquisition and analysis of the PCG and carotid bruit.

Key Words: phonocardiogram, carotid bruit, virtual instrument, spectral analysis, medical instrumentation.

1. INTRODUCTION

The auscultation of the heart gives the clinician valuable information about the functional integrity of the heart. More information becomes available when the temporal relationship between the heart sound and the mechanical and electrical events of the cardiac cycle is known. The phonocardiogram (PCG) provides this relationship. It is a recording of the heart sounds and murmurs as a function of time. It eliminates the subjective interpretation of the heart sounds and murmurs, and makes it possible to evaluate their timing with respect to the electrical and mechanical events of the cardiac cycle. Clinical studies in humans have demonstrated that spectral analysis of heart sounds and murmurs extracted from the PCG provides important information on the heart valve structural integrity and hemodynamic performance [1-3]. Due to its nonstationarity, recent studies used time-frequency distributions to analyze the heart sounds and murmurs [4-6].

The spectral and time-frequency analysis of the heart sounds and murmurs can provide a useful screening tool to detect the degeneration of bioprosthetic heart valves and potential structural defects in mechanical heart valves [2]. Because of inevitable risk to patients with prosthetic heart valves, periodic evaluation of their prosthetic valve integrity is essential. Presently, the detection and quantification of prosthetic valve malfunction rely most on cardiac catheterization and color echo-Doppler estimation of the transvalvular pressure gradient, the effective orifice area, and the regurgitant fraction of the valve. Cardiac catheterization is not practical for periodic evaluations and screening studies. The sophisticated equipment and the requirement of experienced operators limit the color echo-Doppler to use only in urban medical centers. A simple and cost-effective method that is accurate, serially reproducible, and non-invasive would be invaluable for the detection of the malfunction of prosthetic heart valves. A display of the PCG and spectral and time-frequency analysis of the heart sounds and murmurs is particularly attractive for this purpose. Thus, the development of such a heart sound analyzer as a screening tool has great clinical relevance. A clinically useful heart sound analyzer should have the ability to manage patient data, to display the PCG, to perform the spectral and the joint time-frequency analysis of the individual heart sound and murmur, to review the recorded PCG, and to print out patient reports.

The objective of this project is to develop and build a heart sound analyzer using virtual instrumentation technology. Today, the combination of the accelerating performance of desktop and laptop computers and the sophisticated instrumentation hardware has made virtual instruments a reality. Virtual instruments transparently combine the computer resources and the instrumentation hardware with the software for data acquisition, analysis,

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communication, and graphical user interface. They are cost-effective instruments because they are based almost entirely on the software developed using advanced object-oriented and icon-based graphical programming tools. A virtual instrument has the look and feel of a physical instrument. A graphical front panel, just like a conventional instrument's front panel, serves as an interactive display and control interface that is operated through a computer mouse.

2. METHODS

Our virtual instrument for the data acquisition and analysis of the PCG consists of a Pentium 200 computer running Windows95, equipped with LabVIEW software and a plug-in data acquisition board (PCI-MIO-16E-4, National Instrument, Austin, TX), and a two-channel custom designed bio-signal preamplifier. One channel of this bio-signal preamplifier is used for the PCG and another one is used for the electrocardiogram (ECG). Each channel has manually adjustable gain from -7 dB to 50 dB. The bandwidth of the ECG channel is from 0.3 to 200 Hz and the bandwidth of PCG channel is from 15 to 1500 Hz. The heart sound is captured using a contact microphone, while the standard Lead II ECG is captured using disposable Ag/AgCl electrodes. The sampling frequency for both channels were set to be 5000 Hz.

LabVIEW, Laboratory Virtual Instrument Engineering Workbench (National Instrument, Austin, TX), is a graphical programming language for data acquisition and instrument control. It includes a well-defined set of comprehensive user-interfaces for building an instrument control panel. Using LabVIEW, we have created easy-to-use operator interfaces to input patient information, to control ECG and PCG gains, to select the type of patient's heart valves (native, mechanical, or bioprosthetic), to set recording time, and to launch the analysis panel. In the main PCG panel, two charts were designed to display the ECG and PCG in real-time. In the present study, the ECG signal is used as a cardiac gating signal for spectral and time-frequency analysis of the individual heart sounds, the first heart sound (S1), the second heart sound (S2), etc. We designed an analysis panel within which ten cardiac cycles of ECG and PCG signals are displayed in an upper graph. Two cursors can be used to select a heart sound (S1 or S2) from any cardiac cycle as a template. With the synchronization of ECG, a correlation algorithm was programmed and used to extract the sounds corresponding to this template from the other nine cardiac cycles. A phase-shift coherent average was then performed to obtain an averaged sound. The power spectrum and a time-frequency distribution of this averaged sound were computed and displayed. In addition, we have also created a review panel from which the previous recordings can be viewed and the spectrum and the time-frequency distribution can be computed and displayed.

3. RESULTS

After launch of the virtual heart sound analyzer, the computer screen first displays a patient data selection panel which contains a patient database management system listing existing patient files. From this panel, the operator can either start a new PCG acquisition and analysis session or to view a stored file. By clicking on a NEW PATIENT button, a patient panel as shown in Figure 1 is opened. The patient panel allows the operator to enter the patient information of a new patient and write the physician's comments about this session that is very useful for follow-up studies. If Cancel is clicked, the instrument returns to the patiént data selection panel, while if OK is clicked, the instrument proceeds to open the main PCG panel.

Figure 2 shows the main PCG panel. Through this panel, the operator captures both the PCG and ECG signals. A switch is used to start and stop the data acquisition. As can be seen in Figure 2, two knobs are used to control the gains of the ECG and PCG, a Save button is used to start the recording of the PCG and ECG onto the hard disk for a time specified by Save Time option. If the Analyze button is clicked, an analysis panel is opened as shown in Figure 3 with the main PCG panel still active. There are three graphs in the analysis panel, the upper graph displays 10 cycle of ECG and PCG signals. The graph in the lower left displays the averaged heart sound (selected using two cursors in the upper graph with coherent average). The graph in the lower right displays the power spectrum of the averaged heart sound. If further information on time-frequency distribution of the averaged heart sound is required, the operator can click on the Time-Frequency Analysis button in Figure 3, which performs the joint time-frequency analysis on the averaged heart sound.

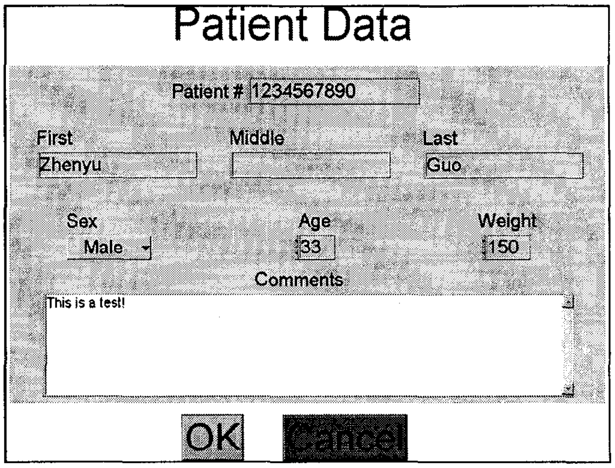

Figure 1. Patient Panel that allows the operator to enter the patient information and write comments.

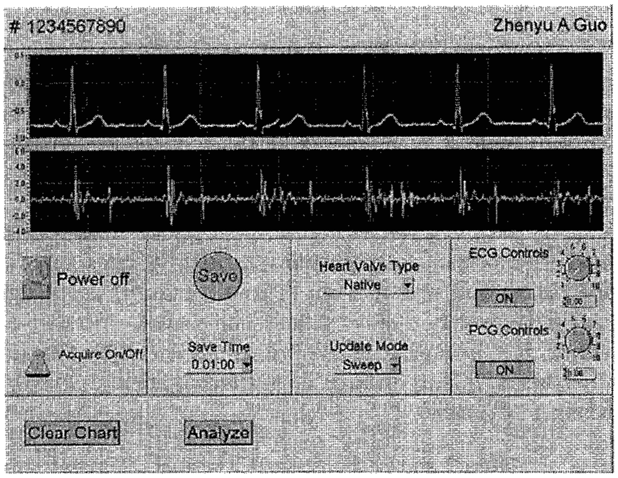

Figure 2. Main PCG panel. Live ECG and PCG signals are displayed. Two knobs are used to control the ECG and PCG gains. ECG and PCG signals can be saved by clicking the Save button. The valve types can also be selected.

Figure 4 shows the time-frequency distribution of an averaged S2 selected from the analysis panel (Figure 3). The corresponding temporal signal and the spectrum are also displayed in the lower and right graphs, respectively. As mentioned previously, our virtual PCG analyzer includes also a review panel. Once the ECG and PCG have been saved to the hard disk they can be played back. As shown in Figure 5, in the review panel, there are five buttons used for playing back the data:

1. Play – Plays the signals from the last stopping point;
2. Stop – Stops playing and saves the stopping point;
3. Pause – Pauses playback;
4. Fast Forward – Moves forward in time through the file;
5. Rewind – Moves backward through the file.

The operator can also access the analyze panel and adjust the ECG and PCG gains from the review panel.

4. DISCUSSIONS

For biomedical engineering research, a very distinct advantage of virtual instrument is that it can be easily customized according to the research protocol. As demonstrated in this project, a less expensive virtual instrumentation solution is used to realize the complicated PCG and ECG acquisition and analysis tasks. The features of the developed virtual PCG analyzer include: 1- Patient information and data file management, 2- Capture and display current signals while saving or analyzing previous acquired signals using the inherent multiprocessing capability of the Pentium PC (This is very important as the traditional instrument can perform only one task at a time; this function allows continuous recording of the signal without interruption by analysis), 3- In the analysis panel, power spectrum and time-frequency analysis can be performed, 4- Previous recordings can be reviewed with the review panel.

Among the methods used clinically for the diagnosis of patients with bioprosthetic heart valves, angiography and cardiac catheterization present some risks of morbidity and even mortality. Duplex color Doppler imaging allows accurate evaluation of the hemodynamic function of the valve, but it is relatively expensive for following-up patients. The virtual instrument developed in this project is low-cost and non-invasive, allowing a periodic, fast and reliable follow-up of patients having prosthetic heart valves. In addition, a very promising extension of this virtual instrument is to acquire and analyze the acoustic signal (the carotid bruit) made by blood flowing through a stenosis in the carotid artery. Phonoangiography, the spectral analysis of the arterial bruit, has been performed for many years as a method of characterizing arterial stenosis [7,8], particularly at the carotid bifurcation. It was shown that the peak frequency of the bruit spectrum is directly related to the residual lumen diameter of the stenotic common or internal carotid artery. Our virtual instrument can be used to conduct carotid bruit acquisition and analysis by placing the microphone on the neck over the carotid artery to acquire the arterial bruit.

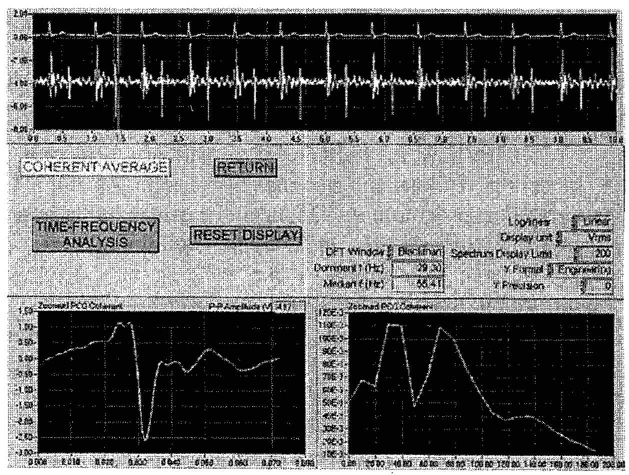

Figure 3. Analysis panel. This panel is launched by clicking the Analyze button in Figure 2. Two cursors in the upper graph are used to select individual sound to be analyzed. Lower graphs show the averaged sound and its spectrum.

To detect the carotid stenosis is very important, because population-based cohort studies have established that people with carotid artery stenosis are at increased risk for subsequent stroke. As for the auscultation of the heart sounds and murmurs, auscultation of arterial bruits has shown considerable interobserver variation among clinicians in the interpretation of the key auditory characteristics like

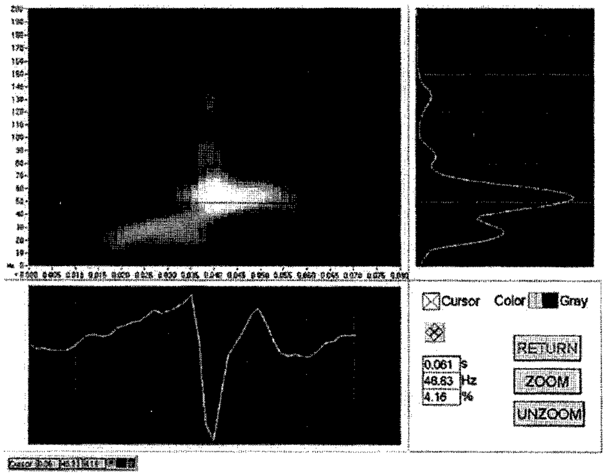

Figure 4. The time-frequency distribution of an averaged second heart sound. The distribution gives the energy distribution of the heart sound as a function of time and frequency. The lower graph shows the averaged heart sound and the graph on the right shows its spectrum.

intensity, pitch, and duration, which are important when predicting stenosis. A computer-based virtual instrument can overcome the limitations of auscultation.

5. CONCLUSIONS

We have developed a virtual instrument to acquire and analyze the ECG and PCG signals or the carotid bruit signal. This virtual instrument can be used to analyze the heart sounds and murmurs for the diagnosis of the heart valve integrity, particularly for the following-up of patients with prosthetic heart valve. It can also be used to analyze the arterial bruit generated by the blood flow in the carotid artery for the detection of carotid stenosis. This study demonstrated that LabVIEW-based medical virtual instrument provides low-cost, reliable, and flexible solutions for the complicated biomedical signal acquisition and processing problems. With this new technique, users can construct their own customized instrument efficiently. It is expected that more and more cost-effective medical instrumentation for clinical environment will rely on the virtual instruments.

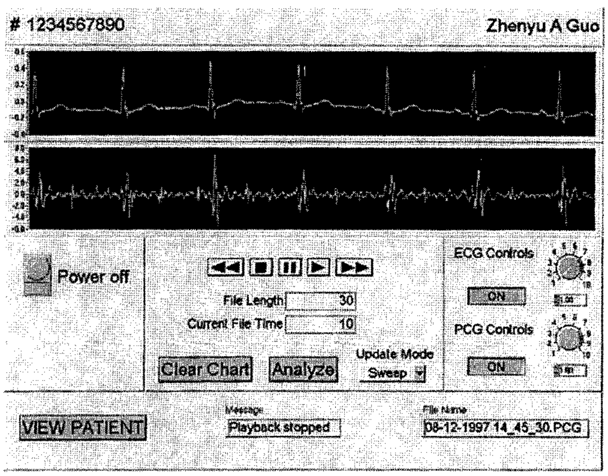

Figure 5. Review panel. Previous recordings can be reviewed from this panel. This panel includes a virtual recorder which controls the playback. A function button, VIEW PATIENT, allows the operator to view the patient information, including physician's comments.

6. ACKNOWLEDGMENT

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